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Stability of Undermining Seam Panel Entries at Retreating Longwall Multiple Mining.

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ABSTRACT

The article analyzes the problem of providing stability for district entries when developing the Polenovsky seam under the previously developed Boldyrevsky seam at the S.M. Kirov mine of SUEK-Kuzbass. It gives the information about mine observations of the ventilation furnace 2594 condition, located in the area of high stress from the pillar along the previously worked seam. It analyzes the influence of various mining, geological, and technical factors on levels of rock displacement in the mine. It presents data on the face influence on development of displacements at the mine outline in the area of high rock pressure (HRP) and contains conclusions of the reasons for a mine collapse. It shows that the district entry collapses due to a combined effect of several factors: mining and geological - presence of a syncline affected area characterized by lower strength of rock mass, and mine engineering - formation of a zone of stronger stresses from the pillar left at the overworked seam and applying of abutment pressure in this area from the selvage of the mass along the developed seam. It shows that the issues of efficient longwall development in conditions of mutual influencing contiguous coal seams are relevant for all leading coal producing countries. The article contains diagrams of preparation and longwall development of contiguous seams used in the USA. It shows that the main method for stable condition of district development entries in HRP areas is to arrange them under the previously developed seam at least 30 m away from the pillar selvage. The article provides the dependency of displacement levels in the districts mine on its location within HRP area for conditions of Polenovsky seam, S.M. Kirov Mine. It gives recommendations on establishing site mine stability in S.M. Kirov Mine conditions. It also defines directions for further studies aimed at providing stability of mines in high rock pressure zones when working at contiguous seams.

Keywords: underground mining, multiple coal seam, longwall mining, panel entries, higher stress zones, abutment pressures zones, excessive deformations, floor heave, convergence.

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INTRODUCTION

The analysis of mining-geological and mine engineering conditions of the leading Russian coal mines as well as challenging situations arising at these mines showed that the biggest safety and economical efficiency problem is the development of contiguous coal seams. Taking into account the fact that coal seam suites are developed at most coal mines of Russia, the issues of rational planning of mining operations are important for such seams. It is worth mentioning that the issue of efficient development of contiguous coal seams is relevant for most world leading coal producers: China, USA, Australia. Over 68% of USA reserves are deposited in contiguous coal seams (Luo, 1997; Mark, 2007), and the nearest perspectives of underground coal mining in Australia are connected with operations in conditions of interacting contiguous coal seams (Suchowerska, 2014). The impossibility to perform a complex accounting of multiple simultaneous mining, geological, and engineering factors result in difficulties for studying problems of interactions of contiguous coal seams (Mark et al, 2007).

This paper provides a detailed analysis of the problematic situation and justification of its solution for the conditions of the SUEK-Kuzbass S.M. Kirov Mine. The mine develops a suite of coal seams using the longwall method leaving pillars between faces. The order of seams development in a suite is downward, meaning the lower strata being mined are overworked. Problems occurred when working the Polenovsky layer at panel entries 2591-2594 (Figure 1) in the area of high rock pressure from selvages of the mass and chain intermediate pillars, left from the previously worked Boldyrevsky layer. The thickness of the Polenovsky seam is 1.6-1.9 m, inclination 9° to 2°. The coal seam is prone to rock bumps and coal dust explosion, though not prone to self-ignition. The thickness of interlayer space between Polenovsky and Boldyrevsky seams at the sites in question is 48 m.

The need to conduct the studies was due to disruption in operation condition of the workings at areas of several hundred meters, which required driving additional entries and leaving unplanned pillars of coal. Thus, the main damage (expenses for additional entries) in development of every extraction pillars was about $1 mln, and additional cost was due to the loss of approximately 65 tons of reserves prepared for extraction in every pillar. Besides, driving additional pillar protected entries made the shape of the next extraction pillar more complex.

METHOD

In 2011-2012, mine observations were performed of the Polenovsky seam entries condition at the SUEK-Kuzbass S.M. Kirov Mine: ventilation furnace 2592, conveyor furnace 2592, ventilation furnace 2593, ventilation furnace 2593bis, ventilation furnace 2594 (Figure 1).

