Rationale for sustainable-safe parameters of highwall slopes in «Kamagan» occurrence while underground cleaning-up

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Abstract: The article presents an approach to managing the stability of slopes of robbed open-cast sites by the example of the Kamagan occurrence located on the territory of the Republic of Bashkortostan. It is proposed to use the principle of a temporary decrease in the slopes stability to extract stocks in the opencast side, and then to restore the long-term factor of safety.

1. Introduction
To date, a significant part of the deep quarries are being cleaned-up. In light of this, it can be assumed that open mining works reach their projected depth, but some of the reserves remain behind the contours: in the sides or below the bottom of the quarry. The basis of all existing technological schemes for the near-stock reserves processing is the open-underground method in various versions [1-3]. Herewith, the greatest difficulty remains in time of the combination of open and underground works [4]. At the same time, open mining works are carried out in the area of possible surface displacement under the underground excavations influence, which reduces the safety of mining operations [5, 6]. In the paper, the author propose an approach to the stability control of the undermined side-slopes on the example of Kamagan occurrence.

The copper-sulphide field "Kamagan" is known to be located on the territory of the Republic of Bashkortostan in Sibai, 3 km to the north of Sibai quarry. The deposit exploitation was started in August 2001. The upper layer was opened and worked opencast to a depth of 150 m. The balance reserves of ore bodies No. 2, 3, 4, 5, 6, 7 and 12 remain behind the contour of the quarry, the volume of which is 2153.4 thousand tons, at the moment they are declined by the underground method. The section of ore body No. 12 presents the greatest difficulty for development, since the 110 kV power transmission line enters the influence zone of underground mining operations (Fig. 1).

Currently, the marking slope robbing is being drifted between open and underground mining operations. Additionally, the initial stage of pillar recovery was complicated by the activation of the northwestern side deformations [7].

Moreover, the deformations are fixed in the form of separate cracks, rubbish-giving of the bench edges. Further deformation takes place in the form of the near edge surface and upper ledges yield, composed of sediments and loose rocks, as well as the opening of cracks and an increase in their number.
The development of the work area of the northwestern side led to the deformation activation in the form of significant near edge surface yield. The ongoing shifts result in deformation of the electrical transmission towers in the form of their tilt to the vertical axis, and the formation of cracks along the haul road track.

2. Materials and methods
The following research methods are applied in the work: mathematical modeling by the finite-element method in the elastic formulation of the problem, graphical-analytical method, method of algebraic addition of forces, statistical methods of processing simulation results.

3. Study
As the main reasons that led to the deformations activation of the northwestern field side, it is possible to single out:
- the presence of a significant number of differently oriented tectonic cracks in the section of the side;
- the lack of the side support in the form of additional loading with empty rocks;
- a possible increase in the coefficient of not enough stowing the goaf with a hardening mixture in the extraction of the main reserves of ore body No. 12, set at a rate of 5% of the chamber height;
- watering weakened loose rocks and sediments on the upper horizons of the side, including the expense of anthropogenic water discharges;
- mass explosions during second working.

Subsequently, the following mathematical models for the sequence of ore body No. 12 mining were developed. The first model examines the stress-deformed state (SDS) of the massif in the final declining period of the main ore reserves. The second stage of modeling assesses the impact of the load on the condition of the robbed band after declining the main reserves. The third and fourth models are options for declining the barrier pillar with the load formation by empty rock and without it. The fifth model appreciates the field side stability when declining the marking pillar by open chambers. The sixth model characterizes the SDS of the rock when declining the marking pillar by the system with collapse and the arrangement of the panels across the pitch.
It has been demonstrated that the development of the main reserves of ore body No. 12 is accompanied by a concentration of stresses on the flanks of the worked space and unloading from the stresses of the central processing chambers roof. In this regard, it is possible to increase the chamber span on the ore body plateau. The value of the principal normal stress $\sigma_1$ in the concentration zones is 21.7 MPa. The normal stresses $\sigma_2$ in the zone of influence of the safety pillar recovery in the sliding prism limits are tensile and make up about 1.3 MPa. The ratio of $\sigma_1$ and $\sigma_2$ on the rock parts of the ore body indicates the limiting steady state of the pit side and the possibility of the slide prism displacement. Additional loading of the pit side (Figure 2) has a favorable effect on the stress-deformed state of the rock. This determines the reduction in the rock tension by 12-15% and, correspondingly, the increase in the safety factor to 150%. The main normal stresses $\sigma_1$ and $\sigma_2$ are in the range from -19.0 (in the pillar roof) to -2.0 MPa and from -6.7 to -0.0 MPa, respectively.

The safety pillar recovery by the development system with the collapse of the overlying ledges can lead to the realization of tangential stresses due to the wall flattening and the prism displacement into the open area, if the loading does not provide additional support to the underworked pit side. It is a "screen" that protects ore from the pieces scattering during blasting workings.

