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UNDERGROUND MINING OF MULTIPLE SEAM OF COAL

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ABSTRACT
The objective of the research is choosing and finding rational parameters of preparation and development of multiple seams of coal under the conditions of their cross-impact. Categories of adjacent seams interaction and their specifics were considered. Examples of wrongful and good impact of adjacent seams development were shown. Adjacent seams interactions being especially complex and with severe consequences were specified. The need to take into account the cross-impact of adjacent seams during mining high gas-bearing formations of seams was noted, as de-stressed zones creation causes high increase of gas permeability of the rock mass and growing methane release into workings from the stripped areas. The analysis was made of the research results on adjacent seams interaction during coal seams development in the USA made by the National Institute for Occupational Safety and Health. The reasons for adjacent seams mining difficulty were shown. Upon the analysis of Russian and foreign experience of adjacent seams development, the conclusions were made on the level of impact of various mining geological and mining engineering factors, and recommendations were given on mining planning and choosing mine workings location. Further research directions were determined, required to improve efficiency and safety of mining in the course of adjacent seams development.

Keywords: underground mining, multiple seam, longwall mining, ground control, mine planning, pillars/remnants.

1. INTRODUCTION

Most coal seams in the Kuznetsk coal basin (Russia) occur in formations at various distances from each other. From the point of view of impact of one seam extraction on the extraction of adjacent ones, independent and superimposed seams are specified. Seams in a formation are deemed independent if they may be extracted in any sequence and superimposed if it is required to account for their adjacency for rational mining. Thus, superimposed seams affect each other during development. That effect may be both good and harmful. In the first case it should be used, in the second case - eliminated (Dorokhov, 2002).

Good effect of superimposed seams development may be used in the following cases:

- for mining seams dangerous in connection with coal and gas burst, when advance mining of protective seam is required;
- when draining-out of gases from adjacent gas-bearing seams is required, efficiency depending on the level of de-stress caused by overworking/underworking;
- for softening solid sandstones occurring in the roof of seams overworked to improve mining pressure control;
- for draining flooded seams by overworking;
- for joint preparation of seams when workings on one of adjacent seams are used for mining others;

Harmful effect of adjacent seams interaction may be manifested:

- while overworking upper very superimposed seam causing difficulties in further extraction;
- under high mining pressure conditions;
- while overworking existing working.

In general, the effect of superimposed seams is manifested in the change of stress and strain behavior of the mass around mined-out spaces and gob solids of the mass and pillars. The degree of geomechanical disturbance of rock mass and propagation length of the said zones finally determine the impact of the seam mined or being mined on the adjacent seams in the formation.

It should be noted that in Russia it is accepted to use overworking and underworking terms. Overworking describes a situation when the lower seam was mined-out first and the upper seam is mined in the conditions of its impact. Foreign sources use the term overmining, i.e., the situation is described in the current moment - a seam is mined above the superimposed seam, already mined-out. Same related to underworking. Underworking (Russia) occurs when the upper seam was mined out and now the lower seam is mined, so undermining occurs when the lower seam is mined under the conditions of upper seam's impact.

The most complex mining engineering situations emerge in the course of mining seams exposed or liable to geodynamic and gas-dynamic phenomena (Instruction for Safe Mining Works, 2000; Korshunov *et al*., 2011, Zubkov *et al*., 2012) and while overworking superimposed seams with interseam thickness of at least six thicknesses of the seam. Methane release control issues need to be paid separate attention while mining superimposed seams

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as de-stress zones creation affects greatly the effective porosity and permeability of the rock mass (Panteleyev and Suraikina, 2000; Saginov *et al*., 1999; Sokolov, 1997; Guryanov and Iofis, 2000).

Widely occurring superimposing seams in Russian mines, mining schemes leaving undamaged coal pillars/remnants between working areas and creation of significant mined-out areas and vast gob solids on their borders caused the rate of occurrence of dangerous impact to grow in the interaction of superimposed seams. Such impact is manifested not only in worsening dynamic and gas-dynamic safety works but also in growing complexity of maintaining preparatory workings in high mining pressure areas.

