Expediency of wet-mix shotcreting in mines of Vostoktsvetmet

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Abstract. This paper offers a substantiation of the transition from heavy and difficult-to-install steel frame support to the cheaper and simpler reinforced shotcrete lining (at the same bearing-capacity of the support). The process line for the preparation of the shotcrete mix is designed. The author of the paper presents calculation of the material inputs and labor costs of installation of different support types in Kazakhstan Mines. The economic efficiency of the wet-mix shotcrete spraying technology is illustrated in terms of Orlov and Artemevsk Mines.

Orlov Mine is going to develop North site of Novaya orebody at Orlov deposit; the targeted area contains ore reserves of category C_1 in amount of 3615 thousand tons [1].

The North site rock mass is composed of alternate ore bodies and lenses featuring complex shape along the dip; the length reaches 800 m along the strike and 400 m along the dip; the height is to 350 m. The ore bodies have mostly steep dip (to 80 deg), are to 4 m thick in horizontal part and have average thickness of 10.5 m in steeply dipping sections. The depth of occurrence of the North site ore is nearly 1000 m

The ore and rock mass are weak-stable. The stability drops in the zones of weathering, faulting and hydrothermal alteration zones, which can be from a few meters to 100–150 m thick. The adjacent rock mass is very unstable due to numerous differently directed microcracks filled with calcite and pyrite, and many slide surfaces.

After transition to deeper levels, mine-technical conditions worsen because of great depth, many unfilled mined-out voids and man-made fills, zones of oxidation of sulfur-bearing ore etc.

In difficult ground conditions of the unstable rock mass subjected to high stress state, the steel frame support deforms, which generates accident conditions in underground excavations.

Artemevsk Mine stage II embraces development of a few ore bodies containing ore reserves of category C_2 in amount of 12722.9 thousand tons [2].

Both Orlov and Artemevsk Mines widely use frame support due to the aggravating ground conditions at deeper levels. However, the frame support in unstable enclosing rock mass lacks mine safety even in case of double framing, which, among other things, impedes ventilation and movement of self-propelled equipment as cross section of roadways is reduced. The process of frame installation can also be unsafe.

A way out of this situation may be the transition from heavy and laborious framing made of special section steel SVP-22 and SVP-27 to a less expensive and readily sprayed (at the same load-bearing capacity)reinforced shotcrete with reinforcement frames.

Today, the mines of Vostoktsvetment only use dry-mix shotcrete without reinforcement fibers and frames.

The problem of dry-mix shotcreting is high rate of bounce. Depending on the surface to be lined (vertical walls or arch), loss of concrete may reach 15 to 35%. The average loss is from 20 to 25% as against 5–10% of concrete loss in dry-mix shotcreting [3–5].

The commercial test of Concrix ES35 fiber manufactured by Brugg Contec AG. Concrix, Switzerland, in dry-mix shotcrete lining with filler and binder made of local materials, as well as the trial of ready-made dry shotcrete mix Master Roc STS 1510 manufactured by BASF and cement-and-sand mortar Stopcem S manufactured by DSI have been carried out in Irtysh Mine of Vostoktsvetment [6]. The bounce of Concrix ES35 in case of the mix made of local materials and with the ready-made mix Master Roc STS 1510 (fiber was added in the mix at the plant) in the dry shotcrete lining method reached 30–50%.

The stop-watch observations show that the process of shotcreting has the same duration in case of the ready-made mortar and the mix made of local material, but the process of the mortar preparation in the latter case takes long time (5–7 min of single-stage mixing per 86 kg of ready mix). Considering this fact, the application of ready-made mixes reduces the time of shotcrete lining nearly 2 times.

With regard to all expenditures connected with mix preparation, the cost of shotcrete lining 40 cm thick per 1 m^2 in Irtysh Mine is USD 9,58 with the mix made of local materials, USD 13,71 with the local materials and cement accelerator Master Roc SA580 and USD 15,71 with the ready-made mix Master Roc STS 1510.

