Close interaction of rock fragments in underground roadway during irreversible movement of surrounding rock mass

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Abstract
The purpose of this paper was to investigate the irreversible movement of the rock masssurrounding underground roadway. We used actual measurements of ground displacement that helped to found spatial movement of the rock mass around the roadway. Any rock mass could not move into the opening synchronously. The rock mass separates into fragments after transition to over-peak state and deforms as a discrete environment in order to accumulate the degree of freedom. The adjacent blocks move by turn, one after another in time and in space. These blocks should move forth and back in anti-phase mode accelerating or decelerating to coordinate their displacements into the cavity. Such a behavior reflects irreversible processes that are quite different from elastic behavior of vertical cross section of the roadway in plane strain state. Disintegrated rock mass is an open thermodynamic system and self-organizes its behaviordue to close interaction of adjacent rock fragments adjusting their nonreversible movements, which facilitates accumulation of degree of freedom. Such an effect has been registered in the first time and allows developing new and modification existent technologies of underground roadway maintenance that is of practical importance.
Key words: ROCK MASS, UNDERGROUND ROADWAY STABILITY, IRREVERSIBLE DEFORMATION, THERMODYNAMICS

Introduction

Mining practices and technologies have significantly evolved overthe course of the last century, yet the problem of underground roadway maintenance remains to be urgent. The main reason is steady increase in the mining depth (Harany et al., 1996, Kang, 2014). Majority of investigators emphasis on specific behavior of the rock mass surrounding underground roadways at the deep mines indicating that it has been normal practice when at least some area of the rock mass collapses and the roadways are maintained in disintegrated rock mass. Zhibiao et al. (2015) and Vorobev et al. (2017) pointed out that certain deformation of the roadway section may be useful because provides some distressing zone around the roadway. This positive effect should be controlled by yielding support, for example using combination of steel frames and rock bolts or cables (Stahlmann et al., 2013; Vorobev et al., 2017).

Development of disintegrated zone around the underground opening follows with specific failure mechanism that depends on the way of rock mass loading and history of the process of the roadway maintenance (Renshu et al., 2017). Nazimko et al. (1997) found new self-supporting effect due to irreversible movement of the collapsed rock mass. This paper describes the results of investigation of the ground movement kinetics due to transition of the rocks over peak strength and their irreversible deformation.

Actual measurement of irreversible ground movement

Irreversible ground movement has been monitored in the belt entry of 12th south panel ("Pokrovs'ka' coal mine, Figure 1). Coal seam $d_4$with thickness of 1.5 m and unconfined compression stress limit (UCS) of 12.5 MPahas been extracted at the depth of 900 m. Immediate roof of the seam was 1.65 m sandy shale of UCS of 58 MPa. The shale was followed by thick competent sandstonewith UCS 80 MPa. Immediate floor of the seam was 10.5 m sandstone, UCS of which was 82 MPa. The surrounding rock mass was moderately fractured with average distance between cleavage 0.66 m.

The belt entry had 18 m^2 section and was supported by yield steel frames with frame to frame distance of 0.8 m, whereas 2.9 m fully encapsulated rock bolts reinforced the roof of the entry. Six rock bolts were installed between every adjacent steel frame. Therefore the belt entry has been maintained by combined support which consisted of rigid rock bolts and yielding frame supports.

Rate of longwall retreat was 8 m per day and the belt entry has been maintained with the cement cribs behind the longwall. Such a measure was implemented at the initial stage of the panel extraction to provide proper flow of exhausted air from the longwall.

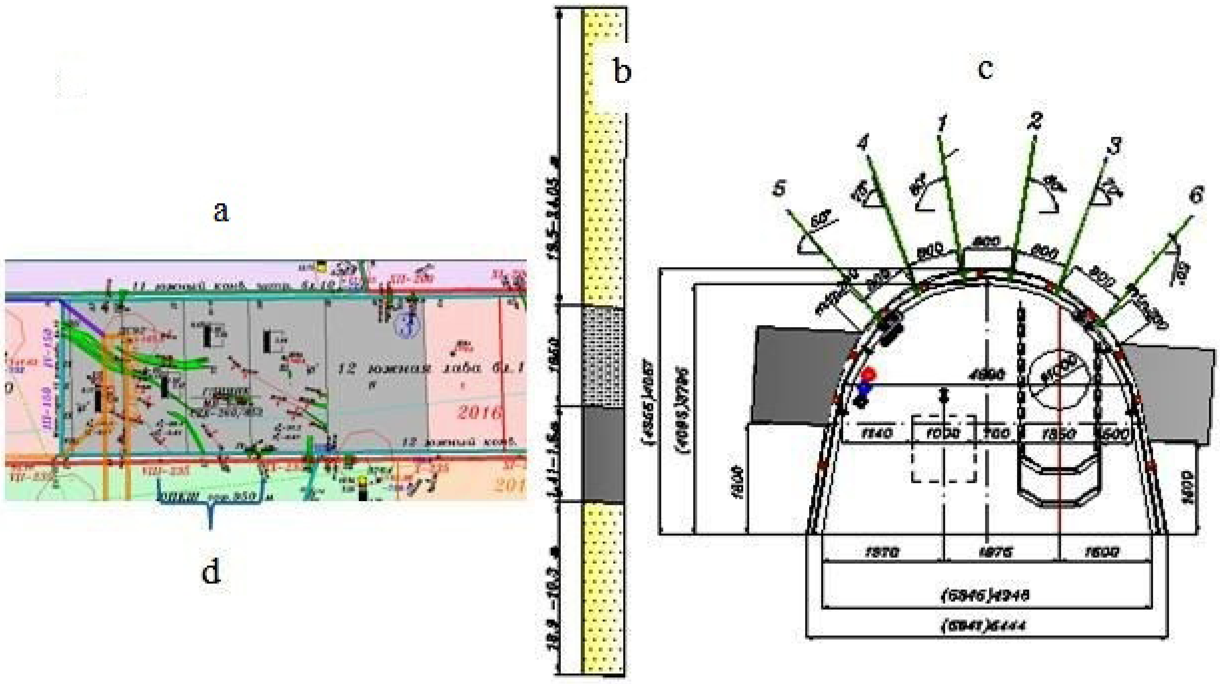

Figure 1. Layout of experimental site (a) and view of vertical section of the entry (c); stratigraphic sequence is shown in fragment (b) and experimental interval (d) indicated by the curve bracket

