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Determination of Parameters of High Stress Zones at Multiple-Seam Longwall Mining.

Andrey Alexandrovich Sidorenko*, and Irina Gennadyevna Gerasimova.

National Mineral Resources University (Mining University) Russia, 199106, Saint-Petersburg, 21 line, 2.

ABSTRACT

The main goal of the carried out research is to select the most suitable parameters of planning and mining multiple coal seams that mutually influence on each other. To reach the goal a number of methods have been used, such as numerical simulation method, observations of mine conditions, analysis of guidelines and legal regulations being in force in Russia. The efficiency of mining operations in single and multiple coal seams has been analysed. Having studied the influence of multiple seams on longwall mining operations, we can conclude that modern powered complexes effectively operate even in the zones that used to be described as “higher risk zones”. It is claimed that zones of high rock pressure should be distinguished as stress rates differ within their limits. The study of guidelines on rational location of mine workings showed that the length of negative impact at multiple-seam longwall mining is determined by the type of lining used in development workings and can reach 180 m at depths of 1500 m. Thus, we can make a conclusion that the “Instruction for calculation and usage of anchorage in collieries”, (2013) considers most mining and geological as well as engineering factors influencing the state of mine workings in the impact zones of multiple coal seams. The paper reveals the important role played by the coefficient that determines the impact length of the zone of increased rock pressure manifestations caused by banded coal pillars. The impact length may vary depending on the width and state of the coal pillars. The coefficient is also important for roof bolting calculation to predict shifts. Fields for further research are described, that will contribute into increased safety and efficiency of mining operations at multiple-seam longwall mining.

Keywords*:* underground mining, multiple seam, longwall mining, high stress zones, rock massif control, mine planning, chain pillars.

****Corresponding author***

INTRODUCTION

The efficiency of underground mining planning is of utmost importance for understanding the amount of production costs and competitiveness as well as viability of the mining enterprise. The use of high-production machines for flat coal seams mining made high performance indicators possible and allowed to get close to the leading coal-mining companies. However, the analysis of underground mining records shows that single seam mining is more effective than multiple-seam mining when efficiency and mining safety decrease (Suchowerska, 2014). The most difficult task is to plan underground mining works for thick multiple gas-bearing coal seams liable to rock bursts or (and) spontaneous combustion of coal.

High output of longwall mining equipped with modern high-performance complexes made it possible to ensure effective and safe extraction of reserves. That is why long-pillar method when inter-panel coal pillars are left and working roof is supported with anchorage has become so popular and widely spread. The formation of elongated rock selvedges and banded inter-panel coal pillars results in emerging high stress zones. These zones substantially increase the probability of dynamic events and deteriorate the support conditions of multiple seams. Moreover, mining operations in multiple seams having thin inter-layers may lead to aerodynamic connection between the worked out parts of the seams and high danger of endogenous fires. Therefore, in order to reduce the negative impact of the worked out multiple layers it is strongly advised to follow the guidelines of mining schedule. In some cases it is necessary to take regional or local extra measures (which are often costly) to ensure safety of mining operations in multiple seams. To provide effective performance in such conditions it is necessary to determine the parameters of impact zones of multiple seams, namely to evaluate the parameters of high stress and discharge. It has to be done in order to plan preliminary development and stoping operations to avoid the negative impact of the former and to use the positive effect of the latter. It should be noted that the influence of various factors on performance and safety of multiple seam mining has been studied by a number of authors and the results have been published in numerous papers (Peng et al., 1980; Su et al., 1984; Wu et al., 1986; Ellenberger et al., 2003; Luo, 1997). Nevertheless, it is a challenging task to take into simultaneous consideration a great many factors of mining, geological and technical nature (Mark et al., 2007). Besides, the changing value of the factors in different mining and technical conditions complicates the development of a unified approach to rational parameters of process flow-sheet of multiple seam mining.

METHOD

In Russia there are a great deal of instructions and regulatory documents providing a means to calculate the parameters of high stress zones and zones of increased rock pressure manifestations for multiple seam mining. However, these documents deal with a narrow field of a wide mining area. Each document covers one specific task only. It can be prevention of dynamic events (“Instruction for safe mining development at mines, extracting coal seams, liable to rock bursts”, 1999), provisions on effective stoping operations (“Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0”, 1984), selection of roof bolting parameters (“Instruction for calculation and usage of anchorage in collieries”, 2013), measures providing stability to mining workings (“Instruction for rational arrangement, safety and maintenance of mining developments in collieries”, 2011). Thus, it is quite difficult to consider all influencing factors in planning mining works. Moreover, having analysed the above mentioned instructions and documents, we can say that each of them has some drawbacks that do not allow reliable forecast of mining operations impact for multiple seams and proper planning of work schedule.

