POTENTIAL MANIFESTATIONS OF ROCK BURSTS DURING URF CONSTRUCTION AND METHODS OF THEIR PREVENTION

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At great depths, the Yeniseiskiy section of the Nizhnekanskiy rock mass selected for the construction of an underground research facility (URF) may involve some areas of firm rocks with high internal stresses that may cause spontaneous rock bursts. The paper provides a qualitative description of the mechanism standing behind the rock burst process, the necessary and sufficient conditions for its occurrence and the conditions for its extinction. It considers some engineering methods dealing with rock bursts which may be applied given special requirements set out for the URF construction.

Keywords: *strength, uniaxial compression, rock burst, unequal compression, rock outburst, dynamic manifestations of rock pressure, necessary and sufficient condition, changes in the strength properties, non-sorbable radionuclides, rock breaking, rock burst prevention, radioactive waste.*

The Yeniseiskiy section of the Nizhnekanskiy rock mass has been selected for underground research facility (URF) construction with its designs seeking to provide comprehensive R&D and to demonstrate the possibility of its subsequent use as a deep radioactive waste disposal facility (DGR). Numerous organizations have done tremendous work in this area [1]—[5]. The Yeniseiskiy section is composed of migmatized gneisses and crystalline schists of the Atamanov sequence belonging to the Archean Kansk metamorphic complex; two secant dike complexes of mafic composition and Late Archean and Early Proterozoic age; granitoid formations of the Early Proterozoic Tarak Complex and modern eluvial–deluvial deposits [1], [2].

Basically, all the hard rocks are characterized as very dense, high-strength and very high-strength, quite hard and hard with high-level deformation characteristics, i. e., prone to potential energy accumulation. Intrusive rocks are characterized with higher density and strength levels than the metamorphic ones [1], [2].

Geophysical borehole measurements have been implemented to evaluate the stress-strain state of the rock mass: the stresses were found to be lower than the uniaxial compressive strength indicating no rock burst risks. However, the block structure and the rock composition are very heterogeneous within the URF area. Statistics show that suture elements of faults and the interfaces between different rock types can act as stress concentrators, potential areas of possible rock burst manifestations [8].

URF sections are going to be excavated in rocks at a depth of 450—525 m, therefore, dangerous dynamic rock pressure manifestations should be evaluated at the initial stages in a timely manner.

This task is seen as a most challenging part of the underground mining operations. Rock bursts can paralyze the operations at the site for a long time with the powerful bursts followed by the destruction of large minefield sections. In Russia, numerous studies have been devoted to this problem, namely, those of professors S. G. Avershin, I. M. Petukhov, A. M. Lin'kov, B. Sh. Vinokur and many other authors [6]—[9].

A big array of statistical data has been accumulated to date on the dynamic rock pressure manifestations with some detailed descriptions available on numerous rock bursts that took place in the underground mines of the Talnakh ore district operated by the Norilsk MMC, Severouralsk bauxite mine (PA North Uralsk Bauxite Mine), the Sheregesh and Tashtagol iron ore deposits, the mines of the Kola Peninsula, Zhezkazgan, Western Deep Level mines in South Africa, Kollar in India, El Teniente in Chile and many other enterprises that faced this complex natural phenomenon [10], [11]. At large mines with the excavation operations performed at great depths, special services have been established in Russia and abroad to monitor the dynamic rock pressure manifestations and to assess possible rock mass behavior at the operational sites.

Rock burst is a spontaneous rock mass breaking process occurring at a speed of a mechanical wave (3—7 km/s) accompanied by explosive shaking and destruction of the rock mass, large seismic energy release covering the mine field sections that can range from several to hundreds of meters.

Professor I. M. Petukhov explains the rock burst process as "a brittle fracture of an overstressed rock part adjacent to an excavation occurring in case if the rate of the stress state alteration in this part exceeds the threshold rate of stress relaxation in it" [8].

A model of a rock burst that may evolve in hard rocks is considered below: the mechanism standing behind relevant processes is described qualitatively, as well as the reasons contributing to the rock burst occurrence.

