ENSURING SUSTAINABILITY OF MINING WORKINGS IN DEVELOPMENT OF ORE DEPOSITS IN COMPLEX GEOLOGICAL CONDITIONS

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ABSTRACT

Recently, there has been an increased demand for aluminum in the Russian and foreign markets due to the rapid development of many technology-intensive industries. Due to the fact that the amount of manufactured aluminum increases every year, intensive development of the raw material base in the aluminum industry is required, which entails development of yet undeveloped horizons, and development of the parts of developed deposits that are usually located at greater depths in complex geological conditions and, accordingly, the use of efficient measures for maintaining mine workings, one of which is the use of earthquake-proof support design. The paper proposes the optimum design of earthquake-resistant supports for the mines developed in complex mining-geological conditions; this design has successfully passed tests at domestic mines in the conditions of dynamic forms of rock-pressure manifestations.

Keywords: mine, deposit, rock pressure, rock burst, deep horizons, seismic support, roof bolts.

1. INTRODUCTION

When deeper horizons of ore deposits are developed, the geological and mining conditions become considerably more complicated. Dynamic forms of rock pressure manifestations appear in the form of rock bursts, which result in injury rate among miners, and reduce efficiency of the enterprises.

Therefore, an urgent task in deep ore deposits horizons development is the determination of rational parameters for the earthquake-resistant supports, which ensure reliable support for mine workings during the entire time of their use, safety of mining, and uninterrupted operation of the mining enterprise.

For example, in Russia, the main reserves of bauxites, which are the main raw material for aluminum production, are located in the Severouralsk bauxite basin, where horizons are developed at depths of over 1,000 m.

The mines of JSC Severalboksittruda make annually up to 40 km of preparatory workings and 3 km of capital workings and the descent of mining is over 20 m. [1, 2]

Rapid descent of mining operations, switching to development of deeper horizons cause deteriorated stability of both preparatory and capital workings, and increased costs of the workings and supports.

Large areas of the mine field and mine workings fall within the scope of increased hazard of rock burst according to the regional forecast. Capital and preparatory workings in deep horizons are made in the conditions of increased rock burst hazard and more often in the conditions of the hazard of pressure bumps and roof breaks.

The mines have accumulated experience in strengthening the workings with reinforcing supports with elements of reinforcement - "bushes", "combs", "pendants". Reinforcing the workings in complex conditions with steel-polymer anchors has been resumed.

Reinforcing workings of ore deposits in the conditions of dynamic manifestations of rock pressure is the area of increased attention of scientists from around the world. In the ore industry of our country, mainly the traditional types of supports are used: shotcrete, rod (anchor) roof bolting with metal mesh or without it, support structures may be adjustable metal linings in preparatory workings and monolithic concrete in capital workings. [3,4,5]

Other, more efficient designs of earthquake-resistant composite and multilayer linings are only at the stage of technical solution, or being tested as prototypes at some mines. [6-10]

2. METHODS

In this respect, the proposal of Mirzaev G. G. about reinforcing workings of the Tekeli mining and processing plant with the use of solid and core seismic screens connected to the anchoring in the conditions of mass explosions [11] seems interesting. The anchor waveguides are connected with the screen to form a joint spatial structure, and the space between the rock surface of the mining and the screen is filled with a seismic distribution layer of adjustable material. In this case, the radial dynamic forces that act from the rock mass toward the working are received by the screen, and transferred through anchors to a site at the distance from the surface that is equal to the length of the anchor waveguides (1.8±3.0 m). This ensures redistribution of dynamic tensile forces over a much larger area and transferring them into the depth of the rock mass, where it is less disturbed and is in 3-dimensional strained state.

