AGH Journal of Mining and Geoengineering • Vol. 36 • No. 1 • 2012

*Jan Walaszczyk *, Dariusz Wiewiórka **

MODELLING THE IMPACT OF ACTIVE FAULT ON EXCAVATION CHAMBERS IN THE CONDITIONS OF LEGNICA-GLOGOW COPPER AREA

1. Introduction

The problems caused by the influence of tectonic dislocations on underground objects and surface infrastructure, including people working in the vicinity is particularly important with regard to the exploitation of mineral resources. Given that shocks with a magnitude of 3.9 on the Richter scale were recorded on January 6, 2012 in the vicinity of Jarocin, it is especially significant to learn about the mechanisms and effects of the activation of large planes of discontinuity, with special emphasis on faults. It is also important to learn about the influence of faults on excavations. The parameters of fault planes, their throws, displacement direction, and location are diversified, and so are their angles of inclination.

In superposition with the effects of excavations in constrained conditions, the complicated natural conditions lead to changes of a fault's state of equilibrium and initiate dynamic dislocations on its surface. In the region of an active fault one can observe the phenomena of energy discharge — known in mining terminology as destressing — which unfold in a violent manner, which are connected with rock destruction. It is difficult, and at times even impossible, to explain these phenomena [5]. Some of the causes and mechanisms of dynamic phenomena in rock mass are discussed, for example, in [1, 5]. One can also find there a definition of *dynamic unloading of rock mass*, and a suggestions to explain and describe the phenomenon of unloading as a releasement of internal forces, which could, for example, result from disruption — planned or not — of the "stressed" object's continuity. The release of energy is connected with the object's movement. Internal forces decrease in those places where continuity is disrupted; local unloading of the object takes place; it is connected with a temporal change of stress and deformation. Naturally, faults are particularly prone to initiate such phenomena.

* AGH University of Science and Technology, Facuty of Mining and Geoengineering, Kraków

A description and evaluation of the effects of a violent continuity disruption on a surface characterised by reduced cohesion and initiating a dynamic phenomenon can be carried out by means of applying discrete models of rock mass based on numerical methods [7]. Extra attention should be paid to the difficulties of numerical dynamic analysis of the rock mass, described in more detail in [6, 7]. A vital issue is to minimize the errors caused by the modelling of rock mass. The authors of this paper postulate that the final signals noted in models should be treated as the sum of the output signals of all elementary sets which comprise a model. With final signals treated as the sum of determined and of random signals, a special analysis was applied; it was based on the separation of the real signal from the output signal distorted by numerical noise. To do this, the signal is filtered through a digital filter [3]. In this case, low-pass filters with cutoff frequency f_c were used. The decision concerning the value of the cutoff frequency f_c was taken on the basis of the fast Fourier transform (FFT) frequency analysis and the spectral power density (SPD) analysis of the displacement signal; the value of the cutoff frequency was then used in processing the velocity signal and the acceleration signal [6, 7].

On the basis of the methodology of solving dynamic problems in rock mass presented in [5, 7], two numerical models were built and solved by means of different equations of equilibrium [1, 5, 7, 9]:

- the first model, with continuity of the modelled object intact; solved statically;
- the second model, which takes the initial state of displacement and stress from the first model, and which accounts for the activated surfaces of discontinuity; solved dynamically.

Such was the method was applied, among others, to carry out research on the behaviour of rock mass under the impact of an active fault in the vicinity of the excavation chambers as with the conditions found in the Legnica-Glogow Copper Area (LGOM) mines [10]. An arbitrarily chosen fault was simulated there; its impact was tested in some points of the model. Examples of displacement, velocity and acceleration are presented in Figure 1, together with their frequency spectra.

The signals of displacement, velocity, and notably – acceleration are shown in the model and are encumbered with numerical errors [7]. With successive differential equations of displacement, with respect to time being solved, a shift of dominant frequencies towards higher frequencies takes place. Digital filtration allows for an effective elimination of these errors.

2. Numerical simulation of the influence of active faults on the change of stress in pillars.

To simulate the phenomena, a rectangular 2500×1300 m model in plane state of strain was prepared (Fig.2). Excavations were placed in the area of a copper deposit at a depth of 1000 m. The model was divided according to a geological profile into horizontal layers; a simplified profile, with parameters shown in table 1, was used for the calculations. The linear-elasticity model was applied to all layers. In the model, chambers and pillars are 4 m high and 6 m wide. The pillar separating the chambers from the fault is 15 m wide. This model is an improved version of the model presented in [10].