The issues of efficient and safe mining of superimposed seams are crucial for all leading coal mining countries (Suchowerska, 2014; Mark *et al*., 2007). Great experience of both successful and unsuccessful mining of such reserves has been accumulated. Meantime, researchers stress on the complexity of finding cross-impact of superimposed seams due to great number of mining geological and mining engineering factors. The absence of strict requirements and recommendations on mining works planning and the variety of mining geological and mining engineering conditions predetermine the actuality of the research on finding dependencies of superimposed seams interaction during mining for the purpose of using positive and eliminating negative effects.

2. METHOD

Development of recommendations on rational planning of preparatory and extraction works on superimposed seams should be based on the study and systemizing of all known cases of superimposed seams interaction. Superimposed seams may be developed downward and upward. Downward mining is the most frequent in mining superimposed seams, applicable in any conditions. Upward mining is less frequent and is applied as a rule only when interseam thickness is over 6 thicknesses of seam.

In the global practice, superimposed seams often mean those occurring under 200 feet (60 m), and in the course of development of those seams, the four main categories of interaction are specified (Mark, 2007):

a) Underworking.

b) Overworking.

c) Dynamic interaction.

d) Mining very superimposed seams.

Superimposed seams may be prepared separately and jointly. In the course of joint preparation, grouped workings are made (gateways, headways, sloping tunnels) by one of seams serving all group's seams connected with cross-entries or blind shafts.

Joint mining of superimposed seams occurs as a rule in the following conditions: interseam thickness under 20-30 m; small depth of working and stable wall rocks enclosing group workings. In the cases when wall rocks of the lower seam are low-stable, group workings are located over empty rocks. In separate preparation, workings are made separately by each seam. The main method of multiple seam mining in Russia is separate preparation and mining of seams or their parts which is explained by the present trend to shift to mine-longwall scheme of operation, i.e., the use of a single working face as a rule.

Accounting for several principally different categories of interaction of superimposed seams they should be considered separately in the course of analysis of the global and Russian experience, first of all, specifying mining geological and mining engineering factors which determine success or danger of certain mining engineering situation in a mine.

3. RESULTS

The analysis of underground mining of leading coal producing countries (Mark *et al*., 2007; Kazanin *et al*., 2014, Korshunov *et al*., 2011, Suchowerska, 2014; Pavlova and Fryanov, 2005): China, USA, Australia, Russia showed that superimposed seams development issue is not typical for all the regions. For example, in Australia, thick single gently sloping seams are mined as the most profitable, although authors stress that further prospects of underground coal mining, including near, are related to mining seam formations in undermining and overmining conditions (Gale, 2015).

The interaction of superimposed seams is one of the major threats in controlling rock mass condition in many American coal mines as evidenced by numerous publications (Luo, 1997, Mark, 2007, Mark *et al*., 2007). Of great interest are the studies by the National Institute for Occupational Safety & Health (NIOSH), based on the empirical approach, namely on creating and studying the database of impact (interaction) of superimposed seams (Mark *et al*., 2007). The database of superimposed seams mining cases has been maintained for a few years. Mines were included in the research upon discussions with employees and Mine Safety and Health Administration (MSHA). The research was concentrated on the mines which experienced great difficulties in reserves preparation and mining in multiple seams condition. Totally, 44 mines were studied; almost all of them were in Appalachian (central area) and Western coal basins. A few mines were studied in the northern part of Appalachian basin, but no case complied with the criteria of the final database.

The main objective of mine research was to see the history of interactions and non-interactions of multiple seams for each mine. Meantime, mining plans were matched: current workings and undermining and overmining. Also, in each mine the field research of

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enclosing rocks was made. The complexity of the research completed was related to the fact that in some cases it was impossible to find the level of impact of multiple seam and other mining geological and mining engineering factors. Therefore, a number of cases of superimposed seams interaction were excluded from the database.

Four-level rating scale of result's assessment was used:

- Interaction was not found (same conditions as during single seam mining).
- Minimal interaction (insignificant change of roof and ground properties without any significant effect on mining efficiency).
- Moderate interactions (inrushes in roof, heaving and destruction of workings in some areas).
- Heavy interaction (termination of mining).
- Type of rock mass element upon reserves mining (selvage/gob solid or pillar/remnant).