According to the manifestation mechanism, if small scales are considered, rock bursts may also include rock outbursts (bumps, microbumps) and rock air bursting.

These processes are triggered by some external influences that alter the stress-strain state of an undisturbed rock mass; thus, its strength characteristics are changing as well.

Necessary condition for a rock burst: the rock mass should be in a triaxial (volumetric) non-uniform compression state and at least one of the acting forces should exceed the ultimate uniaxial/biaxial compressive rock strength [11] (Figure 1a).

Such natural state is typical for hard and medium hard rocks at great depths, as well as for the near-surface geological platforms composed of hard plates. Several such regions are known: in Russia, these are the regions of the Kola Peninsula, the Northern Urals, the south of Eastern Siberia, Mountain Shoriya, South Yakutia and the North Caucasus [12].

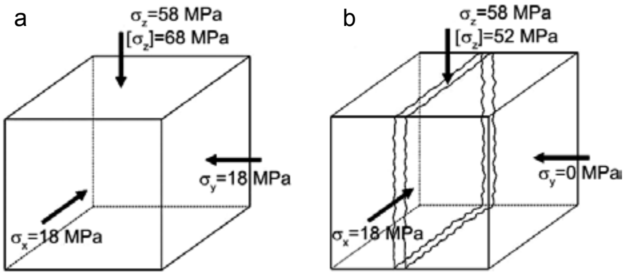

Figure 1. Example. Necessary (a) and sufficient (b) conditions for the rock burst occurrence

Sufficient condition for a rock burst: at least one of the acting compressive forces disappears at once (for example, cracks occurring in the rock mass due to blasting operations) and one of the two remaining forces exceeds the ultimate uniaxial/biaxial compressive rock strength [11] (Figure 1b). In this case the rock mass loses its strength properties changing over its state into uniaxial/biaxial compression followed by its crushing. In this case, the strength level (resistance to the acting forces) drops to 40 % [15]. The crushing rate is equal to the mechanical wave velocity; in hard rocks it ranges from 3.0 to 6.0 km/s, in monolithic basalts it amounts to 7.0 km/s; the process occurs within fractions of a second like an explosion.

During the transient state between the volumetric and the uniaxial compression, rock layers close to the free surfaces of the crack are crushed with some new free surfaces generated (Figure 2). In this case, scaly-shaped particles with distinctive torn edges release from the newly generated surface at a high speed and energy level. This successive destruction process evolves getting deeper from the crack surface into the rock mass.

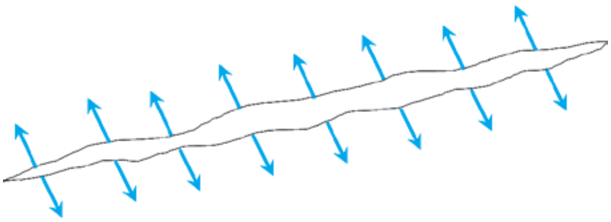

Figure 2. Vectors of rock destruction due to a rock burst propagating from the wall surface of a generated crack

Geophysical studies focused on rock burst manifestation mechanisms and energy show that the parameters of the recorded dynamic phenomena vary over a quite wide range. For example, their seismic energy recorded in the range from $1{\cdot}10^{-3}$ to $1{\cdot}10^{12}$ J was found to be equivalent to the detonation energy of an explosive that would weight from tens of kilograms to several tens of tons, the maximum frequency spectrum appeared to be ranging from $5 \cdot 10^{-2}$ to $2 \cdot 10^{3}$ Hz, the duration ranged from $1 \cdot 10^{-3}$ to 20 s, the maximum linear dimensions of the source were found to be ranging from $3 \cdot 10^{-3}$ to $3 \cdot 10^{2}$ m. In terms of relevant characteristics (spectral density, the presence of longitudinal and transverse waves, duration, the transferred maximum energy and other parameters), large regional rock bursts with their seismic energy of over 10^{6} J and the intensity reaching 4—5 points appear to be somewhat similar to weak earthquakes. During rock bursts, the maximum velocity of rock particle burst reaches several tens of meters per second; the process evolves as a violent dynamic phenomenon [8].

