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DESIGNING SUPPORT FOR NARROW RIB PILLARS WITH SUBVERTICAL FRACTURES

At Magnezitovoye mine, Magnezit, the reserves of magnesite are processed by the chamber system of development in layers in ascending order with the use of a dry bookmark of the worked out space.

When the unit No. 1 was worked out, cracks in the subvertical direction were revealed, signs stretching for tens of meters. Cracks are both tightly closed contacts, and friction-filled rubbers. There were lobes, permeated with one, two or more such cracks, especially with the effects of explosions. Explosive work of the nano-decomposed damage of the configuration of the ends, reducing their geometric dimensions, observance of which affects the bearing capacity of the pillars. Even a slight decrease (change) of the geometric parameters of the target can be reduced for the rest of the area, which in turn can lead to the destruction of the whole.

To solve one of the problems of ensuring the sustainability of targeted programs using software using anchor installations and / or injection. Several variants of the location of the crack (violation) in the whole were considered:

1. Option, when the crack goes to the wall of the lintel above its base (soles)

2. Option when the crack crosses this ground.

The investigated parameters of fastening narrow ribbon pillars in the presence of subvertical cracks in them, which have an opening of 3 mm or more.

Studies have made it possible to establish the necessary number of anchors for 1 m² for fixing such cracks to ensure the stability of the pillar, and the possibility of using resin injections. Features resin is that the binder can penetrate even into small cracks, but only at a shallow depth.

These measures will ensure the sustainability of the structural elements of the development system, as well as improve the safety of people employed in underground work.

***Key words:** chamber system development, cresol, subvertical cracks, magnesite deposit, stability, anchor, resin injection, the category of stability of rock massifs KUM, static loads, overlying layers, base pillar area*

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Introduction

Magnezitovaya Mine, MAGNEZIT Group, extracts magnesite reserves by bottom-up open stoping with dry backfill. Operations in the first layer in block 1 revealed subvertical fractures tens meters long. The fractures were mostly closed or healed with secondary magnesite. There were solid blocks intersected by one, two and more fractures of that kind. In some solid blocks, there were fractures with the opening 0.2 to 2 mm [1–3]. In the upper layers, subvertical fractures were observed in the most of pillars, and the opening of the fractures in some pillars reached 3–5 mm. The presence of the wider fractures is explained by the fact that a pillar 5 m high (the height of one layer) is subjected to compression of 2–3 MPa in the pillar middle, which locks opening of the fractures. In a twice as high pillar, the compressive stresses in the middle part drop down to zero, which slumps the resistance of the fractures to blasting impact and results in the fracture opening. Evidently, such pillars need their load-bearing capacity to be increased [4–8].

Support design for narrow rib pillars with subvertical fractures

Visual observation of the existing pillars shows that slope angles of subvertical fractures are most often range from 60 to 90°.

The Institute of Mining of the Ural Branch of the Russian Academy of Sciences carried out calculations aimed to enhance strength of pillars with subvertical fractures by rock bolting and/or injection. The calculated variants were the cases when a fracture reached the pillar wall above the pillar bottom and when a fracture intersected the bottom.

Table 1. Rock mass stability category

RSC	Description of fractures	K_j	f	I_c
1 very stable	Closed or with strong fill	≤ 1	> 10	≥ 100
2 stable	Width is not more than 0.2 mm, no gouge or slickensides	≤ 2	> 8	≥ 50
3 medium stable	Gouge is mostly absent. Opening is not more than 1 mm, no openings of discission and slickensides	≤ 5	> 6	≥ 20
4 unstable	Opened to 3–5 mm, or filled with mylonite, gouge, openings of discission and slickensides	Have no influence		
5 very unstable	Crushing zones, mylonitizations, large faults	Have no influence		

K_j — jointing factor; f — Protodyakonov's hardness factor of rocks; I_c — average length of full hole core.

The source data for the calculations were:

— hard rock mass stability category (RSC) = 1; 2; 2.5; 3; 3.5; 4 (**Table 1**);

— slope of fracture 80, 75, 70, 60º;

— internal friction angle in fracture 33º;

— bolt diameter 30 mm;

— vertical pillar load σ_z = 18 MPa;

— injection-induced increase in rock cohesion 2 MPa for cement grades 500–600; 1 MPa for lower grade cement and 3 MPa for cement-and-sand grout.

Totally, 96 variants were calculated for vertical fracture resistance to static loading with rock bolting only or with combination support composed of bolting and injection (**Table 2**).

The calculation procedure for the required number of bolts to ensure stability of a pillar with a fracture was stagewise:

1. The rock mass strength was determined from the formula:

$$\sigma_{up} = \exp(5.76 - 0.95\mathrm{RSC}),\ \mathrm{MPa}$$

From the Mohr–Coulomb condition for a pillar, given the minor stresses are horizontal and the lateral stress are close to zero:

$$\sigma_{up} = 2AC_f,$$

where $A = \mathrm{tg}\varphi_f + \sqrt{1+\mathrm{tg}^2\varphi_f}$; φ_f — angle of internal friction in the fracture; C_f — fracture cohesion conditioned by the fracture opening.