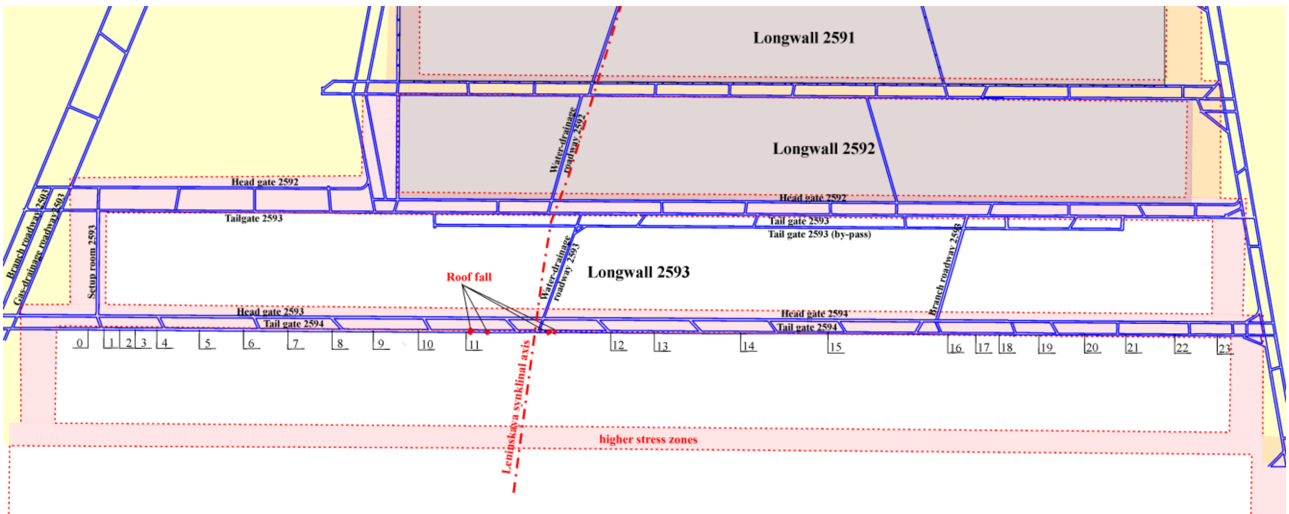

Figure 1 - Plan of Mines and Arrangements of Observation Stations at the Polenovsky Seam Indicating HRP Areas

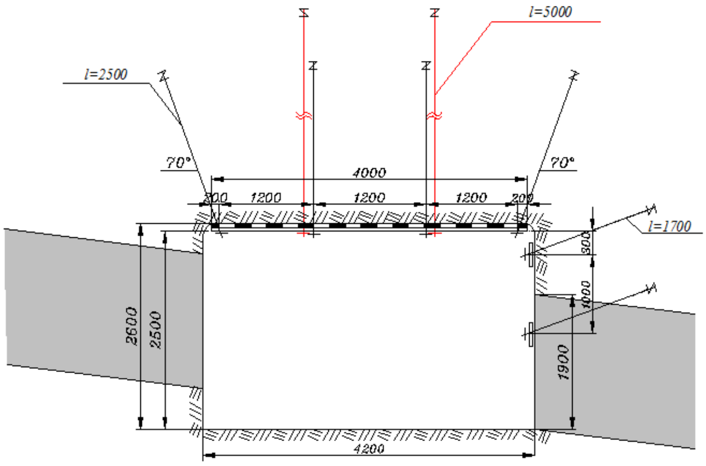

Figure 2 - Diagram of District Entry Support Used at S.M. Kirov Mine

The following visual and instrumental methods were used for mine observations for detailed evaluation of the enclosing rock at the entry outlines of the extraction pillar:

– instrumental methods measuring displacements of deep benchmarks fixed in wells along development entries and coal spall from sides of development entries;
– finding bearing, angle, and intensity of fractures in rock mass at development entry outline (in well using endoscope video);
–

After the analyses and systematizing of the data recommendations were elaborated for entries support pattern parameters.

The main tasks of the study were:

– geomechanical analysis with detailed evaluation of enclosing rock of roof to specify parameters of support schemes of site entries at the face, as well as developing measures to control condition of the mass to provide for the rate of face advance of over 100 m per month;
– establishing geological faults dislocation zones within the extraction pillar, rupture amplitude value, and thinning (of the seam) value in the geological washouts;
– establishing zones of roof segregation and fracturing in development entries.

