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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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CURRENT STATE OF THE PROBLEM OF MINING INDUCED SEISMICITY AND PROSPECT OF USING SEISMIC MONITORING SYSTEMS

Abstract. The paper reviews the literature on the state of the problem of mining seismicity in the territory in the territory of Kazakhstan and Russia mainly caused by rockbursts. Additionally it analyzes prospect of using special seismic monitoring systems as rockburst control tool. Seismicity is the phenomena that occur naturally from an earthquake or unnaturally by man-made activity. Seismicity caused by human activity during mining operations is the subject of the study. In the case of mining, a seismic event identified as a rockburst causes the destruction of an excavation, equipment, staff hurt, and disaster. In terms of safety, efficiency, and production, such effects as rockburst and seismicity may have a significant impact on the development of mines. In spite of technical developments, however, the rockburst estimation is still a challenging and debatable procedure in the mining industry. The majority of seismically passive and quiet mines are shallow and small, with a depth not exceeding 1 km. With the increasing production period and depletion of mineral recourses, underground mines have become deeper worldwide. This reality makes the issue of the mine seismicity quite crucial. That is why microseismic monitoring system is becoming more and more popular with current technical advancements, and this tool is extensively used in the mining industry, particularly in in-depth underground mining projects.

Key words: mine; seismicity; rockburst; microseismic; monitoring.

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ЖАСАНДЫ СЕЙСМИКАЛЫҚ ҮРДІС ПРОБЛЕМАСЫНЫҢ ҚАЗІРГІ ЖАҒДАЙЫ ЖӘНЕ СЕЙСМИКАЛЫҚ МОНИТОРИНГ ЖҮЙЕЛЕРІН ПАЙДАЛАНУДЫҢ КЕЛЕШЕГІ

Аннотация. Мақалада Қазақстан және Ресей аумағындағы тау-кен ісімен байланысты сейсмикалық оқиғалар және тау жыныс соққысы әсерінен болған аппаттарды сипаттайтын әдебиеттер қарастырылады. Сонымен қатар, ол сейсмикалық бақылаудың арнайы жүйесін тау жыныс соққысына қарсы құрал ретінде қолдану перспективасын талдайды. Сейсмикалық оқиға – бұл табиғи түрде жер сілкінуінен немесе техногендік әрекеттер нәтижесінде пайда болатын құбылыстар. Осы ғылыми жұмыста тау-кен жұмыстары кезіндегі адамның іс-әрекетінен туындаған сейсмикалылық оқиғалар зерттеледі. Тау-кен өндіру жағдайында, тау жыныс соққысы ретінде анықталған сейсмикалық оқиға қазбаны, техниканы, қызметкерлерді жарақаттайды және апатқа әкеледі. Қауіпсіздік, тиімділік және өндіріс тұрғысынан тау жыныс соққысы мен сейсмикалық оқиғалар жерасты құрылымынын дамуына айтарлықтай әсер етуі мүмкін. Қазіргі кезде техникалық жетістіктерге қарамастан, тау-кен өнеркәсібінде тау жыныс соққысын болжау әлі де күрделі және даулы үдеріс болып есептеледі. Әлем бойынша сейсмикалық пассивті және «тыныш» шахталардың көпшілігінің тереңдігі 1 км-ден аспайды. Бірақ пайдалы қазбаларды өндіру барысында және жер асты қазбасының терендігі ұлғаюымен бұл объектілердің сейсмикалық қаупі пропорционалды түрде артады. Бұл мәселе шахтаның ғана емес тұтастай алғанда бүкіл тау-кен аймағының сейсмикалық жағдайын өте қауіпті күйге әкеледі. Сондықтан да тау-кен өнеркәсібінде микросейсмикалық бақылау жүйесінің маңыздылығы уақыт өткен артып келеді. Сонымен қатар жоғарыда айтылған бақылау жүйесі қазіргі кезде техникалық жағынан даму үстінде, және бұл құрал кен өндіру өнеркәсібінде, әсіресе кешенді және терең жер асты тау-кен жобаларында кеңінен қолданылады.

Түйін сөздер: кеніш, сейсмобелсенділік; тау жыныс соққысы; микросейсмика; бақылау.