Thus, the lab-scale and commercial tests show that the use of synthetic fibers CONCRIX ES35 in dry-mix shotcrete does not ensure considerable improvement in shotcrete lining quality because of high-rate bounce.

The key advantages of wet-mix shotcrete lining as compared with the dry-mix shotcrete method include reduced bound and, as a consequence, lower loss by two times and more; higher productivity of shotcreting, better labor conditions owing to considerable decrease in dust formation; low compressed-air consumption thanks to hydraulic feed of shotcrete mix, reduced wear of shotcreting equipment and enhanced quality of shotcrete lining due to persistent water and cement ratio.

After research of wet-mix shotcrete preparation and lining in Vostoktsvetmet mines, it has been recommended to use mine concrete-mixing machine Minemix 15 manufactured by Normet or a mobile mine concrete mixing plant with capacity of 15 m^3/h on legs or on a frame, installed in a room of small section of 16–25 m^2 with a storage of cement in big bags, Unimec MF500 Transmixer concrete carrying machine and Spraymec MF050VC or Meyco ME-3 electrohydraulic self-propelled mobile concrete sprayer with compressor.

In Orlov Mine, it is planned to install concrete-mixing machine (CMM) at level 12 near Slepaya shaft; In Artemevsk Mine—at level 10 near a storage of filler materials, at actual elevation of –252.0 m.

According to [6, 8], steel frame support is used in rocks of stability categories II and IV. In rocks of stability category V, steel arch support is combined with the other types of reinforcement.

Rail haulage roadways require 0.67–1.0 SVP-22 steel frame support per 1 m^2 of mine working sin in rocks of stability category IV and 1.25–2.0 steel frames in rocks of stability category V. The excavations with self-propelled carrying machines need 0.8–1.5 and 1.5–2.0 SVP-22 steel frames per 1 m^2 in rocks of stability category IV and V, respectively.

By Q rating of lithological domains at Orlov and Artemevskoe deposits, with regard to classification of rock mass and ore bodies based on [9, 10], the shotcrete lining thickness is assumed as 9–12 cm for unstable rocks and as 12–15 cm for very unstable rocks. The calculation of economic efficiency of the transition wet-mix shotcrete method assumed that dry-mix shotcrete layer 5 cm thick was to be replaced by wet-mix shotcrete layer 7 cm thick and steel frame support was to be replaced by wet-mix shotcrete layer 12 cm thick (with the load-bearing capacity strength reserve)+resin-grouted rockbolts and reinforcement steel mesh.

The calculation of NPV with the current and proposed technology was performed without regard to the realization of marketable products for Orlov and Artemevsk Mines of Vostoktsvetmet (Figure 1).

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(a)

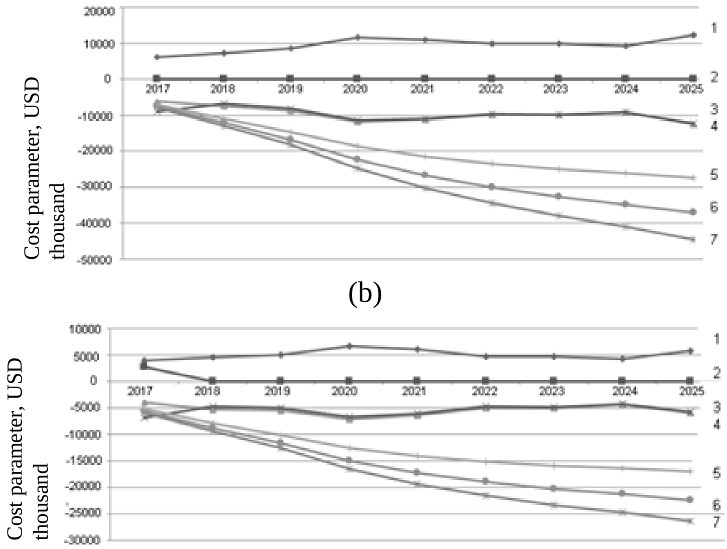

Figure 1. NPV at the (a) current and (b) proposed technologies of support installation in Orlov Mine, USD thousand: 1—operating cost; 2—capital cost; 4—net profit; 4—net money flow; 5–7—accumulated NPV at the discount rates of 0.15, 0.2 and 0.3, respectively.