Rock burst conditions may be triggered by underground mining with excavation operations performed at one or more levels when due to ore breaking and rock pressure redistribution, some sudden load is added to certain safety, panel or support pillars. At PA North Uralsk Bauxite Mine site where mining operations reached the depth of 700 m, rock bursts have been recorded at a depth of 370 m [8].

Dynamic rock pressure manifestations in hard rocks are more extensive in terms of the destruction caused, are accompanied by strong shaking effect and the release of high-level seismic energy. A rock burst that once occurred at the Tashtagol mine spread over 3 levels amounting to 180 m in its vertical dimension. The damage amounted to hundreds of cubic meters with tens of meters of destroyed excavations.

Rock burst process discontinues if:

1. The rock burst stops when the condition necessary for its occurrence disappears, i. e., when the destruction reaches the area of less stressed, less hard, deformable, pliable rocks or the rocks being in other compression conditions [11].

2. When a rock burst occurs in medium-hard rocks near an excavation (f = 6—10 according to the classification system proposed by Prof. M. M. Protodyakonov), rock destruction is accompanied by its arching onto its surface. The process goes on until it takes a spherical shape, after that the rock burst development process stops. The vanished force is offset by the spherical shape, mutual lateral support of adjacent rock blocks-separations in the contour of the natural equilibrium arch. When the rocks at the interface of the excavation get extruded, no rock regrinding is observed; for this reason, a rock burst aftermath may be described as broken rock with large- and medium- block structure covered with a layer of flat scaly shaped particles (which is viewed as a sign of a rock burst) (Figure 3). Rock bump spots within the areas that have suffered the rock bursts are commonly shaped as spherical cavities with a capacity of up to 10 m^{3} [8].

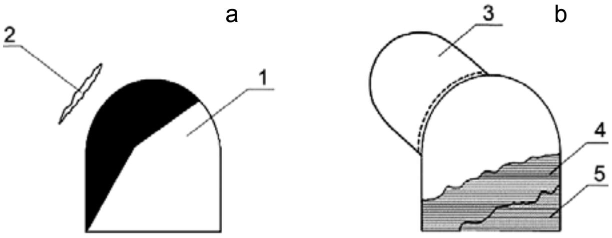

Figure 3. Rock burst in medium-hard rocks (f = 6—10): a) the emergence of a focal point — the necessary and sufficient condition for rock burst occurrence, b) rock burst process gets discontinued due to a stable spherical cavity being formed;

1 — drift, 2 — a crack, a focal point that emerged due to mining operations, 3 — rock bump cavity emerged due to a rock burst, 4 — scaly-shaped particles above the rock pile, 5 — pieces of rocks extruded from the roof and walls of the excavation

3. Rock burst stops if it evolves at a great depth where neither excavations nor cavities are available. Crack wall destruction continues until relevant space is densely filled with the destroyed rock particles, thereby offsetting the vanished compressive force with their support (Figure 4). The explosion-like process also triggers rock mass movement. Regional rock-tectonic impacts occur at depths of up to 2—5 km, which are much greater than the excavation depth.

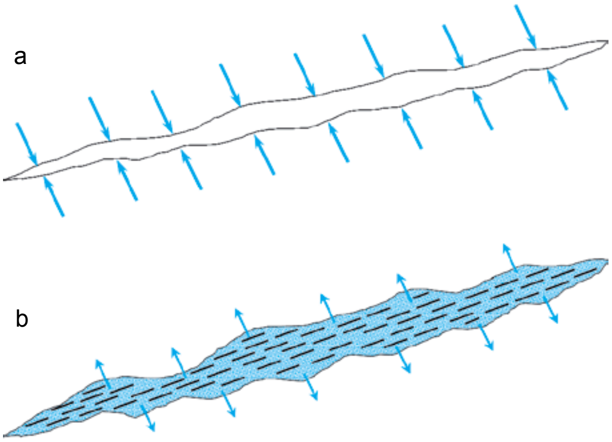

Figure 4. Phases of rock burst development and discontinuation: a) formation of a crack and the rock burst initiation, b) discontinuation of the rock burst process. The acting forces are indicated by arrows

At great depth, the rocks constituting to the Yeniseiskiy section of the Nizhnekanskiy rock mass are characterized with a high strength level and tend to accumulate potential energy. Such areas are commonly categorized as liable to rock bursts.