For instance, the document “Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0” was issued in 1984 which is why its provisions have to be analysed and considered thoroughly at present. A great technological progress has been made since that time, stoping operations have been modernized substantially – it concerns equipment, increased reliability and improved performance of longwall machines (including powered support). Technological advances have resulted in intense extraction work with the use of fully–mechanised longwall. Such intense activities have led to significant changes in the behavior of geo-mechanical processes (deformation and collapse of roof, bearing pressure zones and their alteration with time). So, obsolete documents may not ensure efficiency and safety of longwall mining in the modern conditions of high stress zones

RESULTS

In the course of multiple seam mining it was often difficult to control rock stress in production faces located under (above) pillars and selvedges that are close to adjacent coal seams. In these conditions the mechanised longwall advanced very slowly due to support clamping as well as large areas of rockfall. The speed of longwall mining in high stress zones had to be slowed down. It was done in order to reduce the impact of pillars in the process of mining the layers not liable to rock bumps and sudden outbursts. As a result, technical-economic indicators of longwall mining went down. In accordance with "Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0" (1984) there are three areas: increased hazard area, hazard area, potential hazard area. Longwall mining in increased hazard areas faces regular intense rock pressure manifestations. They are mostly dynamic events leading to immediate destruction of lower roof layers or vast parts of rock massif near the production face up to the collapse of all inter-layers that may result in dramatic overload of support. A common manifestation of hazard areas is rockfall, rigid clamp of powered support units as well as increased face slip and roof swelling. In the course of mining operations in risk zones the roof becomes less stable due to fractures and rock cleavage. Emergency situations in a longwall face caused by the above mentioned conditions are not typical but probable. The most characteristic feature is intense process of rockfall. Considering longwall mining in potential hazard areas it should be noted that pillars and selvedges may not have significant impact, the most likely effect is slight decrease in roof stability ("Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0", 1984).

Research has been carried out in the mine "Komsomolets" to evaluate the impact of pillars located in multiple seams as a result of under-mining works (Kazanin et al., 2015). The research included visual observations and instrumentation control of roof rock movements with the use of deep benchmark stations and visual measuring stations. They were located with the increment of 35-40 m in roadways within the impact zones. The observations revealed minor (up to 20 mm) roof movement in the longwall impact zone during production work in the longwall face #1380 as well as soil swelling in roadways up to 300 mm. However, the movements and soil swelling process are typical not only for the considered high stress zone but for most roadways along their extent within the limits of extraction panel. Thus, the given mining and technical conditions – in the process of mining works in the seam "Baikaimsky" within the zone of under-mining of the seam "Breevsky" - are defined as "hazard area" (Figure 1, A) according to "Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0" (1984). But observations did not reveal any negative impact on the preliminary development roadways and production face as the thickness of inter-layers is significant (185-190 m).

The impact evaluation of overworking was made in the "S.M. Kirov" mine in the gob area of "Polenovsky" seam within the impact zone of the pillar located in the upper seam "Boldirevsky". The thickness of inter-layers in the studied area was 48 m. The zones of pillar impact were predicted (Figure 1, b). According to the prediction, stoping operations were conducted in "increased hazard areas" ("Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0", 1984). However, the analysis of mining activities in the production face in the "S.M. Kirova" mine did not prove large impact of overworking on the longwall advance and load on the working area. The carried out research resulted in the conclusion that the type of powered roof support used in the "S.M. Kirov" mine – with the largest width of canopy bar and sufficient support resistance – provides sustainable longwall mining even with the advance of working areas provided roof backing is ensured. The effective performance was also observed in the "increased hazard areas" as they are defined in the "Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0" (1984), (Kazanin et al., 2015).

