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ANALYSIS OF THE CAUSES OF DEFORMATION OF SLOPES IN OPEN-PIT MINE

Abstract: *The main reasons for the occurrence of deformation phenomena on the slopes of mountain massifs are determined. A brief analysis of possible types of deformation of slopes in quarries is given. To ensure the stability of the rock mass and prevent its destruction from a certain type of deformation.*

A detailed study of the structural structure of rock masses and their physical and mechanical properties, as well as the possible degree of watering, suggests the development of special measures to manage the stability of quarry slopes. Such measures include massif drainage, slope rotation in terms of the identified weakening surfaces, development of a special technology for drilling and blasting operations at quarries, controlled collapse of rock ledges and formation of artificial landslides of clay rocks, and ensuring the required size of the safety platform when filling artificial embankments.

Keywords: *quarry; mountain massif; slope deformations; scree; landslides; subsidence; surfacing.*

Introduction. In most cases, open-pit mining is accompanied by the deformation of the roadside massifs, capital and cuttings trenches, and transport access roads. Deformation processes can be short-term or long-term and usually result in landslides. In any case, deformations of quarry slopes reduce the efficiency of deposit development, cause significant material damage to the quarry, disrupt the design and safe performance of mining operations, and increase the loss of minerals [1] . Therefore, ensuring the stability of open-pit slopes is one of the most important scientific and technical challenges in mining and is certainly relevant. To solve this problem, it is necessary to identify the causes of rock deformations, and all possible variants of their manifestations, and choose the right measures to eliminate and reduce the effects of deformations [2].

Purpose and objectives. Taking into account the importance of ensuring the safety of mining operations, the purpose of the study is to identify the main causes of deformation on the slopes of workings and sides of pits and to analyze deformation phenomena in the worked-out space.

The task of the study is to investigate deformation phenomena occurring in the open pit for further development of preventive measures and measures to combat them.

Material and research results. According to the research of scientists [3], all deformation phenomena on the slopes of ledges, sides of quarries and dumps, as well as transport ramps are divided into five types:

1) scree;
2) cave-ins (collapses)
3) landslides
4) subsidence;
5) surfacing.

In turn, these types of deformations in quarries have many varieties that occur in different mining and geological conditions. In addition, there is no clear boundary even between certain types of deformations.

The main reasons for the occurrence of deformation phenomena are

- Inconsistency of the slope angles of quarry slopes with the mining and geological conditions or insufficient knowledge of these conditions (in particular, structural and tectonic faults in the rock mass and its physical and mechanical properties);
- absence or inefficiency of drainage workings;
- incorrect mining operations at the open pit;
- misconception of the nature of deformation phenomena and underestimation of their consequences;
- application of an incorrect method for calculating slope parameters and assessing their stability.

Let's analyze the most common cases of deformation of quarry slopes at open pit mines. When excavating soils and weak rocks with a straight shovel excavator, the slopes of 10-15 m high ledges are usually concave (Fig. 1, a). Since the slope angle of the slopes is greater than the natural slope angle of the rock, the upper part of the escarpment gradually collapses over time and a slope with an angle of approximately 34-36° accumulates at its base. The process of destruction and slumping of a part of the slope is completed only after the slope reaches the upper edge of the slope.

Otherwise, when massive explosions are carried out in quarries using vertical borehole charges, partial destruction of rocks occurs along the contour of the industrial block. After the excavator removes the crushed rock mass from the industrial block, the rock remains in the ledges, which have been weakened, i.e. have no more than 20-25% of the natural strength of the rock mass. Over time, such slopes of the ledges crumble, i.e., scree is formed.

In the cases under consideration, the protective berms between the slopes of the pit wall are covered with scree from the overlying slope and may be partially destroyed. As a result, the quarry wall in some areas looks like a continuous ledge of considerable height.

Typically, slope collapses in open-pit mines occur along naturally weakening surfaces. These surfaces include tectonic faults, contacts of different rocks with different strengths, cracks of considerable length, and layering that descends towards the interior of the quarry (Fig. 1, b). Since the strength of the rock mass along the weakening surfaces is several times lower than that of the solid mass, the values of the slope angles of the ledges after their collapse completely depends on the orientation of these weakening surfaces in space.