The safety pillar robbing by open chambers over the entire width without collapse forcing the overlying benches will lead to the roof destruction of the open area and the spontaneous elimination of the mined out cavities. In the open area, an uncontrolled self-destruction of the roof is unacceptable through ensuring the safety of mining operations (air wave action).

The main normal stresses $\sigma_1$ and $\sigma_2$ when declining a safety pillar by the panels located across the side are in the same stress condition as in the process of across pillar recovery by short panels. Robbing a safety pillar in the absence of side weight by draw rock results in the formation of tensile stresses $\sigma_2$ (Figure 3) along the pit contour, and in activating high tangential stresses concentrated in the sliding prism, which probably leads to stop prism sliding along the slip line.

**Figure 2.** Isolines of the main normal stresses $\sigma_1$ (a) and $\sigma_2$ (b) in the pit side after processing the main reserves and forming side weight

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**Figure 3.** Isolines of the main normal stresses $\sigma_1$ (a) and $\sigma_2$ (b) when declining the safety pillar by panels (strips) along the strike
Safety pillar robbing, i.e. the removal of the stop prism, regardless of the decline method, leads to a decrease in the stability of the undermined side and its deformation in various forms. It is possible to avoid this only by compensating for the loss of stability by weighting, fastening. However, in the absence of compensating measures, deformations are unavoidable, and when the ore deposit is gently sloping, the sliding surface will deform from the boundary of the robbed ore pillar, i.e. not local, but the total sliding surface.

Furthermore, circular cylindrical slip lines were constructed according to the generally accepted method of All-Russian Research Institute of Mining Geomechanics and Survey ARRIMGS [8], and the calculations of the general and local stability of the northwestern side of the pit were made in the mark 373-323 m, 337-296 m, mark 337-244 m (Figure 4), taking into account underground rob [9].

The coefficient of slope stability in mark 373-323 m was 0.8. The deformation from the initial stage (formation of the spud cracks) has moved to the active stage - the shift of the rock mass and the formation of collapse.

Stability factor for slope at mark 337-296 m equal to 1.05 confirms the actual formation of the spud cracks - the beginning of deformation. The state of the slope is close to the maximum, with additional external action of any dynamic loads, the stage of deformation can go from the formation of cracks to the movement activation.

Stability factor of the entire side at mark 373-244 m was 1.12. The slope is in a stable position, but the state is also close to the breaking one.

Short terms of the pit cleaning-up allow one during this period to use the temporary decrease principle in the stability of slopes. The side life in the reduced stability margin can be regulated by laying the worked out space with draw rocks and injecting them with hardening mixtures to the height which is necessary to restore long-term stability. Under the condition of open-underground mining, this tech-
nology will allow constructing an insulating arch pillar in the process of exploiting the occurrence by opencast before underground cleaning-up.

In order to save the side of Kamagan quarry, it will be necessary to carry out measures to strengthen the structure - excavating the side apex to unload the active pressure prism (the development of deformation on the overlying ledges can lead to disturbances in the lower part of the rock) and weight of its lower part - the horn prism [10].

To date, the deformation processes of the ledges have become more active, so the first stage in strengthening the side may be the buttress dumping in the considerable crack formation place.

The paper performs the value analysis of shearing and retaining forces in the slip prism blocks 337-244 m that showed that the boundary between the active pressure prism and the horn prism is located at the assumed deformation point of the ledges at marks 337 m - 296 m. The prism mass of the dumped wastes of the first stage is 932 t, buttress cross-section area - 730 m$^2$, buttress height - 47 m. With the extension of the spud cracks - 47 m, the expected volume of wastes dumping is not less than 40 thousand m$^3$. The active pressure prism brow for the entire side is at mark 323 m. In order to keep the northwestern side in a stable state after declining the barrier pillar reserves, it is required to fill the buttress with the parameters given below (Fig. 5). In the second fortification stage the prism mass of the dumping wastes is 2019 tons, the cross-section area of the buttress should be 1830 m$^2$, the angle of the natural slope of the buttress wastes is 34 degrees, the height of the buttress is 70 m, and the volume of the weight wastes dumping is 350 thousand m$^3$.

Figure 5. Scheme for determining parameters of second weight stage

4. Conclusion
Thus, the main reason for the slopes deformation in the north-western section of the pit side is the discrepancy between the excavating technology for the marking pillar and the design one, to a greater extent, the absence of the side weight by draw rocks. Declining the marking pillar in the pit side according to the scheme adopted by the project inevitably requires the preliminary muck pile creation in the pit base, which increases the side stability and allows reducing the normative strength of the underground chambers filling in, and, accordingly, its erection costs of [11].
The muck pile formation is planned to realize in two stages. The first stage of strengthening is the rocks dumping in the activation area of the slopes deformation processes; the second stage of buttress dumping is keeping the whole North-West side in a stable state after declining safety pillar reserves. The dumping time for the horn prism will not exceed the temporary stability period of the side slope.

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