The positive experience of preventing rocks pressure bumps and intensive manifestations of rock pressure in the mines of the Lovozersky Mining Plant under the action of mass explosions and ore deposits of the Urals has been obtained through the use of quickly engaged steel-polymer roof bolting with high load-bearing...
capacity and resistance to seismic shocks [12]. Efficiency of the steel-polymer roof bolting combined with shotcrete in the conditions of pressure bumps is also mentioned by Kravchenko G. I. and Asanov V. A. based on the research performed at the Perm Polytechnic Institute. Increasing stability of workings in this case is achieved via strengthening rock mass in the border zone and its transition from flat to 3D stress state, which increases its strength properties, and promotes more uniform distribution of stresses around the working.

Ways of walling, based on damping the pulse impact of the dynamic stress wave in the circuit of workings with multilayer linings, comprising a special buffering layer are being developed [10]. Low-strength adjustable material, such as foaming plastics, cellular concrete, etc., is used as the buffer layer.

The listed methods of walling significantly reduce the amplitude of the rock mass oscillations on the working contour, which allows reducing the value of the maximum contact force in case of rock bumps several times, but in the border zone they do not hinder development of oscillatory processes.

Support structures of malleable metal and concrete linings with cemented walling space are widely used in foreign mines in the conditions of dynamic manifestations of rock pressure. In the mines in Western Europe, linings made of corrugated steel panels (1.08×1.2 m, 2-3 mm thick) are used, which are fixed in the workings with special metal arches with subsequent concreting of the linings space. [10] At the San Manuel (USA) mine, the workings located outside the influence zone of coal-face work are supported with metal cushion supports of special profile, and in the zone of influence of coal-face work - with metal and concrete linings (arches of concrete I-beams) with grouting of the linings space. Similar linings are used in the mines in Ruhr. At the Western Deep Levels mine (South Africa) stability of the chamber at the depth of 3,050 m is achieved by anchoring a 6.7 m lining with a metal mesh and shotcrete.

To reduce the ability of rock mass for dynamic destruction, the use of injection hardening of the rock mass is also proposed.

To harden rocks in the conditions of dynamic manifestations of rock pressure, it is advisable to use polymer compositions, which are initially low-viscosity liquids, and do not shrink after curing. These polymeric compositions are capable of filling cracks in the rock mass with the width from 0.01 mm, opening and developing cracks in case of using these compositions under the pressure of 20 to 25 MPa.

The use of polymeric compositions results in rock hardening.

Equal component volume stress state is restored, thereby increasing the strength of rocks in the reinforced zone, and increasing the ability of the array to absorb high loads.

However, flat stress state is preserved in case of rocks outcropping in the working.

Today, for rock bump-hazardous mines, development of methods of preventing rock pumps that efficiently unload the rock mass but preserve its strength and do not violate the continuity of the rock mass are promising: improvement of the parameters and the technologies of creating relieve slots, the use of the rational (sustainable) shape of the working cross-section and of contour blasting, the optimum mode of mining operations and placing the workings in the rock mass.

Among linings, the most promising are reinforcing anchor structures and combined roof linings, which are quickly engaged and have high load-bearing capacity and resistance to seismic influence. This will allow, by reinforcement, to involve the rock mass around the working, increase its strength properties, and will contribute to more uniform distribution of strains in the rock mass, which will significantly improve workings stability.

Injection hardening of the rock mass also deserves attention, which can also result in improved conditions for maintaining mine workings, especially in combination with anchor linings.

It is most expedient to use such earthquake-resistant reinforcement support structures (ERRSS) that retain their load-bearing capacity under the influence of seismic effects.

This requirement is compliant with the anchors that are quickly engaged into operation after installation, and have contact with the rock mass along their entire length.

The actively used slot-and-wedge anchors do not meet this requirement. An important requirement is that the earthquake-resistant linings should be fit for using them together with various supporting structures, such as the support plates, holders made of rolled profiles, or reinforcement cages, the meshy set lagging, and in combination either with each other, or with shotcrete.