2. The shearing stresses under the uniaxial load were found as:

$$\tau = 0.5\sigma_z \sin 2\alpha,$$

where α — angle between σ_z and the fracture; σ_z — vertical load; the confining shearing stress was given by

$$[\tau] = C_f + \sigma_z \,\mathrm{tg}\varphi_f \sin\alpha.$$

3. Additional confining forces due to a single bolt installation:

Cohesive force $F_c = S_b\tau_b$;

Friction force $F_{fr} = \pi d_b \tau_g l_g \mathrm{tg}\varphi_f \sin^2\alpha$,

where S_b — cross section area of the bolt; τ_b — steel shearing strength; l_g — grouting length; τ_g — concrete shearing strength; d_b — bolt diameter.

4. The number of bolts per 1 m^2 to ensure stability of a pillar with a fracture was calculated from the formula:

$$n_b \ge \frac{\tau - [\tau]}{F_c + F_{fr}}.$$

The calculated data are compiled in Tables 2 and 3. Since the presence of open subvertical fractures suggests that RSC = 3, then RSC was preset as 3.0; 3.5 and 4.0, i.e. the opening of the fracture varied between 0.5 and 5.0 mm.

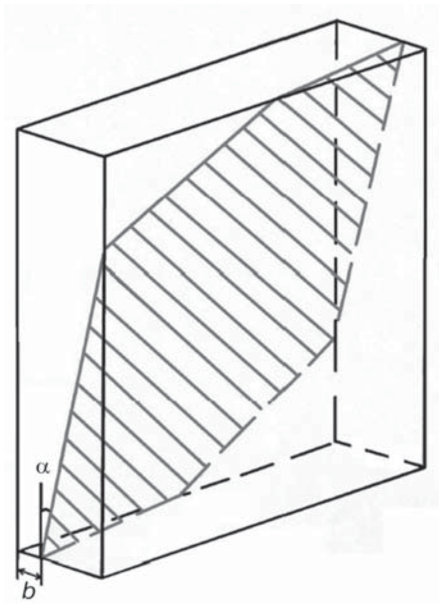
The strength of the fractured bottom of the pillar requires fulfillment of the condition below:

$$\sigma_{up} \ge (\sigma_z \cdot S_{pil} - F_{conf}) / S_{bottom}.$$

In the calculations the pillar bottom area S_{bottom} was set as 1.5; 3.0; 4.0; 8.0 and 16.0 m^2, the fractures intersected the bottom at different angles. The illustration of the model of a pillar with subvertical fractures is given in Figure 1. The calculated stresses in the bottom of the pillar were compared with the allowable rock mass strength σ_{up}= 50 MPa. The negative values of S_{bottom} mean that the confining forces along the fracture exceed the loads applied to the pillar top. As is clear from Table 3, when the pillar bottom part cut off by the fracture has an area S_{bottom} = 8 m^2 and RSC is 3.5 (fracture opening is not wider than 2 mm), the actual stresses are less than the ultimate strength of rocks, i.e. the pillar is stable under the static loading. With the fractures to 3 mm wide and more, the pillars are stable if S_{bottom} = 10–15 m^2. The analysis of the results shows that with the increase in the fracture width, the load on the pillar bottom grows and its stability is thus reduced. Ac-

Table 2. Required number of bolts

RSC (fracture opening)	α, deg	Bolts per 1 m^2			
		Without injection	Low grade cement	Cement grade M500	Cement-and-sand grout
1 (closed)	80 75 70 60	– – – –	– – – –	– – – –	– – – –
2 (≤ 0.2 mm)	80 75 70 60	– – – –	– – – –	– – – –	– – – –
2.5 (0.2–0.6 mm)	80 75 70 60	– – – –	– – – –	– – – –	– – – –
3.0 (0.6–1.0 mm)	80 75 70 60	– 1 2–3 5	– – 1 2–3	– – – 1	– – – –
3.5 (1.0–3.0 mm)	80 75 70 60	1 4 6 9	– 2 4 6	– 1 2 4-5	– – – 1–2
4.0 (3.0–5.0 mm)	80 75 70 60	4 6–7 9 11	1–2 4 7 9	– 2–3 5 7	– – 1–2 4



Model of a pillar with a subvertical fracture

Table 3. Calculated stresses σ_{bot} in the bottom of a pillar with a subvertical fracture