Leading scientific communities have gained experience in rock burst prevention with relevant sets of measures being continuously improved to achieve higher performance levels [6]—[11]. De-stressing methods are commonly applied to mitigate the rock burst risks based on powerful explosions or a system of holes or wells drilled in the rock mass to promote compliance and rock movement potential to relieve high stresses.

In this case, rock burst prevention and de-stressing methods are considered unsuitable if applied on a general-shaft or regional scale since the main URF siting requirement states that the site should be free of cracks seen as potential pathways for non- and low-absorbable radionuclide flows in DGR over geologically significant timeframes.

Local de-stressing within a limited space around the excavations is seen as a possible rock burst prevention method that can be applied to mitigate burst risks and preserve the containment rock mass capacity, namely, targeted fracturing using blasthole charges, adjacent rock shooting with explosive cartridges at a depth of over 4—6 m. Hardening compositions are injected into the created fractured zone (through the same holes) under a pressure level of up to 15—20 MPa. Since liquids tend to spread providing the same pressure level in all the directions, at the injection stage, the injected compositions exert a compressive effect on the blocks-separations within the rock mass in directions normal to the surfaces of the existing cracks.

Injection hardening method enables the transition of the fractured rock mass into unequal volumetric compression state with a hardened rock shell lining formed around the drift (Figure 5a).

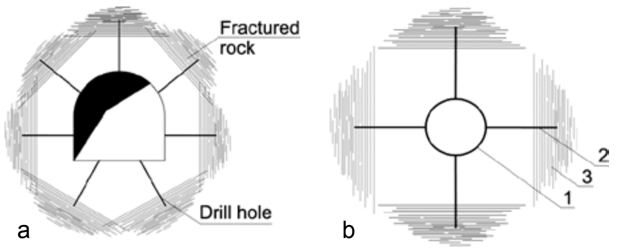

Figure 5. Stages of a local unequal compression shell formation:
a) drift lining from preliminarily softened rocks with their subsequent injection hardening; b) vertical borehole lining: 1 — shaft, 2 — well, 3 — induced fracturing zone

De-stressing ring of boreholes for induced local fracturing and subsequent rock mass hardening should be established in areas liable to rock bursts at 6-10 m intervals along the excavation length. Microcements, geocements with high-level insulating properties are considered as acceptable compositions that can be injected into the cracks to prevent the spread of non-absorbable radionuclides: under pressure, these are able to penetrate into the smallest cracks [14]. These materials are characterized by low initial viscosity, high inherent strength and adhesion to rocks at the hardening stage. In case if a reinforcing composition based on M700 cement (GOST 26633-91) with a compressive strength of 70 MPa is applied, the expected long-term containment and preservation of the material may amount to over 300 years [16].

Similarly to the above method, a local protective shell can be established around vertical URF shafts (Figure 5b). At the same time, boreholes and wells for shell development purposes are drilled according to the layout of excavations intended for high-level waste disposal. At the same time, the main rock mass retains its original properties, whereas induced fracturing and hardening of rocks around excavations and chambers provide some local redistribution of rock pressure forces in the required areas.

The considered rock burst prevention method cannot be applied throughout the entire mine field, but rather in those URF sections where, according to the geophysical data, the rock state is characterized with high-level stress and the acting forces exceeding the uniaxial compressive strength.

Pilot testing is required to set the appropriate parameters of the rock burst prevention method. Neither rock bursts nor rock outbursts were observed at shallow depths in the excavations tunneled at the URF site (MCC, ZATO Zheleznogorsk). Rock pressure manifested itself within the excavation intersection zones: the rocks were crushed due to the hydrostatic pressure.