The reinforced concrete anchor (RCA) shown in Figure-1 that consists of a settled head on the contour end and a support plate, as well as its installation technology have many disadvantages [13].
Figure-1. Layouts of the contour ends of the anchors attached throughout the entire length with a hardening composition: 1 - reinforcement bar; 2 - hardening composition; 3 - flat base tile plate; 4 - nut; 5 - threaded end; 6 - spherical bearing plate; 7 - sealing cuff; 8 - meshy set lagging; 9 - bi-conical contour lock

The linings of this type are only engaged into work after sufficient curing of concrete (on the average, not earlier than 24 hours). It seems impossible to properly monitor the quality of hole mouth filling with the cement-sandy solution, since RCA is used together with such an element as a support plate, and this in turn affects the process of "playing" the anchors.

More than that, according to the results of surveying 576 concrete anchors used in the mines of "Sevuralboksitruda", it was found that many bearing plates (approximately 70%) do not have the necessary contact with the contour of the rock mass.

As practice of using support plates shows, in most cases it was noted that they do not work at all, and do not ensure the necessary quality monitoring, but significantly affect the costs of the enterprise.

In addition to the above, if necessary, this anchor design does not allow strengthening of the linings with crown trees or meshy set lagging.

Given the above factors, the considered design of the anchor is not the optimal basis for earthquake-resistant linings.

3. RESULTS

Below are the designs of earthquake-resistant supports that have successfully passed testing in domestic mines.

A. Anchors immediately engaged into work after installation

A.1. Combined reinforced concrete anchor (CRCA) includes commercially available slot-and-wedge anchor (SWA) with modified wedge. This design of the anchor allows not only being installed in the well with a slot-and-wedge lock, but also to contact the rock mass along its entire length due to the use of cement-and-sand mortar used to fill the hole, before the introduction of a slot-and-wedge metal anchor into it (Figure-2, a).

Due to such combination, the CRCA is immediately engaged in work after installation, and after the concrete cures, it becomes a homogeneous concrete anchor that has all the above advantages.

The additional advantage is the fact that the design of the CRCA widely uses commercially manufactured SWA, and the technology of filling the well with cement-and-sand mortar has already been well developed.

Bench-top and mine tests of CRCA showed that immediately after installation, the bearing capacity of the anchor was on the average 40 kN, and the next day, it exceeded 100 kN.

The time of installation of one anchor was on the average 4 min 55 sec (except for the time of drilling the borehole).

This anchor design has passed numerous tests and was recommended as a basic element of earthquake-resistant linings used at "Sevuralboksitruda" mines.

To monitor the bearing capacity of the anchor of this design, it is recommended to use the methods that are widely used for slot-and-wedge metal anchors (torque wrench or a standard puller).
A.2. A Swellex type tubular hydro bracing anchor (TGBA) (Figure-2, b) is a structure consisting of a pipe, a C-shaped cross section with studs at the ends, which is fixed in the well due to the pressure generated by the liquid injected into the pipe. The use of liquid for fixing the anchor in the well ensures its contact with the rock along its entire length.

Anchors of this design are immediately involved into operation, have high reliability after installation, are quickly erected, and do not require monitoring after installation.

According to tests in the mine conditions, it was found that the bearing capacity of the anchor is 90-120 kN even immediately after installation, and the time spent for anchor installation does not exceed 1 min (without drilling the well).

Given the fact that the TGBAs feature high earthquake resistance and retain their bearing capacity in case of stretching (in the range from 80 to 90% of the initial value); it is recommended to use anchors of this design for earthquake-resistant linings.

A.3. Steel-polymer locking anchor (SPLA) (Figure-2, d) and steel-polymer solid anchor (SPSA) are structures that consist of a reinforcement bar, vials (one or several) with polymer concrete, a metal nut and a bearing plate. Quick setting period (on average up to 3-5 min) are achieved through a properly selected composition, consisting of high-strength rapid-hardening polymer.

For example, if the embedment length is 400 mm, the bearing capacity of anchors from the moment of their installation is 60 kN (after 0.5 h), 80 kN (after 1 h), 140 kN (after 2 h), and 180 kN (after 24 hours).

This type of linings may be recommended as earthquake-resistant linings, since it is quickly engaged in work, has high bearing capacity and resistance to seismic influences. Given the above, this type of linings ensures high efficiency of rock mass strengthening.