Slope, deg	RSC	[τ]	a = 1	a = 2	S_{bot}	$\sigma_{pil}\, F_{pil}$	σ_{bot}	S_{fr}	F_{conf}	S_{bot}	$\sigma_{pil}\, F_{pil}$	σ_{bot}
			S_{fr}	F_{conf}								
80	3.0	5.34	177	945.2	1.5	698.4	–164.5	146	779.6	3	7.14	–21.7
			250	1335	4	1083.6	–62.85	289	1543.3	8	882	–82.7
			296	1580.6	8	1152	–53.6	308	1644.7	16	846	–49.9
	3.5	3.45	177	610.7	1,5	698.4	58.5	146	503.7	3	7.14	220.3
			250	862.5	4	1083.6	55.3	289	997	8	882	–14.4
			296	1021.2	8	1152	16.4	308	1062.6	16	846	–13.5
	4.0	2.28	177	403.6	1.5	698.4	196.5	146	332.9	3	7.14	127.2
			250	570	4	1083.6	128.4	289	658.9	8	882	28.0
			296	675	8	1152	59.6	3,8	702.2	16	846	9.0
75	3.0	6.39	176	1124.6	1.5	1033.2	–60.9	134	856.3	3	900	14.6
			199	1271.6	4	1152	–29.9	192	1226.9	8	1152	–9.4
			224	1431.4	8	1152	–34.9	219	1399.4	16	1152	–15.4
	3.5	4.5	176	792	1.5	1152	160.8	134	603	3	1152	99.0
			199	895.5	4	1152	64.1	192	864	8	1152	36.0
			224	1008	8	1152	18.0	219	985.5	16	1152	10.4
	4.0	3.33	176	586.1	1.5	1152	298.1	134	446.2	3	1152	151.2
			199	662.7	4	1152	122.3	192	639.4	8	1152	64.1
			224	745.9	8	1152	50.8	219	729.3	16	1152	16.4
65	3.0	7.91	163	128.3	1.5	1152	–91.5	128	1012.5	3	1152	29.7
			167	1321	4	1152	–42.2	154	1218.1	8	1152	–8.2
			200	1582	8	1152	–53.8	176	1392.2	16	1152	–15.0
	3.5	6.03	163	982.9	1.5	1152	112.7	128	771.8	3	1152	110,0
			167	1007	4	1152	36.2	154	928.6	8	1152	27.9
			200	1206	8	1152	–6.8	176	1061.3	16	1152	5.7
	4.0	4.86	163	792,2	1.5	1152	239.9	128	622.1	3	1152	159.9
			167	811.6	4	1152	85.1	154	748.4	8	1152	50.4
			200	972	8	1152	22.5	176	855.6	16	1152	18.5

$\sigma_{bot} < 0$ when the confining forces exceed the shearing forces in a fracture.

cording to the calculations, subvertical tectonic fractures in pillars resist static loading, i.e. a key objective of fractured pillar support is prevention of fracture opening under dynamic loading due to blasting. When a production blast wave runs through tectonic disturbances, energy the energy of the wave is halved. It is known that “a fault could result in an increase in vibration amplitude in front of the fracture owing to the reflected signal and drops behind the fracture.” This means that a portion of energy is reflected from the fracture surface, and discontinuities of stresses and displacements arise at different fracture edges. In the reflected wave, tensile stresses may appear along the normal to the fracture surface while, tangentially, shearing stresses at one edge of the fracture may exceed greatly their level at the other edge (**Figure**).

For the reason that most of the observed subvertical fractures in pillars have the width of 1–3 mm, than bolting patterns can be 1×1 m if slopes of the fractures exceed 70 deg and 0.7×0.7 m for fractures at smaller slope (**Table 3**).

Injection of fractures allows less number of bolts to be installed, especially with cement of higher grades and with cement-and-sand grouts, which is recommended as a guide.

Fractured rock masses are efficiently reinforced using polymeric materials having comparable strength characteristics as rocks. Resin injection is the effective reinforcement for rocks with Protodyakonov’s hardness factor f = 8 and higher, with fractures opened to 5 mm. Polymer injection involves drilling of holes to a fractured area and feeding of reinforcing fluid under a pressure of 16–20 MPa. Filling of fractures with resins allows strengthening exposed surfaces of rocks, mitigating effect of blasting operations and decelerating fracture propagation [9–12]. For resins KF-B, KF-Zh, KF-MT and KF-BZh after consolidation for a day, the tensile strength ranges from 2.0 to 2.7 MPa, the compression varies from 11.0 to 14.0 MPa and the shearing strength of the resin-and-rock joint is 2.7–4.1 MPa. These figures exceed the performance of a cement-and-sand mixture by 1.5 times, which will allow elimination of bolting in rocks with fractures having opening less than 3 mm. With a subvertical fracture with a slope of 6–70° and width to 5 mm, 2 bolts per 1 m^2 will be sufficient as against four bolts in case of cement-and-sand grouting [12].

Conclusions

1. As height of safety pillars is increased, the opening of subvertical fractures grows under the impact of vertical stresses, which induces displacement of rocks along the fractures. It is required to reinforce pillars intersected with such fractures.

2. Fractured pillars should be reinforced immediately after detecting open fractures or at the early stage of fracture opening. When the fracture width reaches 3 mm, the required density of bolting pattern grows sharply as cohesion of rocks along the fracture drops by more than 2 times.

3. If a fracture reaches the wall of a pillar, bolting pattern density is not less than 1×1 m for fracture slopes of 75–90°, not less than 0.7×0.7 m for fractures with a slope of 65–75° and not less than 0.6×0.6 m for fracture slopes under 65°.

4. Injection of resins allows elimination of bolting support owing to higher strength and adhesive properties of polymers.

Polymers are not recommended for application in case of fractures more than 5 mm wide.

5. Continuous monitoring of fractures in pillars should be performed for prompt safety measures to be undertaken.

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