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IRON ORE MINING GEOMECHANICAL PROBLEMS IN UKRAINE

The paper deals with problems in Ukrainian iron ore mining industry resulted from enterprises reaching deep levels of mining. There are also described main causes of hazardous situations due to geomechanical factors at such depths, dynamic forms of excessive rock pressure manifestations, and types of external factors affecting the state and behavior of load-bearing elements of mining and technological objects below the surface to enable mining operations. The paper provides recommendations on creating a specialized geomecanics support system for mining enterprises which is based on labour safety risk-management principles as well as it presents geomechanics tasks to be solved by the system.

***Keywords:** geomechanics, problems, iron ores, mining industry.*

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ГЕОМЕХАНІЧНІ ПРОБЛЕМИ ЗАЛІЗОРУДНОЇ ГІРНИЧОДОБУВНОЇ ПРОМИСЛОВОСТІ УКРАЇНИ

Розглянуто проблеми, що виникають у залізорудній гірничодобувній промисловості України у зв'язку з досягненням підприємствами з видобутку залізних руд великих глибин здійснення добувних робіт. Описано основні причини виникнення небезпечних ситуацій, обумовлених геомеханічними факторами, які діють на великих глибинах; динамічні форми прояву надвисокого гірського тиску на таких глибинах; види зовнішніх геомеханічних факторів, що впливають на стан і поведінку несучих елементів гірничотехнологічних об'єктів, які зводяться у надрах для забезпечення можливості виконання гірничих робіт. Надано рекомендації щодо створення спеціалізованої системи геомеханічного забезпечення гірничодобувних підприємств, заснованої на принципах ризик-менеджменту у сфері безпеки праці. Наведено основні задачі з геомеханіки, які повинна розв'язувати така система.

***Ключові слова**: геомеханіка, проблеми, залізні руди, гірничодобувна промисловість.*

Introduction. Mining is one of Ukrainian key industries. It is characterized by the fact that large amounts of the Earth interior are involved into commercial production, and thus its geomechanics is disturbed by mining. The scope of the disturbance is very great; its effects are irreversible and they are hazardous for both mining enterprises and the environment.

Negative effects become significant at great depths of mining characterized by considerable changes of geomechanics and excessive rock pressure. Thus, the risk of dynamic rock pressure manifestations and emergencies rises substantially.

Such situation requires development and implementation of efficient and reliable measures to decrease emergency risks and creation of reasonable safe conditions of mining.

Analysis of latest research and publications. Review and analysis of home and foreign publications on the problem show the ultra-low number of studies on the problem solution.

Recent developments in creating safe mining conditions focus on the only, yet very important, direction – building a computerized system of continuous monitoring of rock mass behavior affected by changes in natural geomechanics due to mining [0]. This monitoring enables prevention of emergencies and accidents due to prompt detection of zones with observed intensive mechanical stress concentration and rock deformations that may soon go beyond the critical boundary while mining. The monitoring results enable timely evacuation of miners from dangerous zones or suspension of operations before emergencies.

Such developments are currently under way in the USA, Canada, South Africa, Germany, Australia, Poland, and Czechia [2, 3]. The mentioned countries have mining enterprises operating at considerable depths (open pits - up to 1.5 km, underground mines - up to 3.0 – 5.0 km).

However, in practice rock mass behavior monitoring alone is not a sufficient means of preventing emergencies and accidents caused geomechanics. Even if the monitoring is applied, there are still accidents due to geomechanics that result in the staff injuries and fatalities [4].

Highlighting previously non-settled issues of the general problem. Development of efficient measures to create safe conditions of deep iron ore mining requires, first of all, a thorough study of the whole range of dangerous geomecanical factors and reasons of their occurrence. It should be noted that in Ukraine this aspect of iron ore mining geomechanics is underinvestigated. This fact complicates further mining at great depths and, as a result, development of Ukraine's iron ore mining industry in general.