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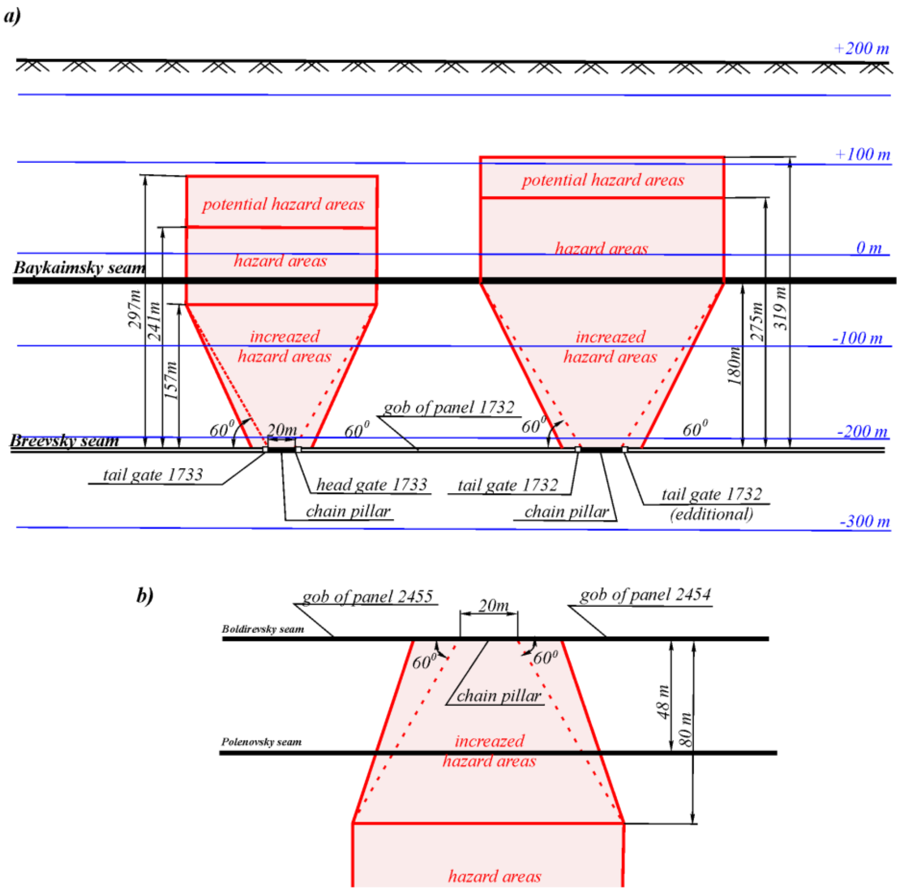

Figure 1: Pillar impact zones determining the intensity of rock pressure manifestations in the production face (built in accordance with "Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0", 1984): a) for under-mining conditions; b) for over-mining conditions.

Having studied the efficiency of modern high-productive complexes in under-mining and over-mining conditions we can conclude that longwall mining is possible in increased hazard areas keeping up the level of production and safety of mining operations. It should also be noted that other authors emphasized the availability of effective control over the rock conditions if the longwall face but not panel entries is located in the high stress zones. (Gale, 2004).

According to the "Instruction for safely mining development at mines, extracting coal seams, liable to rock bursts", 1999, the limits of high stress zones in the crosscut transverse and along the seams should be drawn like it is shown in Figure 2, a. The area of high stress zones covering roof d_1 and soil d_2 from the edge depends on the size of gob a and mining depth H. This approach allows to define the impact limits of selvedges or pillars of the previously mined seams, but it is impossible to make a quantitative evaluation of the impact extent. The strain level within the high stress zone may vary up to 5 times and even more. If the extent of high stress zone if significant it is necessary to divide it depending on the strain level of the rock massif. Considerable difference in the amount of expenses spent on specific technologies and their parameters aimed to control the conditions of rock massif makes it necessary to predict the stress-strain state of the rock massif. The division of high stress zone according to the strain level can be made with the application of numerical methods based on approaches of continuum mechanics. For the evaluation of stress-strain state we can apply elastic approach taking into consideration St Venant principle to save time and cut down the requirement to the computing machine. It means that parameters of high stress zone for the areas located far from selvedges and coal pillars can be defined quite precisely. In Figure 2, b the solution of the above approach is presented. It shows differences in strain areas of high stress zones. The regulatory document however defines the limits of high stress zones only (Figure 2, a).