The final database included 344 mining engineering situations in 36 various coal mines, including: 252 cases of preparation and 92 cases of mining. Distribution of all the cases considered: success and failure, by type of superimposed seam impact: overmining (above mined-out seam) and undermining (under mined-out seam), stage of works: development and retreat is depicted in Figure-1. Figure-1 shows that over half of cases in the database include undermining - development (n = 190). Only about 13% cases of undermining were failures. Further undermining - retreat was success in over 65% cases. In Figure-1(b) the distribution of cases analyzed is shown by type of rock mass elements, exerting impact: gob solid or remnant pillar. As seen from Figure-1(b), in undermining of gob solid, 90% of cases were success. The intensity of failures is almost double for undermining remnant pillars (growing from 10% to 19%). Success of mining in undermining conditions was in 73% cases related to gob solids and in 59% cases related to remnant pillars (Mark *et al.*, 2007).

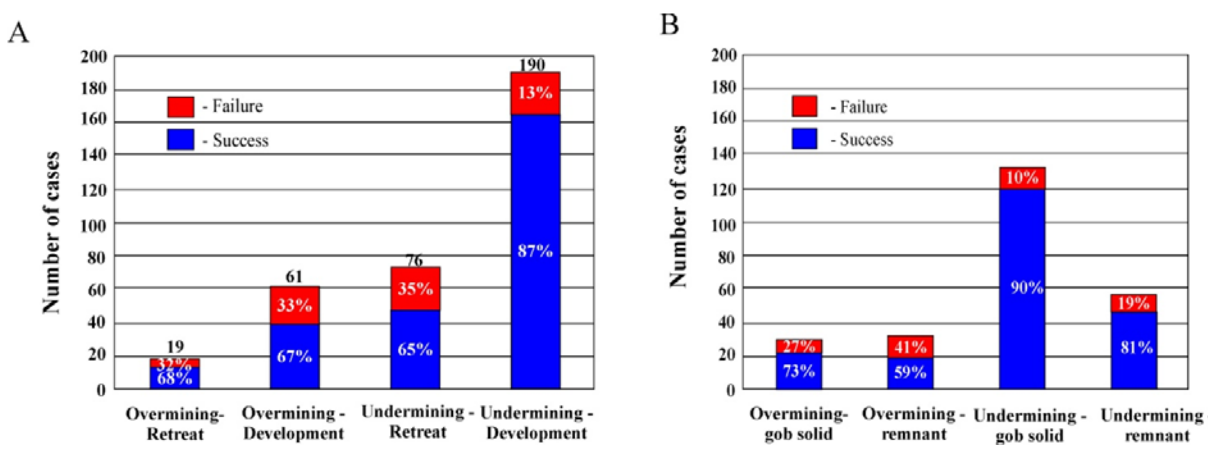

Figure-1. Distribution of superimposed seams interaction: a - by order of seams mining and stage of mining; b - by type of rock mass elements (gob solid or remnant pillar) (built as per data from Mark *et al.*, 2007).

Figure-2 shows the distribution of success and failure depending on the mining depth and thickness of interseam area. In about 90% of cases studied, mining depth was 400-1, 200 feet (120-300 m). Interseam area is less than 66 m (220 feet), except for 20 success cases with interseam of 110 m (380 feet). Figure-2 also shows that there are some cases in which interseam area is from 90 to 150 feet (27-45 m), however the authors think that range is not representative enough for the analysis (Mark *et al.*, 2007).