The Priargunsky Production Mining and Chemical Association (PJSC PIMCU, Krasnokamensk) is thought as a most suitable pilot testing site due to its extensive production and laboratory capacities (central research laboratory), a trained work team and the necessary equipment. Test sites can be established in underground uranium mines operated by PIMCU. At the Antey deposit, uranium ores are mined at depths of over 700 m with some rock bursts occurring along the process [17].

Conclusion

The Yeniseiskiy section of the Nizhnekanskiy rock mass has been selected for the underground research facility (URF) construction with subsequent construction of a deep disposal facility (DGR) for high-level and long-lived intermediate-level waste provided if the long-term safety assessment findings appear to be positive. The existing rock stresses were found to be lower than the uniaxial compressive strength evidencing no rock burst risks. However, since the rocks within the URF siting area appear to be quite heterogenous in terms of their structure and composition, the interfaces between such different rock types should be considered as stress concentrators, potential areas of possible rock burst manifestations. At depths of 450—525 m, the site features some high-strength rocks prone to potential energy accumulation. The paper presents one possible mechanical model showing rock behavior under rock burst conditions. It considers the necessary and sufficient conditions for rock burst occurrence and its discontinuation providing certain examples of their typical manifestations. Large-scale rock mass de-stressing with induced rock fracturing via powerful explosions or by promoting rock compliance appears to be unapplicable in the considered case. The paper considers one of the possible options for rock burst risk mitigation in the area around the excavations, which is local de-stressing and subsequent injection hardening with unequal compression rock mass state achieved and a protective shell established. In this case, the layout of boreholes and wells depends on the one of the RW disposal sections. Pilot testing is required to set the parameters of the rock burst prevention method in a timely manner. The Priargunsky Production Mining and Chemical Association (PIMCU) with its extensive production and laboratory capacities is considered as a most appropriate site for such pilot testing.

References

1. JSC Krasnoyarskgeologiya. *Proekt na vypolnenie rabot po ob"ektu: Razvedka uchastka zakhoroneniya radioaktivnykh otkhodov (Eniseiskii uchastok Nizhne-Kanskogo massiva)* [Project specifications: exploration of a radioactive waste disposal site (Yeniseiskiy section of the Nizhnekanskiy rock mass)]. License KRR 16117 ZD, State contract of September 23, 2019 No. D.4sh.244.20.19.1061, Contract of November 5, 2019. No. 1061/3/2019.

2. Karaulov V. A., Zabolotskiy K. A. et al. *Geologicheskoe doizuchenie (otsenochnaya stadiya) gornogo massiva uchastka «EniseiskiI» dlya obosnovaniya rasshireniya intervala zakhoroneniya radioaktivnykh otkhodov do glubin 450—525 metrov (+5 — -70 m BS) ob"ektov okonchatel'noi izolyatsii radioaktivnykh otkhodov (Krasnoyarskii krai, Nizhne-Kanskii massiv)* [Additional geological study (assessment stage) of a rock mass at the Yeniseiskiy site demonstrating the reasons for the expansion of the radioactive waste disposal interval to a depth of 450—525 meters (+5 — −70 m BS) for final radioactive waste disposal facilities (Krasnoyarsk Territory, Nizhnekanskiy rock mass)]. JSC Krasnoyarskgeologia, Krasnoyarsk, 2015.

3. Kryukov O. V. Strategiya sozdaniya punkta glubinnogo zakhoroneniya RAO [Strategy for the development of RW deep disposal facility]. *Radioaktivnye otkhody — Radioactive Waste,* 2018, no. 3 (4), pp. 114— 120.

4. Abramov A. A., Bolshov L. A., Dorofeeev A. N., Igin I. M., Kazakov K. S., Krasilnikov V. Y., Linge I. I., Trokhov N. N., Utkin S. S. Podzemnaya issledovatel's-kaya laboratoriya v Nizhnekanskom massive: ehvolyutsionnaya prorabotka oblika [Underground Research Laboratory in the Nizhnekanskiy Massif: Evolutionary Design Study]. *Radioaktivnye otkhody — Radioactive Waste,* 2020, no. 1 (10), pp. 9—21. DOI: 10.25283/2587-9707-2020-1-9-21.