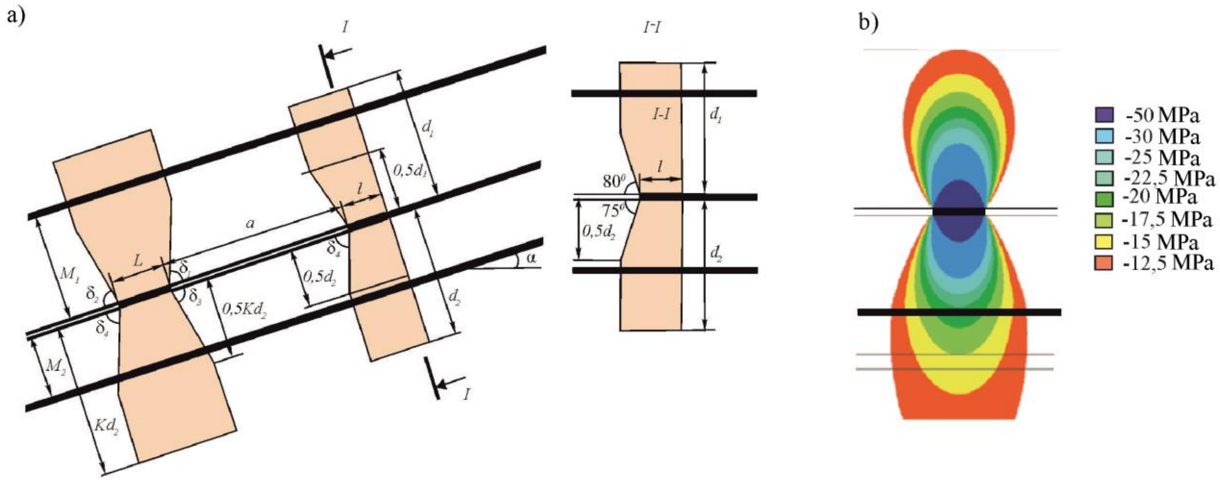

Figure 2: High stress zones: a) drawn in accordance with regulatory documents; b) based on the results of numerical modeling

It should be highlighted that powerful computing complexes are capable of solving tasks related to the assessment of rock stress-strain state in a short time. One of the advantages is that it can be applied for any configuration of rock massif adjacent to openings network and any size of the considered three-dimension area. Thus, modeling can be successfully applied for any cross-section of a three-dimension massif, and not only for distribution of a specific parameter in particular cross-sections in plain strain conditions. In Figure 3 high stress zones in the overworked seam (cross-section in seam plane) are shown. In Figure 3, a the results of regulatory documents application are presented – the limits of high stress zones are defined. In Figure 3, b the results of numerical modeling with the zone differentiation according to the stress distribution with regard to the initial geostatic stress level are shown. The differences in stress levels within the high stress zone for the mine-engineering situation given in Figure 3 is confirmed by the mine observations of preliminary development areas in the "S.M. Kirov" mine owned by JSV "SUEK-Kuzbass".

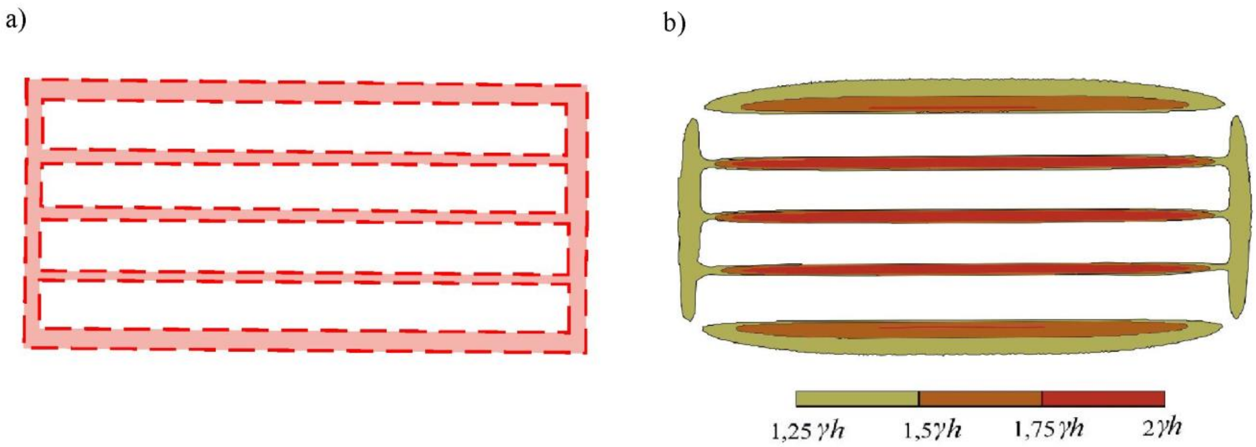

Figure 3: High stress zones in the overworked seam after completing 4 working areas: a) drawn in accordance with regulatory documents ("Instruction for safely mining development at mines, extracting coal seams, liable to rock bursts", 1999); b) results of numerical research work