We monitored distance between heads of adjacent rock bolts along the axis of the belt entry (Figure 2). Theoretically, surrounding a long roadway rock mass is to be in plane strain state what means that there is impossible movement of rock mass fragments along the roadway axis.

However it is not the case, because rock mass collapsed during the longwall extraction and surrounding rocks moved and deformed irreversibly. Schema- tic of the experimental site indicated in the fragment (a) in Figure 2. Distance between adjacent rock bolts were fixed with plumbs and has been measured by portable laser device PD-54Nof accuracy of 0.1 mm. Final standard error of the distance measurement was ±0.4 mm. Initial distance between bolts heads 1 and 2 as well as between 2 and 3 was approximately 0.8 m.

Diagrams in Figure 2,b demonstrate incremental variations of the initial distance. Significant fluctuation of the distances between bolts heads 1 and 2 along with 2 and 3 has been registered when the longwall approached the experimental site to 60 m or to the length of the abutment zone. Intervals x_{1-2} and x_{2-3} varied in anti-phase mode: when one pair converged, the other diverged and vice versa. Maximum magnitude of the fluctuation occurred at the interval immediately after moving longwall or from 0 to 50 m behind it. This interval corresponds to the zone where the undermined strata were in state of active subsidence, and the belt entry has been rigorously deformed, reducing its section area twice. Total residual extension of the monitored interval accumulated up to 191 mm that exceeds by order the error of measurement. Such amplitude of expansion proves the conclusion that there is not a state of plane strain in the vertical section of a long roadway.

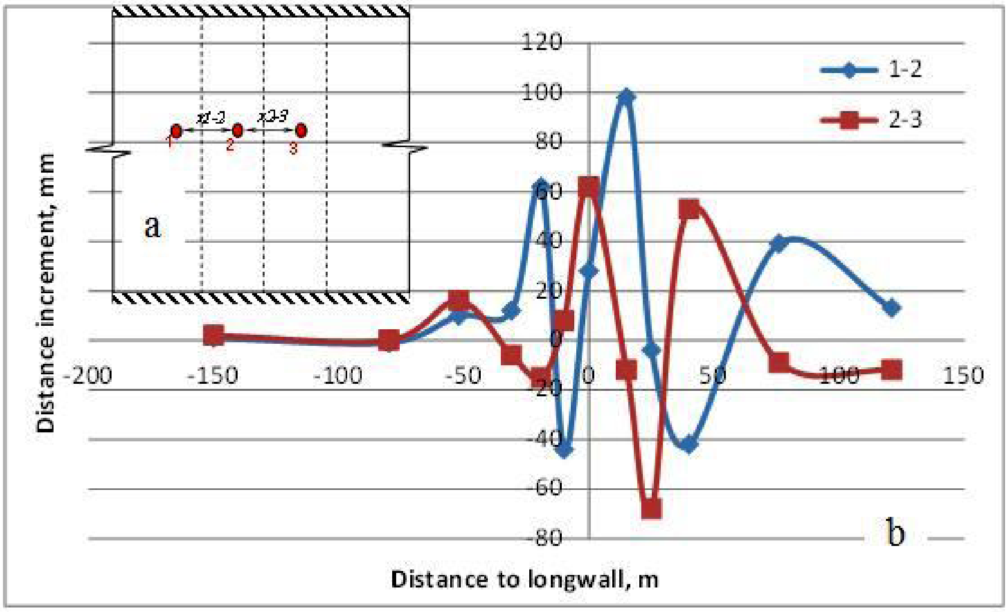

Figure 2. Incremental displacement between adjacent rock bolts (b); layout of the experimental site is demonstrated in fragment (a)

Such a rock mass behavior demonstrates that adjacent fragments of the disintegrated rock mass could not move into roadway cavity and should give the way each other. If the fragments strive to move synchronously, they self-wedged as found Nazimko et al. (1997) in vertical section of a roadway. The author of this paper revealed this effect in third direction, namely along the roadway. Therefore the irreversible ground movement occurs in 3-dimensional space despite the popular approach using plane strain state during mathematical simulation of the process of rock mass damaging around a long roadway.

Discussion and conclusion

The rock mass surrounding underground opening is an open thermodynamic system that passes through the ground pressure energy and substance and transforms this energy into heat and surface energy of the fractures. According to Kondepudi et al. (2015), such a system may trigger a self-organized state which is usually followed by cooperation between the components that this system includes. In the case, adjacent rock fragments cooperated with each other to adjust irreversible movement into the roadway cavity. Such a behavior reflects irreversible processes that are quite different from elastic behavior of vertical cross section of the roadway in the plane strain state. Disintegrated rock mass self-organizes its behavior due to close interaction of adjacent rock fragments adjusting their nonreversible movements, which facilitates accumulation of the degree of freedom in 3D space. Such an effect has been registered in the first time and allows developing new and modification existent technologies of underground roadway maintenance that is of practical importance.

Mining engineers should develop such methods of underground roadway supporting and maintenance that restrict the degree of freedom for surrounding rock mass in 3D space. Noticeably, both the translational and rotational degree of freedom should be constrained that is a very complex task.

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