Mine observation in ventilation furnace 2594 (Figure 2) included measuring displacements of roof, sole, sides of the entry under the influence of rock pressure at observation stations installed at development entries. Initially, 15 observation stations were created (1-15, Figure 1). Observations were carried out from September 27, 2011 to March 6, 2012. Besides, later 8 more stations were installed (16-23, Figure 1) that operated from June 28, 2012 to October 17, 2012.

RESULTS

Figure 3 shows a graph of displacement development in time peculiar for the ventilation furnace 2594 (Station #7). As seen at Figure 3, displacements in the entry are irregular. We can see a period of minimum displacements (first 60 days), fast growth (days 60 to 120) and a period of relative stability (from day 125) characterized by floor heave.

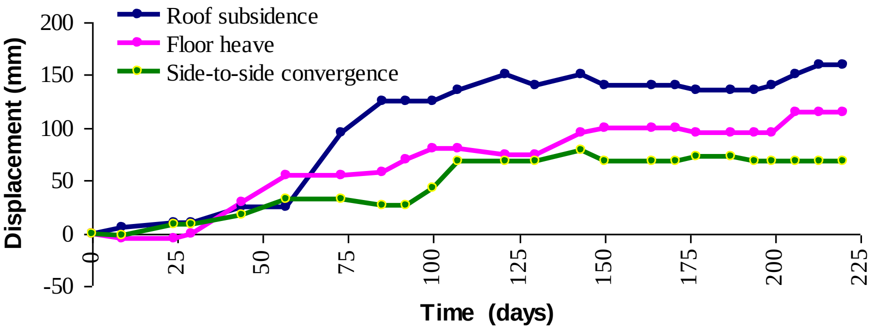

Figure 3 - Changes of Displacements at Ventilation Furnace 2594 Outline Depending on Face Advance (Observation Station #7)

Figure 4 shows data of displacements accumulated over the time of mine observations at the ventilation furnace 2594 outline: roof subsidence, floor heave and sides convergence. As seen at Figure 4, the measured values are distributed irregularly at the stations - all values are seen to rise from selvages at the station extraction pillars to the central parts - 10 and 11. At the same time, major displacements are characteristic of the floor - heaving at central stations 10 and 11 reaches and exceeds 450 mm. Maximum roof displacement - 220 mm, sides convergence - 325 mm. Based on the resulting data, preliminary conclusion can be made about increasing displacements at the entry outline as the work progresses reaching maximum displacements in the central part. However, irregular station distribution along the entry lengths predetermined the necessity to consider the displacement distribution at the outlines along the entry (setup room taken as starting point). A graph pictured at Figure 5 was built for that.

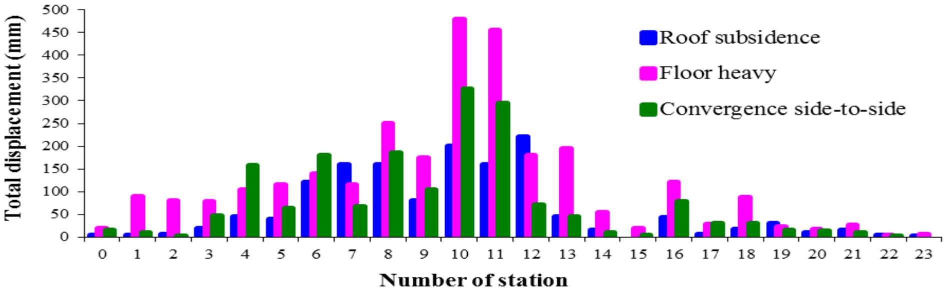

Figure 4 - Level of Complete Displacements in Ventilation Furnace 2594 (for Observation Stations 1-23)

As seen from Figure 5, the maximum displacement level at the ventilation furnace 2594 outline is characteristic not of the central part of the entry, but is shifted 700-900 m away from the setup room. In this zone within the extraction pillar 2594, the axis of Leninskaya syncline passes, meaning that this area has minimum height marks within the pillar 2594 of the Polenovsky seam. Thus, displacement development at the entry outline within the Leninskaya syncline effect zone is largely due to changing deformation and strength characteristics of enclosing rocks due to increased humidity and fracturing.