B. Anchors that become operational only after certain time

B.1. RCA with a double-cone contour lock (RCA2C).

They are made of 18-20 mm diameter ribbed steel.

To prevent mortar leakage, a sealing cuff is put onto the end of reinforcement bars during installation. It should be noted that when these anchors are used either independently or together with shotcrete, the bearing plate is not installed.

When support elements and meshy set lagging are used, which are recommended for the use in unstable rocks, a two-cone bush is used, which is mounted to the contoured end of the concrete anchor.

According to the results of the tests, it has been found that the bearing capacity of the lock is 80-140 kN. Under dynamic effects, the lock works in adjustable mode of increasing resistance.

The main advantage of these linings is the simplicity of visual and instrumental monitoring of the installation process; monitoring may be performed at any moment after erection. If rapid-hardening solutions with high strength characteristics are used, the linings may be engaged into operation within the first 24 hours after installation. In this case, shotcrete, slot-and-wedge metal
anchors, and CRCA may be used as temporary linings for the borehole zone.

B.2. The design of the cable-and concrete anchor (CCA) developed at JSC "Sevuralboksitruda" with loop circuit end (Figure-2, c) has s bearing plate with an oval cut and a locking wedge.

At the beginning, this anchor is installed without the bearing plate (similar to the RCA2C anchor). For reinforcement, this type of linings can be used together with shotcrete, meshy set lagging with a bearing plate and a locking wedge (combinations are possible).

This kind of linings is similar by its characteristics to the design of the RCA2C anchor, but this design of roof linings cannot be used when rocks delamination from the contour end of the anchor has already occurred. Nevertheless, this type of roof linings can be used as earthquake-resistant linings.

B.3. At the enterprises of JSC Norilsk Nickel, concrete single-core anchor with loop end (RCA 1 P) is actively used (Figure-2, e). This anchor design is used to create a reinforced structure of combined linings, and consists of anchors with ø16-18 mm ribbed bars and a bearing plate with an oval cutout, which presses the mesh to the rock with a steel wedge. This linings design is also recommended as earthquake-resistant linings.

B.4. Another design of earthquake-resistant linings is a two-core RCA with a loop end (RCA 2P) (Figure-2, f). Its design is different from that of RCA 1P in the fact that the reinforcement ribbed bars have diameter of 12-14 mm, bend easily, and are used to make the anchor core, are folded in two, thus forming a loop at the end of the anchor, which is used for the wedge on the contour end. This anchor design is convenient for reinforcing low workings up to 3 m high, since its length is 3.4-4.5 m, as well during the installation of "combs", "suspensions" or "bushes."

B.5. considering the characteristics of shotcrete lining, it can be used as seismic-resistant, both alone and together with anchor lining. In cases where workings are made in difficult geological conditions, it can be used with metal holders, meshy set lagging, and sometimes combination of both.

The shotcrete lining can align irregularities of the contour of the working; besides, protective coating is created on the contour of the working, thus reducing strain concentration.

When the shotcrete solution is used, hardening of the borehole; it comes into operation immediately after installation and has high adaptability of the design. It is efficient as temporary lining in the borehole zone. It can be used as permanent lining alone, or in combination with other types of lining. It is subject to corrosion. TGBA anchors were positively tested at LSC "Sevuralboksitruda". The main obstacle for their widespread use is their relatively high cost. In new conditions, where expensive SPAs are also used, this factor requires further analysis.

D. Hydro bracing anchor

Tubular hydro-bracing anchor TGBA is made of a pipe crumpled to the C-shaped cross section with stubs at the ends, which is fixed in the borehole with the pressure of the fluid injected into the pipe. The anchor has contact with the rock along the entire length of the borehole; it comes into operation immediately after installation and has high adaptability of the design. It is efficient as temporary lining in the borehole zone. It can be used as permanent lining alone, or in combination with other types of lining. It is subject to corrosion. TGBA anchors were positively tested at LSC "Sevuralboksitruda". The main obstacle for their widespread use is their relatively high cost. In new conditions, where expensive SPAs are also used, this factor requires further analysis.