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СОВРЕМЕННОЕ СОСТОЯНИЕ ПРОБЛЕМЫ ПРОЯВЛЕНИЯ ИНДУЦИРОВАННОЙ СЕЙСМИЧНОСТИ И ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ СИСТЕМ СЕЙСМИЧЕСКОГО МОНИТОРИНГА

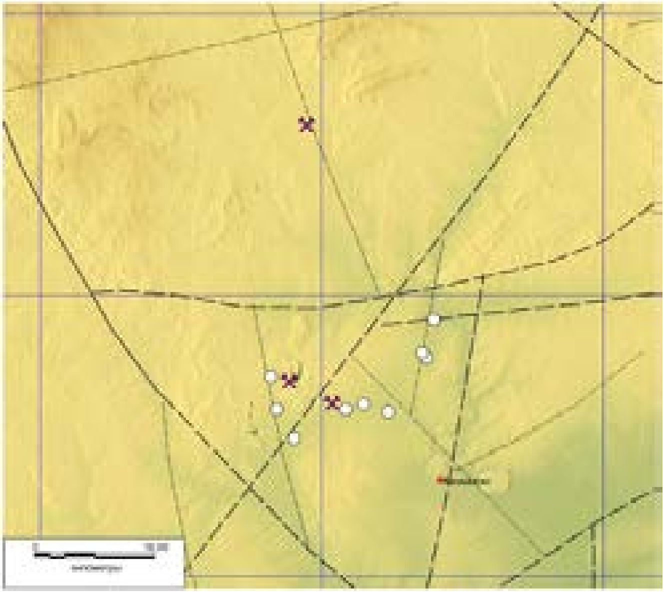
Аннотация. В статье проведен обзор литературы по состоянию проблемы техногенной сейсмичности при горнорудной деятельности на территории Казахстана и России, в основном вызванной горными ударами. Дополнительно анализируется перспектива использования специальных систем сейсмического мониторинга в качестве средства контроля горных ударов. Сейсмичность – это явление, которое возникает естественным образом в результате землетрясения или неестественно в результате антропогенной деятельности. Сейсмичность, вызванная деятельностью человека во время горных работ, является предметом исследования. В случае горных работ сейсмическое событие в виде горного удара вызывает разрушение выработки, выход из строя оборудования, травмы рабочего персонала и может стать причиной остановки производственной деятельности на длительное время. С точки зрения безопасности, эффективности и добычи такие эффекты, как горные удары и сейсмичность могут иметь значительное влияние на разработку рудников. Однако, несмотря на технические разработки, прогнозирование и предупреждение горных ударов по-прежнему является сложной и актуальной проблемой в горнодобывающей промышленности. Большинство сейсмически пассивных и «тихих» рудников являются малоглубинными, с глубиной не более 1 км. С увеличением периода добычи и истощением минеральных ресурсов эти же подземные выработки во всем мире становятся все глубже и, соответственно, сейсмичность этих объектов увеличивается пропорционально. Эта реальность делает вопрос о сейсмичности рудника и района добычи в целом весьма актуальным. Именно поэтому система микросейсмического мониторинга становится все более критичной в горнодобывающей промышленности. А в связи с современными техническими достижениями подобные аппаратно-программные комплексы стали более доступными и поэтому широко используются в горнодобывающей промышленности, в особенности в проектах с глубокозалегающими подземными выработками.

Ключевые слова: рудник, сейсмоактивность; горный удар; микросейсмика, мониторинг.

The seismic situation in local mining regions. Microseismic monitoring systems are currently being designed to analyze and monitor the specific region of the mine. The Bachat earthquake that occurred on June 18, 2013 in the Kemerovo region (Russia) with a local magnitude ML = 6.1 is the world's strongest man-made earthquakes associated with mining operations during the development of the coal (Fig. 1). The maximum observed intensity of shaking was I = 7 points. The earthquake was accompanied by an intense aftershock process. Bachatsky coal mine, laid in 1948, - one of the largest coal mine in Russia, its dimensions are 10 km in length, 2.2 km in width and 320 m in depth (at the time of the Bachat earthquake). The average annual coal production is more than 9 million tons. Coal production in this open pit continues and the planned depth of the open pit is ~ 550 m. The results of these studies presented in (Emanov A.A. et.al, 2020), such as the spatial coincidence with the coal-mining area, the pulsating nature of activation, the mechanism of the main shock, indicate the technogenic nature of the Bachat earthquake. Also this paper presents the results of the last years of observation, the time series and the history of seismicity in mining area.