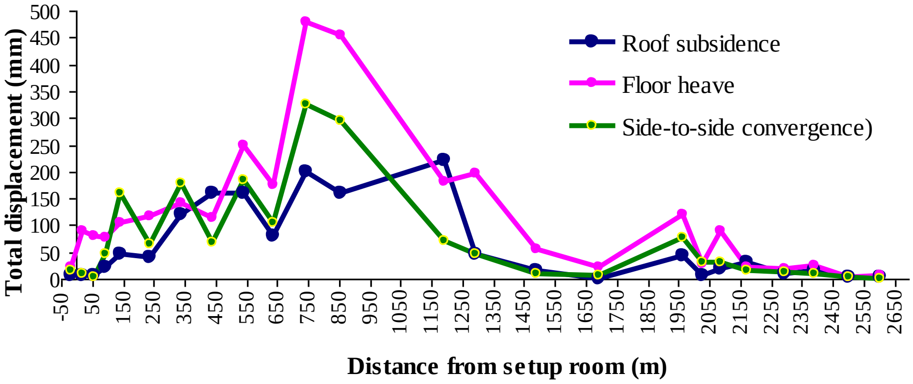

Figure 5 - Displacement Level at Ventilation Furnace 2594 Outline by End of Mine Observations

It is worth mentioning that fast growth of displacement rates was observed at the advance of the face, which was due to the influence of abutment pressure zones formed both before the face and at the selvages of the mass bordering the worked out space. The Figure 6 shows a graph of entry roof subsidence depending on location of the measuring station with respect to the face for stations 5-11.

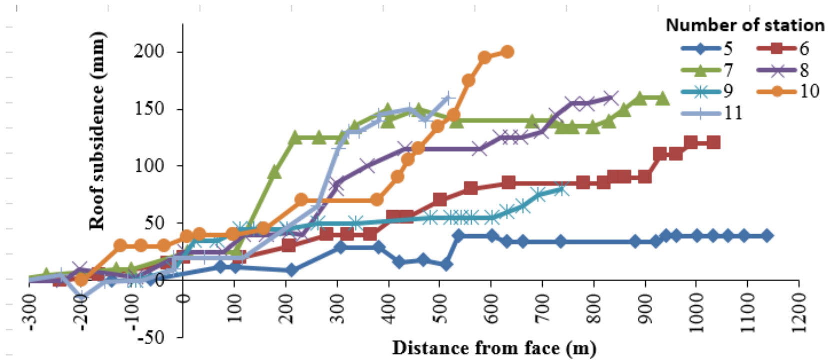

Figure 6 - Roof Displacements at Stations 5-11 at Different Distances from Face

As seen at Figure 6, the roof subsidence rates start to gradually rise at a distance of about 50 m before the face. Further fast growth of roof subsidences is observed after passing of the face (at a distance of about 100 away from it). The period of relative stability is identified when the face goes 400-500 m away from measuring stations.

The Figure 7 presents results of floor heave measurement in ventilation furnace 2594 from stations #2594. At the Figure 7, it is seen that floor heave manifests at about 60-70 m away from the face and develops before the face reaches the distance of 200-400 m away from measuring stations, after which comes the period of relative stability.

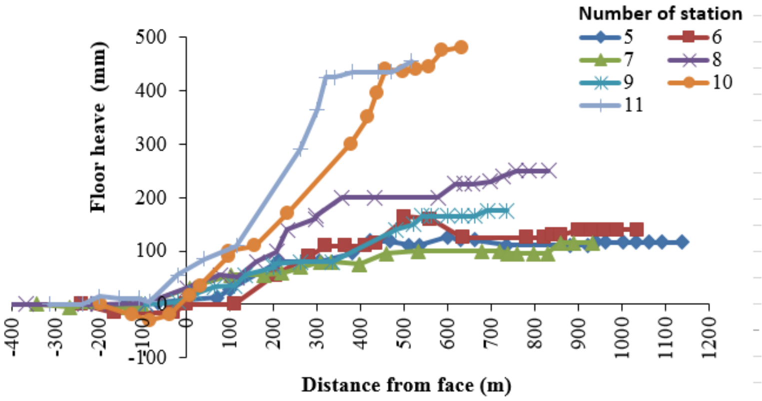

Figure 7 - Floor Heave at Stations 5-11 at Different Distances from Face

The mine observations performed at the SUEK-Kuzbass S.M. Kirov Mine proved that:

- when working at extraction pillar 2593 rock bolting deformation and roof and sides collapse in ventilation furnace 2593-bis are observed at considerable areas of the drift;
- considerable convergence of sides is observed at some parts of ventilation furnace 2594;
- zones of high segregations of roof rocks and coal are characterized by lower strength properties of coal and enclosing rock in the process of entry operation;
- formation and realization of cavings in zones of high roof subsidences exceeds bolting depth and reaches 3.5–4.0 m;
- as the face 2593 advances, with pillar width of 25 m, floor actively heaves in ventilation furnace 2594, which is accompanied by growing roof-floor and side-side convergence, which results in unacceptable operational condition of ventilation furnace 2594 at considerably extended areas, which results in decision to introduce additional ventilation furnace 2594-bis for driving of extraction pillar 2594.

DISCUSSION

In Russia, a large number of publications are dedicated to issues related with establishing mine stability in the zones of high rock pressure (Atrushkevich, 2001, Shevelev et al., 2000). Also there are papers about formation of high rock pressure zones (Belov, 2006; Khalimendik, 2011; Pawlova and Frianov, 2005; Khalimendik and Zabolotnaz, 2011) and stability of mines with rock bolting (Haritonov et al., 2005; Rogachkov, 2008; Remezov, 2003), including those with mining and geological conditions like in this work (Rogachkov, 2009). Special attention should be given to issues of cable support in difficult mining and geological conditions (Zharov et al., 20004; Rogachcov et al., 2011). At the same time, papers of a whole number of authors are applied in nature and chiefly dedicated to modernization of bolts design (Rogachcov et al., 2011; Remezov and Klimov, 2011) disregarding formation mechanisms of high rock pressure zones.

The mine observation at the S.M.Kirov Mine showed that working in an overworked mine is connected with maintenance of development entries operational condition in conditions of high rock pressure from selvages of pillars left at the overlaying mined out seam. At the same time, in the case in question, (working under the previously mined out area) a considerable part of ventilation furnace 2594 collapsed. However, mine observations show that the entry collapsed primarily at the zone of low strength characteristics of the mass while at other areas the entry was operated successfully. At the same time, the entry collapsed only in the zone of face influence, prior to passage of which the mine was successfully supported in the HRP zone. Thus, an entry collapses due to a combined effect of several factors: mining and geological - presence of a syncline affected area characterized by lower strength of the rock mass, and mine engineering - formation of a higher stress zone from the pillar left on the overworked seam and applying of abutment pressure on this area from the selvage of the mass along the developed seam. It is the combined influence of the stated factors cause the entry to collapse. Thus, eliminating one of them would result in keeping the site entry in operational condition, which is proved by mine observations. For example, mine observations show that it is possible to support it in zones of combined HRP and face abutment pressure outside the syncline influence zone. Besides, outside the face influence zone there have been no problems with maintaining an entry at the HRP zone at the site going through the syncline influence zone.

However, works are performed in existing mining-geological conditions - the synclinal fold whose axis crosses the extraction pillar - and also using technological scheme leaving pillars and supporting the mine in the area of face influence. Thus, these factors are actual conditions of development and it is impossible to disregard them at the stage of mining for reserves of an overworked seam. Thus, the only possible solution is to minimize the influence of the HRP zone on site entries, which may be provided by rational arrangement of entries with respect to the HRP zone.

For substantiation of entry arrangement, using the "Instruction for Calculation and Application of Bolting Support in Coal Mines of Russia" (Instruction, 2013), values of rock displacement in mine HRP zones from intermediate coal pillars were calculated for the S.M. Kirov Mine conditions. Also graphs reflecting the influence of entry location on predicted rock displacement were built (Figure 8).