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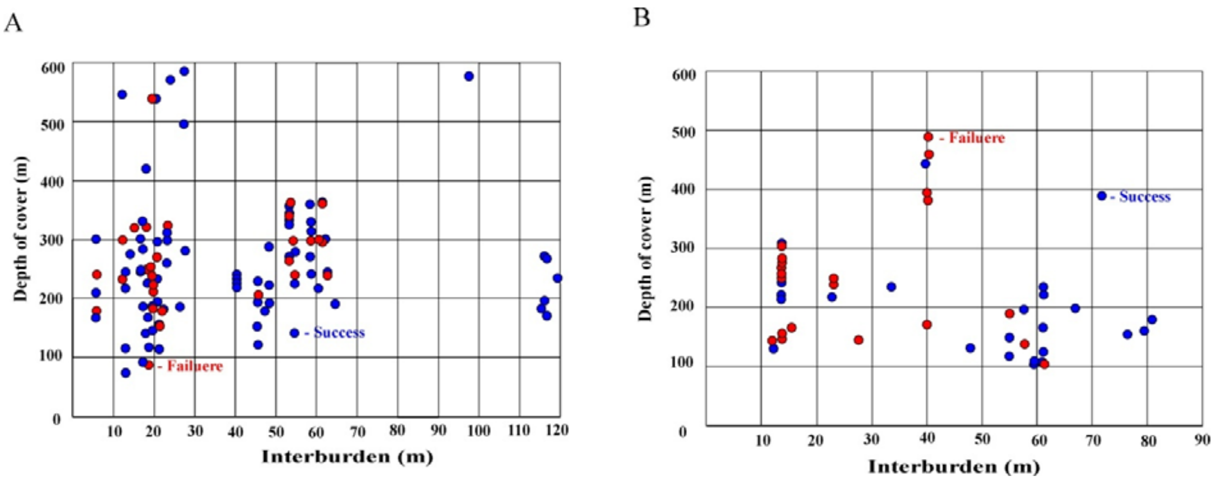

Figure-2. Distribution of success and failure at various depths and thicknesses of interseam area under the conditions of: a - undermining, b - overmining built as per data from Mark *et al*., 2007).

In Figure-2(b) seams interaction at various mining depth and interseam area thickness under overmining conditions is shown. As seen from Figure-2(b), growing thickness of interseam area to the value exceeding 200 feet (60 m) ensures successful mining.

Figures 2(a) and 2(b) demonstrate the general trend for decrease of emergency cases as interseam area thickness grows. As seen from the Figure, if interseam area thickness is over 200 feet (60 m), no emergencies occurred in mining of superimposed seams, therefore foreign literature classifies only seams with interseam area under 60 m as superimposed.

A great number of geological and mining engineering factors covered by the cases of superimposed seams analyzed have complicated the analysis. The empiric research failed, as opined by authors and they concluded on the insufficiency of the data collected for so many affecting factors (Mark *et al*., 2007).

Applying dependencies obtained upon the case study of the US mines is complicated in Russian conditions by the fact that the analysis was done without technological schemes and development systems and their specifications. For instance, in Russia the main technology of underground coal production is longwall mining while in the USA it accounts for about 50% only.

It should be noted that in compliance with the Instructions on Rational Location, Protection and Maintaining Mine Workings in Coal Mines (2011) all seams should be prepared and mined in relation to each other, as a rule, applying technological schemes with non-pillar methods of protection of workings and ensure that coal pillars undamaged by mining pressure are not left near tectonic faults. Thus, the instruction does not provide for locating workings close to pillars left in mined-out area.

The fullest consideration of the impact of pillars and gob solids on section development workings located on superimposed seams is provided for by Instruction on Calculation and Use of Roof Bolting in Coal Mines, 2011 (Federal Norms and Rules, 2013), which contains an annex enabling to calculate roof bolting of development workings located in the areas of high mining pressure. However, in compliance with this instruction, high mining pressure zones are not built but calculations are made in connection with expected rocks shift on working's contour.

Development of machinery and engineering of underground mining of coal seams caused the change of labor conditions and efficiency of reserves development. That was followed by changes in regulations providing for the mining procedures accounting for the impact of various geological and mining technical factors. In the course of coal seam formations development, mining pressure control conditions may get very hard in working faces going under/above pillars and gob solids left on adjacent seams. In those conditions, rate of advance during complex longwall mining of working faces and daily production decline greatly because of gripping of and impact on roof bolting, growing inrush area, etc. As a criterion for impact of pillars during seams mining subject that they are not liable to mining bumps and spontaneous bursts, rate of advance in working faces was used while passing through high mining pressure zones, causing great decline of feasibility parameters of longwalls. In compliance with Instructions on Control of Mining Pressure… (1984), three zones are specified: high danger zone (HDZ), danger zone (DZ), predicted zone (PZ). The document stresses that working face in HDZ is characterized by the highest intensity of mining pressure: dynamic phenomena causing immediate destruction of lower layers of roofing or great part of rock mass around working faces, to the extent of cutting all interseam area which may cause catastrophic increase of load on roof bolting. A typical manifestation of HDZ is sharp decline of roofing stability. In that zone, the most frequent are cave-ins of working faces, stiff gripping of powered roof bolting, coal sloughing, roof heaving. In DZ development, immediate roof stability loss occurs due to fissuring and rock lamination. Emergency situations on working faces in connection with the above are not typical but possible. The most typical feature is growing inrush. In working face development in PZ, pillars and gob solids may not exert evident impact; the most probable is slight decline of immediate roofing stability.