Fig. 1. The Bachat earthquake epicenter

The second largest induced seismicity observed in Zhezkazgan field in Central Kazakhstan with magnitude MS = 4.6, mb = 4.8 (Fig. 2). It was a large-scale seismic event that killed 6 people and caused destruction many active underground structures and buildings on the surface. The power of the earthquake were so strong that they practically led to a complete work termination at one of the mines, the closure of a number of mines and the transfer of surface structures from the hazardous zone. Rail tracks were twisted, carriages were overturned (Aristova I.L. et.al, 2013).



— — — faults; ○ – epicenter; – open pit.
Fig. 2. The Zhezkazgan earthquake epicenter

In the (Aristova I.L. et.al, 2020) the underground mine industrial explosions study methodology and generalized results of long-term study registered in Kazakhstan by a network of seismic and infrasound stations are described.

In (Geman V.I. et.al, 2007) information about man-made earthquakes induced by mining operation on the Zhezkazgan copper deposit is given. This copper deposit has been mined by a room-and-pillar mining method for several decades. During this period, open stope space with a total volume of about 180 million m^3 was excavated and supported by thousands of pillars. The gradual degradation of the geomechanical situation at the field is expressed in an increase in the number of destroyed pillars, as well as in an increase in the area of hazardous, instable zones. Since the mid-90s of the last century, qualitative changes began to take place in the geotechnical environment: individual weakened areas with destroyed pillars were combined into large instable zones, and the collapse of the overlying stratum over large areas began to be accompanied by induced earthquakes on the surface and air strikes in underground space. Currently, most reserves have already been recovered and secondary mining is widely used, which makes the problem of forecasting collapse more acute. At the same time, a significant part of the workings has already collapsed or in unstable state. Many collapses have a geomorphic effect (an surface area of about 5-6 km^2). During 2007-2008 this area increased about ¼ km^2.

On June 21, 2014 according to (Velkhanov A.E. et.al, 2015) all IGI (The Institute of Geophysical Research) seismic stations are registered a fairly strong earthquake in Central Kazakhstanzh. Any earthquake in this region is a rare event, and especially if it is a strong earthquake. Usually industrial blasting works associated with the development of minerals are most often recorded in Central and Northern Kazakhstan. The station closest to the epicenter of the earthquake was the ISI Ortau station located at a distance of about 160 km.

The epicenter of the earthquake is located within Kazakh Upland, near the southern border of the Karaganda coal basin. In connection with the location of the source in the aseismic platform zone subject to intense technogenic impacts, the question arose about the nature of this seismic event. Is it connected with the work in the coal mines, intensive in this area? Is it natural or induced seismicity?

According to the information presented in (Velkhanov A.E. et.al, 2015) the earthquake of June 21 is not a consequence of an explosion or simple rock collapse, but was realized under the conditions of a regional stress field, under the action of which a rupture occurred in the source. It can be concluded that this is a tectonic earthquake. At the same time, it is not ruled out that the earthquake could be provoked by active blasting activity in a nearest mine - Saranskaya Underground Mine.