DISCUSSION

The regulatory document ("Instruction for rational arrangement, safety and maintenance of mining developments in collieries", 2011) states that flat and inclined seams should be mined in a certain manner. The sequence of their development and mining as well as the location and period of preliminary seam development should be scheduled with regard to the closeness of seams to each other. It should be noted that "Guidelines for sustainable location, protection and maintenance of mining openings in coal mines" (2011) are based upon ("Instruction for rational arrangement, safety and maintenance of mining developments in collieries of the USSR" (1987). Seams in a coal formation can be divided into three groups in relation to their closeness: non-contiguous seams (single), contiguous non-undermining seams and contiguous under-mining seams. Non-contiguous seams are those which are mined as a single seam within the limits of the considered mining area. Non-contiguous seams have thick inter-layers, their thickness exceeds the value of safe under-mining (over-mining) which depends on the depth of mining operations and estimated compression strength of rocks in the roadway contour. The safe height of under-mining for roadways with support having the flexibility of 300 mm is between 50 m (if the depth of mining operations is less than 200 m and rock strength is over 120 MPa) and 180 m (if the depth of mining operations is over 1500 m and rock strength is up to 20 MPa). The safe height of over-mining varies if rigid support is used between 30 m (if the depth of mining operations is up to 200 m and rock strength is over 120 MPa) and 130 m (if the depth of mining operations is over 1500 m and rock strength is up to 20 MPa. If flexible support with the flexibility rate of 300 mm and 500 mm used, the safe height is reduced by 30% and 50%, respectively. It is highlighted in the "Instruction for rational arrangement, safety and maintenance of mining developments in collieries», 2011, that if the seams are considered to be contiguous (non-undermining and under-mining) they have to be developed and mined in relation to each other with the use of pillarless techniques of roadways safety. Pillars not liable to destruction by rock pressure should not be left close to tectonic faults. A number of authors strongly believe that pillars should not be left in on coal mining roadways (Whittaker et al., 1971; Peng et al., 1980; Chekan et al., 1993). Other authors pointed out unfavourable conditions in multiple seams when pillars had not been removed (Su et al., 1986; Chase et al., 2005). However, the most favourable conditions for intense and safe production in longwalls can be created when the impact of the previously worked out extraction panels is significantly reduced. It can be achieved by the presence of wide indestructible pillars. Besides, roof bolting which is widely used in panel entries of coal mines proved its efficiency for roadways safety with the use of coal pillars. Moreover, coal pillars are necessary to isolate the gob and therefore prevent endogenous fires during mining operations in the seams liable to spontaneous combustion ("Spontaneous underground fire prevention and combating manual for Kuzbass mines", 2007). Thus, the most promising methods of multiple-seam mining rely on longwalls with indestructible pillar leaving that create high rock pressure zones in multiple seams.

Having studied "Instruction for calculation and usage of anchorage in collieries" (2013), we can draw a conclusion that it takes into account most mining, geological and engineering factors influencing the rock massif in the zones of under-mining and over-mining. Appendix #12 contains calculation methods of bolting roof parameters for preparatory mining workings located in the zones of increased rock pressure manifestations. It is noted that zones of increased rock pressure manifestation are formed due to high strain caused by pillars and selvedges that were left during mining operations in adjacent areas or seams. But the parameters of such zones are different from those of high rock pressure zones. Unlike high rock pressure zones, zones of increased rock pressure manifestations are not liable to rock bumps, coal bursts (rocks) and gas ("Instruction for calculation and usage of anchorage in collieries", 2013). According to the Instruction zones of increased rock pressure manifestations in seam selvedges look like as follows (Figure 4, a). It generally fits the results of numerical study (Figure 4, b). But the "Instruction for calculation and usage of anchorage in collieries" (2013) has a drawback – it is the lack of distinction between the impact range of the selvedge and pillar. In addition, displacement level within the impact zone is determined by the coefficient of displacement modification that can have maximum values of 2 and 3.5 for selvedge and pillar respectively.

The differences between the impact range of the selvedge and pillar are obvious. The impact range of pillar depending on its size with regard to the extension of bearing pressure zone is considered in the "Instruction for safely mining development at mines, extracting coal seams, liable to rock bursts" (1999) by multiplication of values d_1 and d_2 describing selvedge and coefficient *K* describing the pillar width *L*.