Problem statement. Considering mentioned above, the authors were determined on reviewing and analyzing the situation in the Ukrainian mining industry in terms of deep iron ore mining geomechanics focusing on the following: determining current geomechanics conditions at great depths; determining types of geomechanics hazards at the depths, determining the tasks to be solved to decrease emergency risks.

Material presentation and work results. Iron ore is one of basic production resources of the contemporary industry. Ukraine is a large-scale producer of commercial products of this type. The development strategy and policy of Ukrainian economy are directly connected with further functioning and development of the iron ore mining industry [5].

At present Ukraine houses one of the largest iron ore mining industries in the world. The country mining capacity ranks 7^{th} out of 52 iron ore mining countries, in terms of iron ore raw materials commercial types production. This industry considers 8 – 10% of the country GDP and is one of the major foreign exchange earners as nearly 40% of its produce is exported [6]. Besides, the iron ore mining industry is a major supplier of the basic raw materials (iron ore) for the national metallurgy. Iron ore mining and metallurgical industries form Ukraine's integrated mining and metallurgical complex (MMC of Ukraine).

Such opportunities are ensured, first of all, by the country significant mineral raw material base. The reserves of various iron ore kinds make Ukraine one of the world leaders in this field. 80 large proved deposits on the country territory contain 14% of the world iron ore reserves.

In Ukraine there are 10 large iron ore mining enterprises operating in surface and underground modes (11 open pits and 9 underground mines).

In Ukraine, iron ore has been mined for 120 years. The largest scale mining started in the 1950 s. It should be noted that since the very beginning of this period, iron ore had been extracted very actively accompanied by the depth increase. As a result, by 2000 main enterprises of Ukraine had reached great depths of mining (350 – 460 m in open pits, 1400 – 1500 m in underground mines). These depths are planned to reach 500 – 600 m and 1600-1800 m respectively. According to this, all iron ore enterprises of Ukraine are rated as «deep» [7].

Development at such depths is accompanied by serious geomechanics challenges: quick durability loss in structural units of mining and technological facilities caused by excessive rock pressure; specific behavior of rocks under developing mechanical stresses close to their strength limits; complicated or even impossible forecasting of behavior of mining and technological facilities and rocks at great depths under changes in their natural geomechanics.

These conditions lead to significant rise of risks of hazardous rock pressure manifestations (their rate increasing with depth) and the hazard level rises as the depth increases.

All the dangerous phenomena occur in mining and technological facilities that are built for mining purposes: open pit walls, benches, trenches, mining blocks and panels, mine workings, chambers. They house workplaces, mechanical means and equipment.

The mentioned facilities are intended for various activities, have various structures and building technology and operate in different ways. However, they all have an important common feature – load-bearing structural elements. These elements are parts of facility constructions (open pit wall faces, inter-block/inter-panel pillars, underground chamber ceilings, undercut massifs, arch roofs of workings) that carry the main rock pressure load and prevent the whole facility construction from failure. The «bearing capacity» feature [8] of the elements must meet the strictest requirements as the function they fulfil in terms of safety of their operation is very essential for preventing possible catastrophic consequences in case of their functioning failure.

It is given more detailed consideration to geomechanics hazards at great depths.

In their natural state (before human intervention) rocks occur in the condition of triaxial compression. This does not lead to dangerous consequences as the rock cannot be deformed even under high loads. However, at great depths the rock massif accumulates considerable mechanical stresses.

If the monolithic rock massif is distorted due to the human impact (ore mining), there appear voids and free surfaces. These disturbances are concentrators of mechanical stresses. On the disturbance interfaces there develop stresses that can be 10 – 20 times greater than those in natural conditions. The developed rock deformations result in high risks of hazardous dynamic manifestations of rock pressure. Rock failure forms may be as follows: rock bumps (the most dangerous form similar to the earthquake), large scale rock slides, rock outbursts, rock displacement, sheeting, ultra high local deformations [9]. Places, time and scale of such manifestations are extremely hard to forecast. The above mentioned phenomena form particularly dangerous conditions of mining as workers may possibly be trapped in a rock failure zone.