5. Dorofeev A. N., Bolshov L. A., Linge I. I., Utkin S. S., Saveleva E. A. Strategicheskii master-plan issledovanii v obosnovanie bezopasnosti sooruzheniya, ehkspluatatsii i zakrytiya punkta glubinnogo zakhoroneniya radioaktivnykh otkhodov [Strategic Master Plan for R&D Demonstrating the Safety of Construction, Operation and Closure of a Deep Geological Disposal Facility for Radioactive Waste]. *Radioaktivnye otkhody — Radioactive Waste,* 2017, no. 1, pp. 34—43.

6. Avershin S. G. *Gornyye udary* [Rock Bursts]. Moscow, Ugletekhizdat Publ., 1955. 236 p.

7. Petukhov I. M., Lin'kov A. M. *Mekhanika gornykh udarov i vybrosov* [Mechanics of Rock Bursts and Outbursts]. Moscow, Nedra Publ., 1983. 279 p.

8. Petukhov I. M., Yegorov P. V., Vinokur B. Sh. *Predotvrashcheniye gornykh udarov na rudnikakh* [Prevention of Rock Bursts in Mines]. Moscow, Nedra Publ., 1984. 230 p.

9. *Metodicheskie rekomendatsii po otsenke sklonnosti rudnykh i nerudnykh mestorozhdenii k gornym udaram* [Guidelines for the assessment of ore and non-ore deposit susceptibility to rock bursts]. Approved by order of the Federal Service for Environmental, Technological and Nuclear Supervision on May 23, 2013 No. 216.

10. Sanders E. J., Merguerian Ch. *Geologic setting of New York Harbor.* Geology Dept. Hofstra Univ., Hempstead, N. Y., 1997.

11. Kuz'min Ye. V., Lyashevich S. I. Predotvrashcheniye udaroopasnosti massiva metodom in"yektsionnogo uprochneniya gornykh porod [Prevention of Rock Burst Hazard via the Injection-based Rock Hardening Method]. *Gornyi zhurnal — Mining Journal,* 1989, no. 11.

12. Turchaninov I. A., Markov G. A., Ivanov V. I., Kozyrev A. A. *Tektonicheskiye napryazheniya v zemnoy kore i ustoychivost' gornykh vyrabotok* [Tectonic Stresses in the Earth Crust and the Stability of Mine Workings]. Leningrad, Nauka Publ., 1978. 256 p.

13. Bronnikov D. M., Zamesov N. F., Bogdanov G. I. *Razrabotka rud na bol'shikh glubinakh* [Ore Mining at Great Depths]. Moscow, Nedra Publ., 1982. 292 p.
14. Kuz'min Ye. V. *Uprochneniye gornykh porod pri podzemnoy dobyche rud* [Rock Hardening During Underground Ore Mining]. Moscow, Nedra Publ., 1991. 252 p.
15. Bich Ya. A. *Gornyye udary i metody ikh prognoza* [Rock Bursts and Relevant Forecasting Methods]. Moscow, TSNIEIugol' Publ., 1972. 101 p.
16. Gataullin R. M., Davidenko N. N., Sviridov N. V. et al. *Konteynery dlya radioaktivnykh otkhodov nizkogo i srednego urovnya aktivnosti* [Containers for Low- and Intermediate-level Waste]. Moscow, Logos Publ., 2012. 256 p.
17. Rasskazov I. Yu., Petrov V. A., Gladyr' A. V., Tyurin D. V. Geodinamicheskiy poligon Strel'tsovskogo rudnogo polya: praktika i perspektivy [Geodynamic Testing Area of the Streltsovskiy Ore Field: Practice and Prospects]. *Gornyi zhurnal — Mining Journal,* 2018, no. 7, pp. 17—21. DOI: 10.17580/gzh.2018.07.02.

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