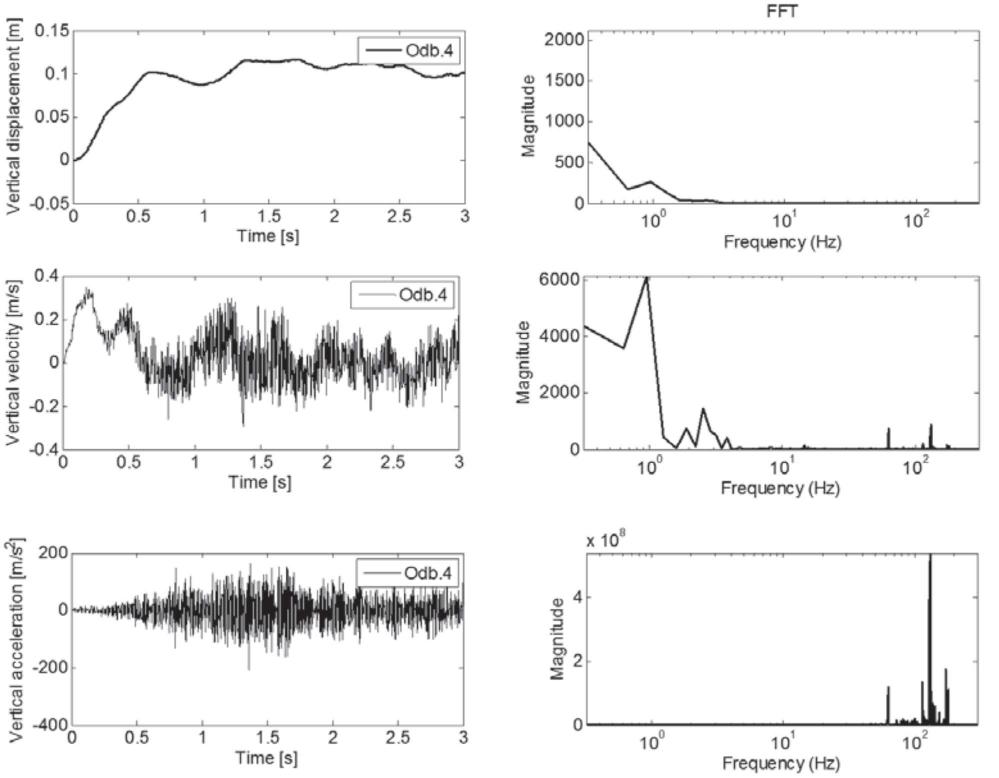

Fig. 1. Vertical displacement, velocity and acceleration in the Odb. 4 and their frequency spectra [10]

TABLE 1
Mechanical parameters of rock layers [4]

Layer	**Density** ρ**, kg/m**^{3}	**Young's modulus** E**, MPa**	**Poisson ratio** ν
Sandstone	2 300	28 500	0.17
Anhydrite	2 850	55 500	0.26
Limestone and dolomite	2 450	46 500	0.225
Copper deposit	2 450	13 500	0.185
Red sandstone	2 300	6 500	0.14

The problem was solved by means of the finite difference method, using the FLAC program [2]; the model was divided by a grid (130×94 zones) which is denser around the excavations and the surfaces of discontinuity (Fig. 2). Neither structural damping, nor damping of the model boundaries were applied. The problem was solved statically; the resulting states of stress and deformation were the initial state of the dynamic simulation. At this phase, the surfaces of discontinuity which serve as the model of the fault remain fixed and have no influence on the general distribution of deformations.