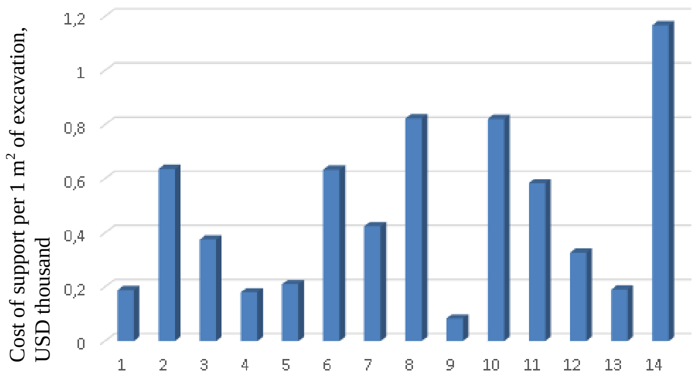

Figure 2. Cost of different-type support per 1 m^2 of excavation: 1—resin-grout rockbolting in Orlov Mine (pattern of 0.8×0.8 m, 9 rockbolts per row); 2—SVP steel frame in Orlov Mine (frame spacing l = 1 m); 3— SVP steel frame in Orlov Mine (frame spacing l = 0.59 m); 4—dry-mix shotcrete lining 5 cm thick in Orlov Mine (at the shotcreting cost of USD 15.74/m^2, rough section S_r = 16.0 m^2, finished cross-section S_f = 14.3 m^2, P = 11.47 m); 5— resin-grout rockbolting in Artemevsk Mine; 6—SVP steel frame in Artemevsk Mine steel (frame spacing l = 1 m); 7—SVP steel frame in Artemevsk Mine steel (frame spacing l = 0.67 m; 8— SVP steel frame in Artemevsk Mine steel (frame spacing l = 1.3 m); 9— dry-mix shotcrete lining 5 cm thick in Artemevsk Mine (at the shotcreting cost of USD 7.25/m^2, S_r = 16.0 m^2, S_f = 14.3 m^2, P = 11.47 m); 10—hybrid support: shotcrete 12 cm thick+resin-grout rockbolts 2.2 m long+reinforcement steel mesh; 11— shotcrete 12 cm thick+resin-grout rockbolts 2.2 m long; 12—shotcrete 12 cm thick; 13—shotcrete 7 cm thick; 14—protective support of shotcrete 12 cm thick and resin-grout rockbolts 2.2 m long.

The total cost of wet-mix shotcrete lining is composed of capital and operating costs. The capita costs are determined at the current price level of 2017 in accordance with [11, 12] and with regard to local construction conditions in East Kazakhstan. The capital cost included expenditures connected with the purchase of main process equipment, drivage and support of underground excavations for placement of underground concrete-mixing machines and other equipment and development of project paperwork. The operating cost included expenditures connected with the amortization, basic process materials (components of mix), protective clothes, food, power (electric energy, compressed air, diesel fuel), water supply, external services, wages and fire-protection measures.

The cost of different types of support per 1 m of underground excavations for mines of Vostoktsvetmet is illustrated in Figure 2.

Conclusion

According to the resultant calculations of economic efficiency of the two technologies of mine support shows that for the conditions of Orlov Mine, at the discount rate of 0.3 (without regard to the commercial output realization), 2025 NPV makes USD -27303 thousand with the current support (steel frames) and USD -16948 thousand with the proposed technology (reinforced shotcrete with the reinforcement), which is reflective of the efficiency of the proposed method of wet-mix shotcreting. In Artemevsk Mine, with the amount of frame support making 80% of the amount of permanent and development drivage in 2017–2034, at the discount rate of 0.3, 2034 NPV is USD -24884 thousand with the current technology and is USD –22711 thousand with the proposed method, which is also proves efficiency of the recommended wet-mix shotcrete lining.

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