In underground mining beginning with 200 – 400 m levels the rock fall trough changes its shape from a cone to a fissure above which there is a hanging wall crystalline rock console.

This also results in redistribution of loads in rocks around the trough. The growing depth of mining leads to mechanical stress accumulation in the console as it is underlain by unconsolidated rocks and rests upon them. Loads on unconsolidated rocks result in their deformation and the console slide similar to deformation of a wall rested on the foundation of non-coherent materials. The scale of this process contributes to generation of «a rock bump» – one of the most hazardous forms of rock pressure manifestations [10].

At great depths, when technogenic voids appear, fragile crystalline rocks that have accumulated great stress begin to discharge and undergo deformation (similarly to a compressed spring released), i.e. «stress release» is generated [11]. This phenomenon may cause such great deformations that rocks lose strength, the bearing capacity of large rock massifs decreases and thus jeopardizes bearing elements of mining and technological facilities that cannot resist external forces any more.

Under actual mining conditions there is another hazardous aspect consisting in the fact that bearing elements of mining and technological facilities are influenced not only by rock pressure (which is static in nature) but also by a number of dynamic factors such as shock and seismic waves of explosions and earthquakes.

Bulk blasting shock waves result from blasting operations during ore breaking and run to relatively small distances (several scores of meters) but in terms of force impact they are one of the most powerful destructive factors for both ore and mining block elements.

The blasting shock wave is about several centimeters long, it propagates within a massif and has a frontal forward pressure zone (the first wave half-period) and a rear direct stress zone (the second inverse half-period). The wave is dangerous due to the fact that on hitting an exposed surface it bounces back and its direct stress zone causes breaking stresses in rocks. This results in ore breaking in a stope and may destroy bearing elements of mining blocks if there are initial stresses in them.

The bulk blasting seismic wave has a specific character. It is generated by explosive gases impact on the rock mass when there are factors stretching it in time (short-delay charge initiation, shock wave reflection from massif disturbances). This transforms a shock wave into a seismic one and changes its frequency. The seismic wave is hundreds of meters long and its danger consists in the fact that bearing elements of mining and technological facilities possess certain elasticity and may resonate with seismic wave oscillations and fail.

The phenomena resulted from bulk blasting require thorough and reliable determination of optimal parameters of drilling and blasting operations with simultaneous provision of ore mining safety and efficiency. The critical importance of the correct solution of this problem has generated a new research direction aimed at developing methods and ways of enhancing mining parameters [12].

The physical action of seismic earthquake waves is similar to seismic bulk blasting waves but their power and duration are considerably greater. These waves are generated by earthquakes in zones of great tectonic faults and local earthquakes.

Ukraine lies within several dangerous natural seismic zones. «The Vrancea zone» located at the junction of the South (Romania) and East (Ukraine) Carpathians is the most hazardous of them. Ukraine's territory is located within M 4 – 6 seismic district of this zone. «The Vrancea zone» is extremely active, 30 earthquakes magnitude 6.6 – 7.0 were registered in the XX century, and some of them had catastrophic consequences. Bukovyna and the Crimean-Black sea zone are also considered an earthquake endangered area with magnitude 5 – 6 and 8 – 9 respectively. There are also several seismic zones (earthquake magnitude up to 4.0 – 5.5) in the platform part of Ukraine «the Ukrainian shield» to which all its iron ore deposits are limited. One of them is Kryvyi Rih iron ore basin with 80% of all Ukraine's iron ore deposits and 90% of the country's mining industry.

The following events testify to the geomechanical danger of earthquakes. On November 29, 2016 the M 4.4 earthquake caused a collapse of the «Rudna» mine in Poland that left 8 miners dead and 16 miners were trapped 1100 m underground. On March 9, 2005 the M 5 earthquake near Stilfontein (South Africa) killed 5 «DRD Gold» miners and 42 people were trapped 2000 m underground. On August 5, 2017 the M 5.3 earthquake in Orkney killed 1 miner and caused mass destruction.