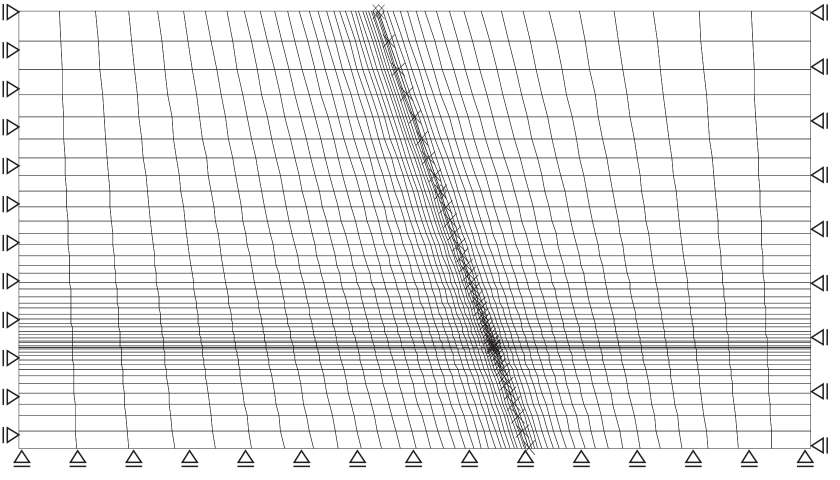

Fig. 2. The grid of the numerical model in the W-II variant, with boundary conditions marked

Both observations in practice and geological research, show that fault planes are highly diversified. Their filling, throws, displacement, vertical and horizontal span, the angles of inclination, etc. are all different, depending on the fault. In this research, averaging parameters of stiffness and friction of the surfaces of discontinuity were used in all variants; attention was paid to the influence that changes in the angle of inclination of a surface of discontinuity on the behaviour of a set of chambers as seen in the some conditions at the LGOM.

Inclinations of the surfaces of discontinuity which simulate the fault(s) were chosen arbitrarily for six angles of inclination with respect to the vertical direction (Table 2). The numerical model presented above was used in calculations. A change in conditions of the

TABLE 2
The angle of inclination of the discontinuity plane

Variant	The angle of inclination of the discontinuity plane
W-I	+30°
W-II	+20°
W-III	+10°
W-IV	0°
W-V	–10°
W-VI	–20°

surfaces of discontinuity and their releasement (the ability to slide and separate on their length) initiated a dynamic processes in the model.

A graphic presentation of the model variants is shown in Figure 3.

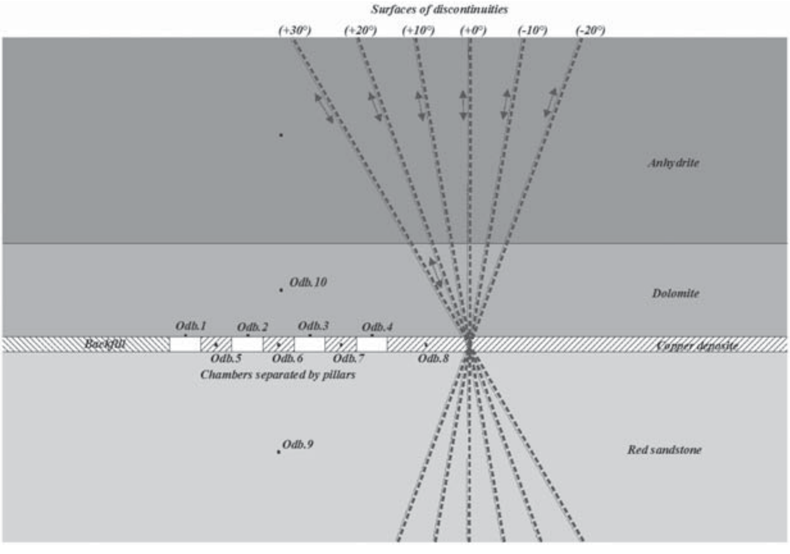

Fig. 3. A schematic diagram of the models with different angle of inclination of the discontinuity plane

In some points of the model (Odb. 1–10) rock mass changes resulting from displacements in released surfaces of discontinuity were noted. The distribution of the Odb. points is shown in Figure 3. The noting and calculation lasted 3 seconds; the timestep was selected automatically in FLAC program. In the Odb. points, horizontal and vertical displacements were noted; then an analysis of their frequency spectra was performed.

The filtering of numerical errors was performed by means of a low-pass filter. An FIR type digital filter was built on the basis of the FFT and the SPD analyses of displacement function [3]. The value of the cutoff frequency was determined as f_c = 10 Hz. The filter was then applied to signals of displacement. After filtering, velocities and accelerations were recovered from the signals. Digital processing of the results was then performed by means of the MATLAB program [8].

During calculations, the changes in stress in all variants of the model were noted. An analysis of their frequency spectra was also performed. Figure 4 presents stress at Odb. 10 as a function of time — W-II variant.

The frequency analysis of stresses showed that low frequencies dominated in the ranges similar to those of the frequencies of dislocation. In the light of the above, filter built for dislocations was also used in digital processing of stress values. The W-II variant results of the vertical stress increment in pillars are presented in Figure 5.