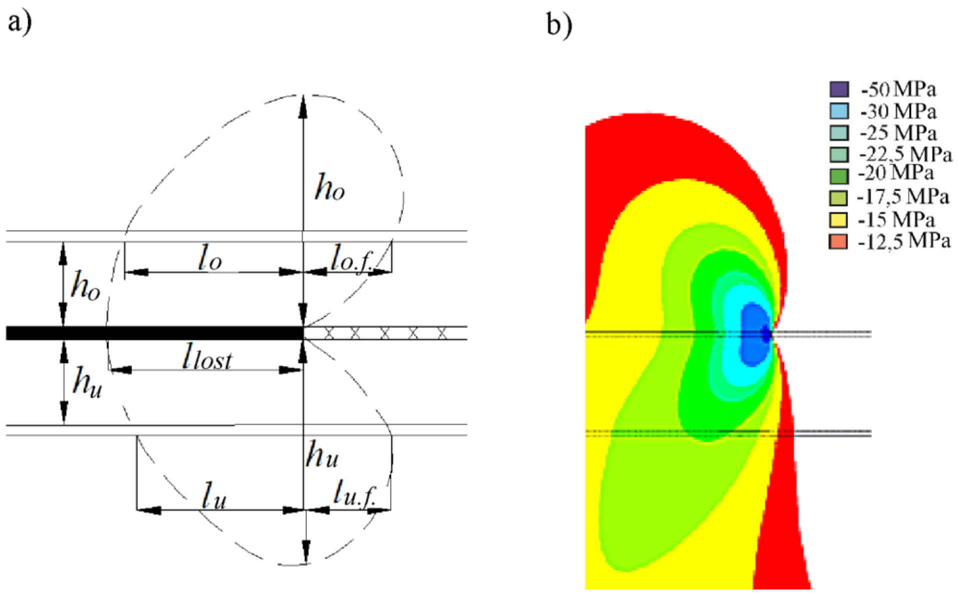

Figure 4: Zone of increased rock pressure manifestation from the seam selvedge: a) in accordance with the method ("Instruction for calculation and usage of anchorage in collieries", 2013), b) numerical study

Coefficient K has to be used for the determination of the pillar impact range as zones of bearing pressure overlap and the resulted loads increase to a certain limit as the pillar gets smaller (whereas K increases and has values >1). The limit is linked to reaching the maximum width and further destruction (whereas K decreases and has values <1). Thus, coefficient K can be calculated with the use of Table 1.

Table 1: Coefficient considering the pillar width. It is used for determination of the pillar impact range on multiple seam.

L/l	≤ 0,1	0,15	0,20	0,25	0,35	0,5	1,0	1,5	≥2,0
K	0	0,25	0,5	0,75	1,0	1,13	1,25	1,13	1,0

L –width of the pillar, m

l – width of the bearing pressure zone, m.

CONCLUSIONS

The carried out analysis of methodological approaches used for the determination of parameters of high stress zones and zones of increased rock pressure manifestations during multiple seam longwall mining showed the need for the improvement of calculation methods, namely:

- high stress zones should be differentiated for mining operations conducted in seams liable to rock bursts ("Instruction for safely mining development at mines, extracting coal seams, liable to rock bursts"), as the degree of dynamic danger is directly linked with the level of stress condition in rock massif;
- critical approach to the practical application of provisions regarding the evaluation of pillar and selvedge impact on the effectiveness of production faces ("Guidelines on ground control in working faces under (over) pillars and massif edges at multiple seam mining of thickness up to 3.5 m with the slope up to 35^0", 1984), as the practice of mining operations proves that it is possible to use modern mechanized complexes in "increased hazard areas" without slowdown of mining productivity;
- for the determination of impact zones and expected displacements when anchorage parameters are calculated it is necessary to use a correction coefficient which determines the impact range of the zone with increased rock pressure manifestations from the formed coal pillars according to their width and condition ("Instruction for calculation and usage of anchorage in collieries", 2013).

Further research work should be connected with the study of impact of width and strength properties of coal pillars on formation of high stress zones and modification of their parameters with time. The main goal of further research is to work out scientific rationale of predicted parameters of high pressure zones and discharge. This data will be essential for design of process flowsheet of preliminary development and mining operations with regard to mutual interaction between multiple coal seams.

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