Spectral acoustic and seismological monitoring of enclosing rock condition in the face area during roof softening by means of directional hydraulic fracturing (DHF)

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Abstract. The article reveals information about the results of directional hydraulic fracturing practical application which implied the reduction of actual main roof rock caving steps. The authors calculated initial main roof caving steps taking the implementation of hydraulic fracturing into account. They demonstrate the scheme with boreholes location and present their estimated parameters. The authors controlled the implementation of hydraulic fracturing by means of acoustic sounding. They give the results of seismic activity control of enclosing rock in the extraction column profile at the time of the mechanized complex leaving the installation chamber. Considering the results of the conducted research, the authors have made a conclusion in relation to the effectiveness of the hydraulic fracturing implementation scheme under these conditions.

1. Introduction

At the moment industrial experimental works aimed at further introduction of directional hydraulic fracturing practice, when working face is functioning under tough roof, are taking place in Kuzbass [1, 2]. Roof rock softening was performed under mining and geological conditions of coal deposit extraction in longwall face 16-19 of seam 16 in a mine section of the JSC “Yubileynaya” Mine” when the mechanized complex was leaving the installation chamber.

The main roof of seam 16 is tough. Near installation chamber its thickness is from 20.0 to 27.0 meters. It consists of siltstones of various coarseness, from fine grain to coarse grain, as well as fine-grain sandstone. Rock hardness of siltstones varies from 3 to 9 according to Protodyakonov scale. As for sandstone, it is within the range between 6.0 and 12.0 (figure 1). The thickness of the immediate roof represented by fine and coarse siltstone is generally from 2.0 to 3.0 meters. The depth of installation chamber location in relation to the surface is 345 meters. Seam 16 is prone to sudden coal and gas outbursts, coal displacement, and dynamic destruction of bedrock starting from 268 meter deep point. It is hazardous in relation to rock bumps in the depth lower than 400 meters.

Thus, complex mining and geological conditions of coal extraction indicated that there is a possibility of considerable roof hanging at the time of the mechanized complex leaving the installation chamber and, as a result, increase of stress on the mechanized supports of the complex. That can lead to the possibility of gas-dynamic notions which are related to the rise of stress in the seam periphery [3].
2. Main part
In order to reduce the initial caving step the members of the Institute of Coal of the Federal Research Center for Coal and Coal Chemistry, Siberian Branch of the Russian Academy of Sciences, in collaboration with technical department of the JSC “Yubileynaya” Mine” made a decision to perform work aimed at main roof preliminary softening in seam 16 by means of directional hydraulic fracturing at the time when the mechanized complex was leaving the installation chamber. During installation work the authors were developing the roof softening scheme. Cut-off boreholes were drilled at an angle to the strata from the installation chamber and development workings (figures 1-4) [4].

![Figure 1. Process flow scheme with borehole location for implementation of directional hydraulic fracturing (DHF) method at the time of the mechanized complex leaving the installation chamber 16-19.](image1)

![Figure 2. Vertical scheme of borehole location for implementation of directional hydraulic fracturing (DHF) from installation chamber 16-19 (cross section A-A, G-G).](image2)
Figure 3. Vertical scheme of borehole location for implementation of DHF from airway 16-19 (cross section B-B).

Figure 4. Vertical scheme of borehole location for implementation of DHF from conveyor roadway 16-19 (cross section B-B).

The depth of boreholes ($l_{crb}$) was calculated depending of the depth of initiation of the initial crack ($Z$) and its angle to the strata plane ($\gamma$) according to the following formulae 1-3 [5]:

$$h_n = \frac{m_8 - h_{po} \times (K_{\gamma o} - 1)}{K_{\gamma o} - 1} + h_{po}, \text{m}$$  \hspace{1cm} (1)

where: $h_n$ - roof rock caving height at which there is a cleavage of tough rock mass;
$m_8$ - extracted stratum thickness;
$h_{po}$ - thickness of the free-caving roof;
$K_{\gamma o}, K_{\gamma o}$ - free-caving and tough rock fragmentation index.

$$Z = (h_n + h_{po})/2, \text{m}$$  \hspace{1cm} (2)
Estimated length of boreholes was 7.8 m.

Implementation of directional hydraulic fracturing was performed using both standard equipment for general use and special devices. The process consisted of the following stages:

- drilling of the inclined hole using rock crowns with 46 mm diameter and cutting of initiating crack in its bottom using a crack initiation device SHCHM – 45/1 (figure 5);
- promotion of sealer to the bottom of the borehole using high-pressure pipe set by means of their connection with the high-pressure system of the mechanized complex through flexible high-pressure hoses (figure 6);
- borehole sealing and pumping of the fracturing fluid in the initiating crack area.

Roof rock softening was made after installation of the mechanized complex. Distance between boreholes was 20 m. During DHF implementation the authors had been monitoring the effectiveness of the method using spectral acoustic method. They applied software complex on the basis of RIPAS device (figure 7).

Acoustic sounding was carried out according to the “Procedure of rock mass acoustic sounding…” [7]. As a result of acoustic impulses processing, the authors calculated the coal seam relative stress index before and after the DHF. Figure 8 presents the results of the measurements taken in the airway 16-19 at the time of the mechanized complex removal from the installation chamber.

Dashed lines in figure 8 denote the location of boreholes for DHF in reference to the working face (in meters). X-axis shows the distance from the working face to the locations where geophon was installed, Y-axis shows the relative stress index.
Starting from the moment when the authors began proving scientific support for activities in longwall 16-19 located under tough roof, the scientific research institute VNIMI organized a system of continuous instrumental monitoring including seismic equipment recording. Besides, local network of seismic stations installed on the territory of the JSC “Yubileynaya” Mine” mining allotment was used. During seismic monitoring, at the time of the longwall face advance from the installation chamber at a distance of 35 m, the authors registered 18 seismic events almost on the entire territory of the examined area. These events were connected with roof caving which manifested itself even on the earth surface as perceptible ground vibrations preceded by the DHF. In figure 9 there is a graph showing registration of seismic events during seismic monitoring (figure 9-a) checked against the dates when DHF was made (figure 9-b) [8, 9].
3. Conclusion
Thus, the authors determined that roof softening by means of DHF, when the mechanized complex was removed from the installation chamber, made it possible to implement safe initial roof caving. Besides, the authors recorded no enhanced gas emission which is usually due to sudden “instantaneous” gas displacement form the gob that happens at simultaneous caving of main roof rock that had been hanging in vast areas. The authors recorded the decrease of the relative stress index in the edges of the coal seam after DHF. That shows that there was a redistribution of stress in the coal and rock mass. The results of seismic monitoring confirm the cyclic character of the seismic vibrations reduction after roof softening and its increase in the following days.

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