4. DISCUSSIONS

The Instructions for choosing linings for preparatory and capital mining workings in the mines of JSC Sevuralboksitruda envisage further expansion of the application scope of the reinforcing composite structures of the lining in building permanent workings. [15]
Figure-3. Fastening a capital two-way of cross-cut in the fractured chloritized porphyrites with inclusions of zeolite that are prone to weathering, disintegration and swelling. Temporary lining is combined: SPA along the roof (la =1.4 m, on a 1.2×1.0 m mesh), RCA along the roof and on sides (l_a=1.8 m, on a 1.2×1.0 m mesh), metal mesh set lagging, shotcrete.

The procedure of erection: 0.5-1.0 cm of shotcrete for hammering → SPA → RCA → mesh → 3-5 cm of shotcrete.

Permanent lining is monolithic concrete.

An important advantage of the combined lining is the possibility of its gradual strengthening, for example, in the sequence: RCA - short anchors - metal mesh - shotcrete - additional RCAs - re-application of shotcrete. In unstable rocks, in the borehole zone, SPA SWA or CRCA are used. In such combinations, lining in many cases may replace the monolithic concrete lining with an economic effect.

For example, capital working in the rocks of categories II-III of stability, lagging of application of the mesh and shotcrete is chosen based on the condition of roof break damping along the contour up to the moment of placing the mesh. [16] Otherwise, rocks delamination behind the mesh adds a time-consuming operation of removing delaminated layers and restoring the lining. For this reason, lagging of lining elements from the face should be adjusted according to the experience of lining workings in similar conditions. In particularly difficult environment, in the rocks prone to weathering, the surface of the rock should be covered with shotcrete in the critical zone (Figure-3). It is possible that the lining (SPA, RCA, mesh, shotcrete) will be sufficient for long-term support of the working. If necessary, monolithic concrete lining may be built.

For preliminary workings in the areas of coal-face work, recommendations are limited to combinations of various types of rods and supporting types of lining. Hanging the mash of the anchors is possible but inefficient, due to the high complexity and low efficiency in case of systematic violations of the rock contour. Shotcrete as a hardening agent and a protective coating is widely used in similar conditions at other ore deposits and could be useful in preparatory workings. In the areas of seismic activity, in the rocks of III resistance category, combined lining should be reinforced by bushes of the deep rods.

In haulage gates, bushes should be shifted towards the anticipated center of dynamic phenomena (Figure-4), and in arch shaped access crosscuts in the areas remote from ore body up to 10 m, bushes are to be installed in the center of the arch. Bushes lagging from the working face on the schemes is taken as the minimum to prevent rocks fall-out from the roof. This parameter should be specified for the state of the workings maintained in the same conditions. Covering access crosscuts with shotcrete may be omitted.
RCA up to 5 m
Shotcrete up to 20 m
RCA up to 5 m
Bushes of deep anchors up to 10 m
3.5 m

Figure-4. Fixing the North haulage gate in sustainability category III rocks in an area of high seismic activity. Combined lining: RCA along the roof (l= 1.8 m, placement mesh 1.0×0.8 m), bushes of deep anchors, 3-5 cm shotcrete

5. CONCLUSIONS

Earthquake resistant design of linings described in this article, and the practical experience of their use in the workings of the mines of Sevuralboksitruda allowed reducing costs for installation of preparatory and capital mine workings, and improving the safety of mining operations.

The design of earthquake-resistant linings described in the article may be used by companies and organizations involved in design, building, and operation of underground mine workings in difficult mining and geological conditions, and the information contained in the article may be useful for educational, scientific and engineering-technical workers of companies, organizations, scientific-research and engineering institutions involved in securing and maintaining the mining workings in rock burst-hazardous ore deposits.

The perspective issues for further research in this area are the improvement of the existing, and development and validation of fundamentally new rational designs of earthquake-resistant linings of mine workings, in development of rock burst-hazardous deposits at great depths.

REFERENCES