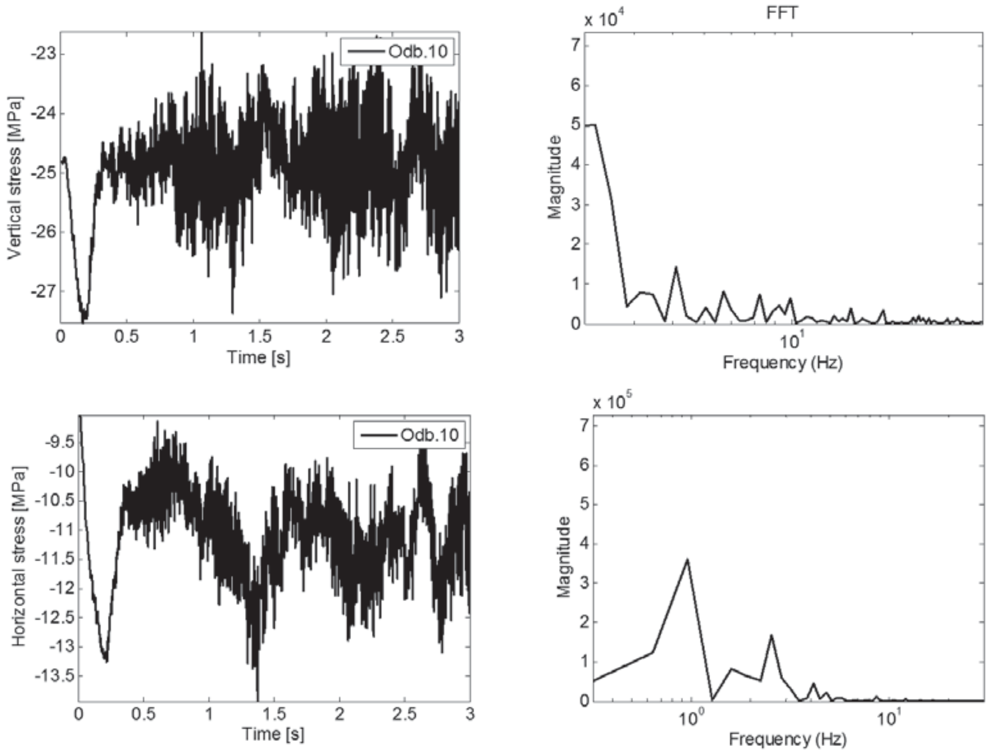

Fig. 4. Vertical and horizontal stress at Odb.10 — W-II variant, and their frequency spectra

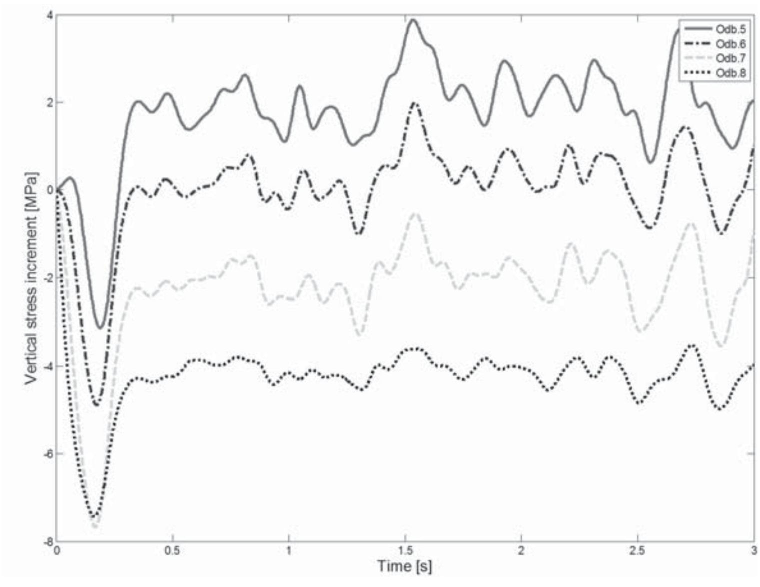

Fig. 5. Vertical stress increment at Odb.5–8, W-II variant

3. Summary

The mining-geological situation simulated during the research — especially the changes of the angle of inclination of active faults — results in a state of dislocation and stress of the model excavations which is variable in time. A more detailed analysis of the rock mass behaviour allows one to conclude that the releasement of the surfaces of discontinuity characterised by large inclinations will result in the greatest levels of dislocation, velocity and acceleration. In the case of the variants with positive values of the angle of inclination, a tendency for upward movement of the footwall is observed; downward movement is observed when the surface of inclination goes under the excavation. The greatest increments of the values noted in all variants are observed in the first phase of movement.