At Figure 8, *1* is the graph of predicted displacement in an entry outside the abutment pressure influence zone from adjacent block going along the Polenovsky seam in the HRP zone from the pillar left along the Boldyrevsky seam. Roof displacement values are calculated for different locations of the same with respect to the pillar boundaries. As seen from Figure 8 (graph 1), there is an area that is 1.5 times wider than the pillar. Within this area, the displacement exceeds the permissible level for using the bolting support (300 mm). While the width of the pillar left is 25 m, the length of the limit displacement area is 45 m.

At Figure 8, *2* is the dependence of displacement level in a similar mine, protected by a 25 m coal pillar located both in the HRP zone and in the face abutment pressure influence zone formed during development of the adjacent face. In this case, the width of dangerous displacement zone is 93 m, so it exceeds the pillar width almost four times. It is also worth mentioning that the full length of the HRP zone within the Polenovsky seam is 135 m (over 5 times more than the pillar width).

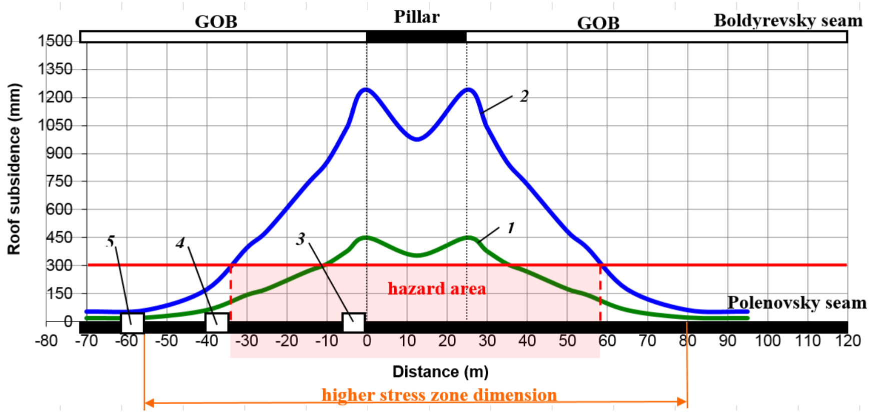

Figure 8 - Dependence of Displacement Levels in Mine on its Location within HRP at Intermediate Pillars.

Thus, when arranging an entry in position 3 (Figure 8) - in the dangerous displacement zone - it can collapse as early as at the stage of exploitation outside the mining area influence. Obviously, to avoid collapse, an entry is to be arranged in position 4 (Figure 8) - in the HRP zone outside the dangerous displacement zone, i.e. at a distance greater than 35 m away from the pillar boundary projection on the plane of currently developed seam, or in position 5 outside the HRP area.

It is worth mentioning that the issues of longwall mining efficiency are relevant for most world leading coal producers. The analysis of mining conditions and global experience of contiguous seams mining (Mark, 2007; Peng, 2006; Mark et al., 2007; Suchiwerska, 2014) showed that for the USA mining in conditions of interacting contiguous seams is an extremely relevant issue and has been studied for a long time. With the results of the studies, a whole range of recommendations has been developed, but at the same time the authors point at the complexity of mining efficiency and safety issues as a result of simultaneous influence of a number of mining, geological and mining technical factors. (Mark et al., 2007). In our opinion, the complexity of such mutual influence is primarily due to high changeability of individual factors' influence degree, both in space - within the extraction pillar or a mine field - and in time.