Rockburst control strategies. The rockburst issue can be overcome in two ways: firstly, by controlling the damage caused by seismic activity, and secondly, by controlling the location, time of occurrence and magnitude of the seismic event. In the case of multiple exhibits and of high intensity, support systems cannot prevent damage to the mines. If the potential harm is high and cannot be handled primarily by the support system, then the latter solution is required. The second approach to rockburst control is called a strategic approach, and it has been found that certain forms of rockburst are triggered by mining sequences, stop shapes or variations of these influences with geological structures. The strategic approach focuses on modifying mining sequences, stopping and, in some cases, discovering that the initial configuration of the mine is not convenient for a rock mass response to mining activities (Graham G et.al). Recently, however, an integrated solution that incorporates both preventive steps such as remote mining, enhanced ground support, upgraded advanced support systems, and reduced exposure to staff and equipment using a seismic monitoring system has been found to be more beneficial than the single implementation of each individual element (Trifu C.I. et.al, 2009). If the rockburst occurred in several isolated sections of the mine and remained life of the mine is short, then the monitoring device is not needed. However, if the damage to the rockburst occurs in the prevailing rock masses and near the footwall of the mine with a long production period, then a seismic monitoring system is required(Graham G et.al). The efficiency and accuracy of the microseismic monitoring system, however, depends on the velocity model used for the calculation of seismic source locations. The calculation algorithm for static input velocity assumes the value of homogeneous rock mass, which is far from the actual one. In (Hachai O.A. 2017) described how natural and man-made fractures of rocks affecting to propagation of seismic waves. Such factors and operation leads to the primary source of error which can result to an unacceptable outcome (Collins D.S. et.al, 2014). The source of the rockburst is one of the most complex and distinguishable operations to describe. This phenomenon is also supported by Trifu and Suorineni. According to their study, rockburst is hard to forecast, and the best way to solve this issue is to classify potential rockburst areas using computational modeling and experience (Trifu C.I. et.al, 2009). However, some researchers (Gerrman V.I. 2014) from Russian Federation and Kazakhstan shows that using special methods of rockburst prediction works precisely. In (German V.I. 2014) their experience of the rockburst forecasting on the Zhezkazgan copper deposit is described. Information about man-made earthquakes induced by mining on the deposit is given. Also they showed that seismic monitoring is an effective tool to control the current state of excavations. Finally, they considered that analysis of the space-time and the energy distribution of recorded seismic events based on modern physical concepts to the process of rock failure allows to forecast mine collapses.

Rockburst prediction methods. During the extraction process of the mineral resources, mining operations cause the change in geomechanical situation, therefore, it is important to prevent dynamic forms of rock pressure manifestation. To do this, it is required to predict the dangerous events and reduce damage severity. A number of techniques have been developed based on the use of various physical effects. Some types of statistical and adaptive methods can be used to forecast large seismic events, however, the reliability of forecasting in difficult mining and geological conditions does not exceed 75%.

During the analysis of catalogues of seismic events the significant increase of seismic activity in a local area are traditionally considered as main signs of hazardous situation. Such approach was used as the basic one for the assessment of current situation in copper mines of mines in Norilsk, Zhezkazgan deposit, Vorkutaugol JSC mine, mines of the Far East. In particular, in Zhezkazgan deposit considerable activation of weak seismicity was regarded as the feature for referring extraction units to weakened ones, and registration of seismic events with energy release exceeding 104 Joules in some region gave reason to refer it to instable area or to the area of intense shifts.

Concepts of multistage model of solid failure on the occurrence of downfalls when defects reach some critical concentration are also used in prediction(German V.I. 2014). Besides, for prediction of strong seismic events some researchers use such parameters as the inclination of magnitude–frequency curve and fractal characteristics of seismicity. However, in most cases these parameters cannot be applied in practice of downfall prediction, as the number of preceding seismic events is small and insufficient for reliable determination of the specified characteristics.

In a number of cases the concentration parameter k can be used in the evaluation of large downfall hazard.

Further development of ideas about interaction of defects in places of their high concentration is the introduction of the parameter of contingence of seismic events which represents the modification of the concentration parameter (German V.I. 2015).

“Seismic gaps” of the first and the second type (areas of weak seismic activity) as well as seismicity migration are additional important forerunners of a future large downfall (Zhurkov S.N 1984). These two parameters have become widely spread in seismology in earthquake prediction.

The kinetic concept of strength became a physical foundation for the rock failure study . The similarity of the rock-failure processes at different scale was proved in (Zhurkov S.N 1984). However, at present only in the laboratory experiments, the time and place of the main fracture are accurately predicted(German V.I. 2014). Under real conditions, it is as yet impossible. The authors associate the problem solution with the formalization of prediction, which results in more detailed and complex processing of the available data with the help of mathematical statistics, pattern identification theories, etc.

The prediction of large-scale failures consists of two stages:

- localization of microseismic events corresponding to nucleation of failure focus;
- determination of failure time from the parameters controlled.