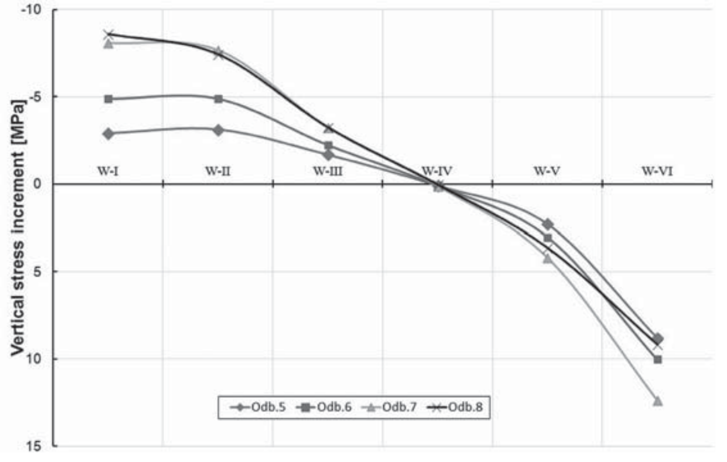

Fig. 6. Maximal stress increments in selected Odb. points located in pillars

When the behaviour of the pillars is analysed, especially changes in vertical stress caused by the releasement of the surfaces of discontinuity, it must be stated that the most destruction from the exposed pillar is between the first two chambers on the side of the surface of discontinuity. Odb.7 notes greatest stress increment. As figure 6 shows, in the case of the W-I, W-II, and W-III variants compressive stress increment is observed, while the W-V and W-VI variants represent pillar decompression.

In conclusion, it should be stated that there is a possibility of an effective modelling of dynamic unloading of rock mass. Minimization of errors in numerical calculations is also possible, particularly in the case of velocity and acceleration calculations in the given points of rock mass. The digital filtering presented in this paper seems to be an effective way to process the calculation results.

The research was conducted under the statutory project No. 11.11.100.277 at AGH University of Science and Technology in Kraków, Poland.

REFERENCES

[1] Filcek H., Walaszczyk J., Tajduś A.: *Computer methods in mining rock mechanics* [in Polish], Śląskie Wydawnictwo Techniczne, Katowice 1994.

[2] Itasca Consulting Group Inc.: *Fast Lagrangian Analysis of Continua v.4.0, Users Manual*, Minneapolis 2000.

[3] Oppenheim A.V., Schafer R.W.: *Digital Signal Processing*, Prentice-Hall International, London, 1986.

[4] Piestrzyński A. [red.]: *KGHM Polska Miedź Co. — the Monography* [in Polish]. CBPM Cuprum, Wrocław 1996.

[5] Walaszczyk J.: *About Some Possible Applications of Numerical Methods to Problems of Rock Mass Unstressing* [in Polish]. ZN AGH Górnictwo z. 107, Kraków 1980.

[6] Walaszczyk J., Barnat A., Hachaj S.: *Identification of Velocity and Acceleration in Dynamic Models of Rock Mass* [in Polish]. XXV Zimowa Szkoła Mechaniki Górotworu, Zakopane. Wydawnictwo KGBiG AGH, Kraków, 2002.

[7] Wiewiórka D.: *Computer Modeling of the Dynamic Effects of Unloading Rock Mass* [in Polish], PhD thesis (unpublished), AGH, Kraków, 2003.

[8] Zalewski A., Cegieła R.: *MATLAB — Numerical Calculations and Applications* [in Polish]. Wydawnictwo Nakom, Poznań, 1996.

[9] Zienkiewicz O.C.: *Finite Element Method*. Mc Graw-Hill, London, 1977.

[10] Walaszczyk J., Wiewiórka D.: *Modelling of Influence Income of Tectonic Disturbance on Roof Oscillations in to Stratified Rock Mass* [in Polish]. Górnictwo i Geoinżynieria, Akademia Górniczo-Hutnicza im. Stanisława Staszica, Kraków 2008.