Another dangerous phenomenon related to the seismic activity is so called «induced seismicity» [0]. It is caused by the coupling of the seismic action of technogenic factors (bulk blasting) and local earthquakes.

The coupling is seen in seismic areas within which mining is carried out and mechanical stresses can be accumulated naturally. If the accumulation reaches a certain level, bulk blasting seismic waves may trigger a destructive earthquake.

The complicated great depth geomechanics problem demands creating «The Geomechanics Support System for iron ore deposit mining». Way back in the sixties – seventies of the XX century leading specialists in iron ore mining geomechanics forecast reaching great depths and emphasized the urgency of the system. In late 90s, the problem became a burning issue in terms of further iron ore mining [14, 15]. However, no effective measures to develop this direction have been taken so far.

«The Geomechanics Support System for iron ore deposit mining» means solution of problems of ensuring durability of mining and technological facilities, forecasting and monitoring impacts of mining on stressed and distorted rocks and engineering structures during the building period, operating and dismantling mining and technological facilities. The main objective of the geomechanics support is prevention of accidents and emergencies in mining.

National mining enterprises do not currently have the system of the kind. Thus, its development becomes one of the prime tasks of ensuring accident-free iron ore mining in Ukraine.

The scale and complexity of tasks to be solved in creating the system require relevant institutional, regulatory, methodological, engineering, tooling and organizational support.

The system creation should be based on principles of risk-management in useful mineral mining safety [16] which has become a central one in advanced countries [17].

Creation of the system requires the following steps: development of the legislative and regulatory framework of the risk-management functioning in the field of geomechanics support of mining enterprises; development of the methodological principles of solving geomechanics tasks based on modern approaches and means; creation of the automated system for monitoring rock geomechanics; development of information support for the risk-management system to provide the latest research data in the field and increase efficiency and reliability of its functioning.

The system of this kind should function according to the following chart: monitoring the situation in the deposit area planned for mining and collecting relevant data; modeling real situations; determining possible hazardous geomechanical factors on the basis of the modeling results; forecasting potential negative risks and consequences of the mentioned factors; developing measures to prevent hazardous processes and risks of accidents and determining necessary parameters of these measures; solving organizational, engineering, technical, and economic tasks in implementing the measures; monitoring the situation after the measures are implemented and assessing their actual effectiveness; creating the analytical database of hazardous situations and their types, taken decisions and their results; forming the data-based decision support system for hazard forecasting, preventive methods development and selection of relevant decisions on accident consequences elimination, development of emergency elimination plans.

Conclusions. The review and analysis of publications and practical data on iron ore mining geomechanics performed in this article enable the following conclusions:

1. The current situation in Ukrainian mining industry is considered dangerous due to the enterprises reaching great mining depths.

2. The hazardous character of the situation results from the specific character of the natural geomechanical disturbances and increased risks of mass dynamic excessive pressure manifestations.

3. Forms and reasons of manifestations are various and depend on specificity of great depth geomechanics, character and parameters of mining operations and processes and external factors.

4. The great number of accidents caused by geomechanics factors testifies to the fact that current methods of solving geomechanics tasks and securing safety of mining operations do not provide the sufficient durability of mining and technological facilities or prevent geomechanics hazards.

5. The situation is also conditioned by obsolete approaches and theoretical principles on the basis of which methods and means of securing labour safety.

6. The most efficient method of settling the problem is creating a specialized geomechanics support system for iron ore deposit mining based on risk-management in the field of iron ore deposit mining geomechanics.

7. The paper recommends on the order of the mentioned system creation and tasks to be solved for this purpose.

8. The paper presents the order and reveals the essence of tasks in the geomechanics support of national mining enterprises with the view of ensuring safe working conditions in mining at great depths.

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