Long standing of Instructions on Control of Mining Pressure… (1984) and great progress of engineering and stoping technologies since its introduction - improvement of structures, great increase in reliability and improvement of longwall equipment (including powered roof supports) causing great growth in intensity of development by longwall mining finally led to the change of intensity and flow of geomechanical processes (deformation and fall of roof, abutment pressure zone parameters and their change with time) provide for the need to study the provisions of the above regulation to be applied to ensure efficiency and safety of room works in danger zones.

4. DISCUSSIONS

To avoid negative cross-impact of superimposed seams during separate development it is required to plan the sequence of extraction in such a way to divide extraction and preparatory works by seams in time and space. However, the time shift excluding the effect of mining works on adjacent seams as we assess may take from 7 to 15-20 years which, in the course of highly productive longwall mining at relatively limited sections of adjacent seams, may not be ensured. Average time lag in adjacent seams during intensive production may reach 10 years. However, the analysis of real mining engineering situations shows that currently the need to distribute works in time is not accounted for and mining is done with time shift of 2-5 years.

Mining shift in space working under mine-longwall conditions should be ensured only regarding extraction and preparatory workings of adjacent seams. However, the analysis of real mining engineering situations, when adjacent seam preparatory works are carried out in the extraction works zone, also evidences insufficient attention to the observation of this principle.

The next matter arising in an attempt to mutually combine mining in adjacent seams is the fact that for the recent 10 years the parameters of extraction districts have changed greatly. In the USA, average highwall and longwall length in 2004 was about 2,650 m and 250 m respectively, while in 2014 - 3, 558 m and 359 m (Piscor, 2015). Existing recommendations on location of assembly and breakdown chambers and preparatory workings in the adjacent seam impact zone is reduced, as a rule, to the shift under mined-out area for some 30 m. However, under the conditions of extraction length and breadth almost 1.5 times, following the existing recommendations on location of preparatory workings regarding gob solids and mined-out areas becomes impossible.

5. CONCLUSIONS

The analysis of the global experience of superimposed coal seams and the analysis of mining engineering situations in the Kuznetsk coal basin mines enabled to do the following basic conclusions:

a) Solution of the problem of efficient and safe development under the conditions of impact of adjacent seams is complicated by joint effect of a great number of factors, defining its intensity.

The main mining and geological factors include the following:

- mining depth (and its change accounting for the terrain);
- interseam area thickness;
- features of interseam area rocks (and their changes within pillar);
- features of enclosing rocks (and their changes within pillar);
- The main mining engineering factors include the following:
- development and leaving of stable pillars (as a result of wide use of roof bolting in mines);
- no matching works by seams;
- change of parameters of extraction pillars (highwall and longwall length) in adjacent seams (inability to match works);

b) The highest complication of longwall mining is the maintenance of preparatory workings sections in the areas of extraction works impact along developed seam in HDZ of adjacent seam.

c) The most favorable conditions for maintenance of preparatory workings sections are ensured when they are shifted under mined-out areas of developed seams (shift of 30 m).

d) HDZ zones, if located within longwall, as a rule do not exert material effect on extraction efficiency.

e) The necessary condition for efficient and safe development of adjacent seams development is combined planning of works in adjacent seams.

The case study of interaction of adjacent seams enabled to mark the directions for further research required to increase efficient and safe mining.

- development of guideline to find rational locations of sections, assembly and breakdown chambers regarding mined-out areas of adjacent seams for certain mining geological and mining engineering conditions;
- assessment of the opportunity to form aerodynamic connection of adjacent seams and development of recommendations to eliminate it (especially for seams liable to spontaneous combustion);
- assessment of the feasibility of multi-entry development and yield pillars to reduce the stress concentration and ensuring stability of workings;
- HDZ differentiation accounting for their effect level;
- study of time effect on stress and strain behavior in adjacent seams areas;
- development of comprehensive recommendations on combined design/matching of mining in adjacent seams (spatial layout solutions matching in time).

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