The failure nucleation region D must correspond to the place of crack initiation. Therefore, we can assume that D will have a shape of ellipsoid, and as the failure approaches, it will contract and tend to take the flatter form characteristic of rupture. According to the hierarchical concepts, the larger is D, the greater is the scale of failure.

The regions D are determined by means of two approaches:

• estimates of experts;

• scanning of the object controlled by the permanent spatial window and analysis of the selected prediction parameters.

The disadvantage of the first approach consists in subjectivity of an expert, as a result of which formalization is impossible. In the second approach, we cannot ensure the conformity between the shape of scanning window and the forming focus of failure. In addition to it, even for the events of the same energy class, the dimensions of D are not constant and can vary as demonstrated by the long-term observations in the Severouralsk bauxite mine. The focus localization procedure proposed in is based on the pattern identification theory and does not possess a high stability of the results.

In problems of forecasting large collapses are considered on the example of the Zhezkazgan copper deposit. The basic physical concepts of the process of rock mass destruction are presented. A modified concentration criterion for the rock mass destruction, which is the main approach for predicting collapses at the Zhezkazgan field, is described and substantiated, data on additional forecasting methods, on the organization of work to control mined-out spaces at the Zhezkazgan field are given. An example of forecasting the occurrence of collapse in one of the sections of the field is given.

In it is shown that the dynamic process of mining can be controlled using the catastrophe theory. The control parameters can be values of blasting energy and locations of explosions relative to an area under study or operation. The kinematic and dynamic parameters of the deformation waves, as well as the structural features of rock mass through which these waves pass act as internal parameters. The use of the analysis methods for short-term and medium-term forecast of rock mass condition with the control parameters only is insufficient in the presence of sharp heterogeneity. However, the joint use of qualitative recommendations of the catastrophe theory and spatial–temporal data of changes in the internal parameters of rock mass will allow accident prevention in the course of mining.

Conclusion. The literature review studied mining-induced seismic background of Kazakhstan and Russia, microseismic activity in underground mines and rockburst prediction methods. The Republic of Kazakhstan falls within the top twenty of countries with highest reserves and production of most of these minerals. Kazakhstan is the number one producer of the world's uranium and contains the world's largest reserves of chromium.

Unfortunately, mine safety records in Kazakhstan are nothing to be proud of. Kazakhstan has had a poor record in health and safety in the mining sector, especially coal. This is partly attributed to the labor-intensive nature of the mining sector in Kazakhstan. High labor-intensive activities increase the exposure of workers to hazards and their chances of getting injured. Continuing research in this area will assist to improve worker safety in Kazakhstan mines nationally and contribute internationally to worker safety. In Kazakhstan, most underground mines are still less than 1.2 km deep, and while at these current depths, rockbursts and seismicity may not be of immediate threat, cautionary measures must be put in place in preparation for future deepening of these operations. As mining depths increase, seismic and rockburst potential increases in frequency. It is critical to understand how rock masses respond to mining at these depths. Additionally we can conclude that in most cases the signal processing approaches are based on a homogeneous rock mass assumption for a single velocity model or variable static velocity models for a layered rock mass assumption. However, in-depth mines with continuously changing ground conditions, depth, climate conditions and dynamic backfilling geology involve an intensively-changing velocity model. The development of a novel approach with paying respect to changes in complex environments due to mining operations and to real-time monitoring of source locations is therefore critical. However due to complex geological environment and intensive acoustic noises from all kind of mining equipment it is a hard to implement above mentioned source localization methods. All widely used wave tracking methods highly depend on geological situation, equipment performance and level of background noise. Consideration of the present-day views on rock failure leads to the conclusion that each large defect is conditioned by the accumulation of smaller defects (cracks, displacements) that can be registered with currently available equipment. This gives evidence of the possibility of failure prediction, including large-scale failure. Currently using mine collapse prediction methods successfully proven by field approbation in Zhezkazgan field and can be enhanced if monitoring equipment/software will be adapted. And there is a weak point – small cracks generates high frequency and much weaker acoustic waves which can not be registered using traditional seismic monitoring systems. To create suitable tools to register those signals we have to know wave parameters for each of seismic events and factors could affect to signal propagation. Nowadays, in the era of cheap IOT technologies it will be very absurdly miss a chance to use them for live-saving projects.

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