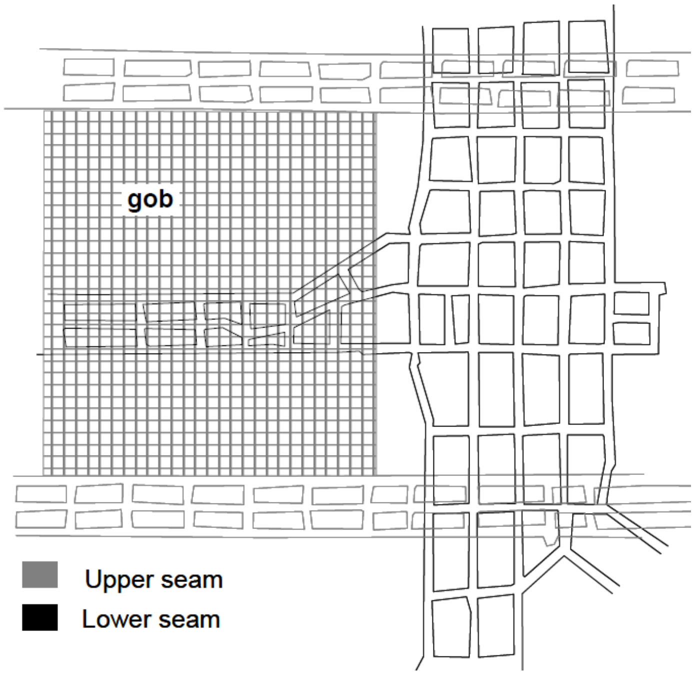

Figure 9 - Recommended Schemes of Rational Arrangement of Overworked Site Entries in Contiguous Seams (Mark, 2007)

The practice of mine works development when using longwall based on the US experience of mining contiguous seams is mainly based on the following recommendations. When planning a location for an overworked site development entries, it is provided that site entries are shifted under the previously developed space, increasing the pillar width between the entries and decreasing the number of holings in the area of entry crossing under the mass selvage (Figure 9) (Mark, 2007). At the same time, it is worth mentioning that recommendation on rational arrangement of entries in the USA have long implied arrangement of entries in contiguous seams one above the other (Luo, 1997; Suchiwerska, 2014), such schemes being currently successfully used at a number of US mines.

In conditions of SUEK-Kuzbass S.M. Kirov Mine, preparation of the following pillars (2594 and the following) for extraction was performed by shifting site development entries under the worked out space for about 30 m, which provided for their operational condition over their lifespan even in condition of HRP manifestations, influence of syncline and mining operations.

Thus, it can be concluded that maintaining entries in HRP zones is achieved by shifting under the worked out space - beyond the HRP effect area or to the area of lower stress. However, the analysis of real mining technical situations shows that there is a number of factors that make mutual linking of mining operations at contiguous seams difficult. First, mineral reserves in Russia is currently mined according to principles of full recovery of reserves (as per requirements of the State Commission for Mineral Resources), which results in difficulty of justification for leaving extra reserves to ensure safety and efficiency of mining with no regulations and scientifically substantiated recommendations on mutual linking of works on the seams. Second, for the past decade, improvement of equipment used in underground coal mining lead to considerable increase of its reliability and productivity, which significantly increased (in the USA - about 1.4 times) extraction area parameters: face length and length of extraction pillar. Thus, when mining seams simultaneously, there often may appear situations when not only length of face and pillar can change (with respect to the overworking seam) but also the number of panels in the mine field.

CONCLUSIONS

The main conclusions of the observation of ventilation furnace 2594 outline displacements in the HRP zone and from the analysis of mine maintenance in Russia and USA are:

- Arrangement of district development entries in HRP zone directly at the selvage of the pillar left over the overlaying worked out seam in the conditions of the S.M. Kirov Mine can cause the entry to collapse as a result of simultaneous action of many factors: natural - influence of the Leninskaya syncline, and technological - combined influence of HRP zone and face abutment pressure zone.
- Operational condition of district development entries at the Polenovsky seam in conditions of the S.M. Kirov Mine is provided with its arrangement with a shift under the worked out space with respect to the projection of the pillar's selvage left in the seam above of at least 30 m.
- Displacement development at the district development entry outline along its length is determined by the influence of HRP and face abutment pressure zones. As a result, expected displacements are the least at the section of the entry from the setup room to the 300 m mark, which is comparable with the face length where the HRP zone parameters are changing as long as mining develops from minimum to medium values.
- Joint design of contiguous seams mining with linking of district entries locations and intermediate coal pillars and evaluation of expected displacements considering changeability of deformation and strength characteristics of enclosing rock along the mine length using the "Instruction for Calculation and Application of Bolting Support at Coal Mines" (Instruction, 2013) is necessary to provide for operational condition of overworked mines.

Further studies of stability of overworked district development entries have to be directed at studying of the influence of width and deformation and strength characteristics of intermediate pillars for parameters of the formed HRP zones and changing of those parameters in time in order to choose and substantiate the rational planar-dimensional solutions for contiguous seams.

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