There are several types of rockfalls, depending on the weakening surfaces and their spatial location:

1). Rock collapse along the longitudinal or diagonal slope of the weakening surface relative to the slope of the workings;

2). Landslide with the collapse of the rock prism along the steeply falling and undercutting weakening surfaces;

3). Collapse of the rock wedge along the connected weakening surfaces, which are undercut by the working face;

4). Collapse of the rock prism along two diagonal weakening surfaces of steep dip;

5). Falls of rock prisms and pyramids formed by at least three weakening surfaces.

Like scree, cave-ins form continuous slopes of the pit sides. However, unlike scree, in which the volume of rock mass on the berms gradually increases, the formation of cave-ins is sudden and lasts for several seconds, and the results can be catastrophic.

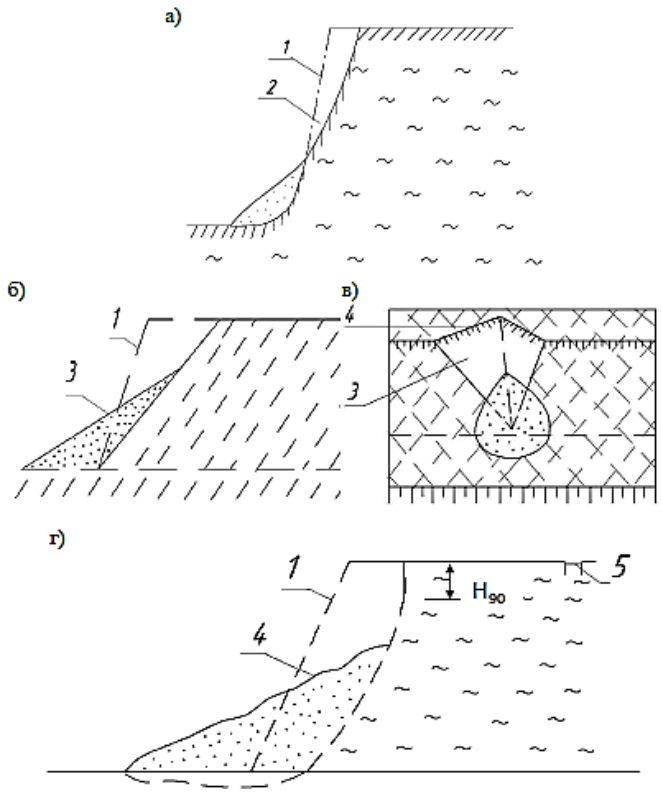

Figure1 – Deformations of slopes in quarries: a - slope in clay and loam; b, c - slopes in rocky fractured rocks; 1 - design position of the slope; 2 - after the formation of the slide; 3 - after the collapse; 4 - after the landslide; 5 - drainage ditch; d - slope in clay rocks

Landslides can occur in mountain ranges composed of weak, usually clayey rocks, if there are drainage ditches or depressions in the vicinity of them where water accumulates (Fig. 1, c, d). In this case, the water that penetrates the massif remains in it and saturates the rocks to the full extent of swelling. The water-saturated

massif moves along the sliding surface in the form of a vertical crack at the top and a smooth curve in the lower and middle parts. In this case, the part of the rock mass that has slid away is usually completely loosened and becomes even more capable of absorbing water.

Loosened and fully saturated with water, clay rocks acquire the properties of a soil paste. They accumulate on the ledge areas at an angle of 12-14°, and later, the water-saturated landslide mass can turn into quicksand. The width of the rock sliding depends on the plasticity of the clay and the height of the ledge. The higher the values of these parameters, the greater the width.

Subsidence, as a type of rock deformation, is most common in clay rock dumps, but it can also occur in the open pit space on artificially filled transport routes [4]. As a result of natural gravity sorting, when the clay is dumped, the bottom layer of the artificial embankment is formed from large pieces (the so-called highly porous layer). The middle layer contains medium-sized pieces of rock and the top layer contains the smallest rock particles, which form a zone of continuous medium. As the height of the artificial embankment increases, the pressure on the rocks in the lower and middle layers increases. The weakest pieces of rock are destroyed and fill the free space, which leads to compaction of the embankment and its subsidence. The process of embankment compaction and subsequent subsidence is intensified when the rocks are moistened. In many cases, subsidence is the initial stage of landslide phenomena, especially when the dumps are based on clayey rocks.

At almost every open-pit mine in Ukraine, you can find slope failures of various types of rock. Slopes consisting of rock and semi-rock are prone to localized collapses. The slopes of the massif composed of clayey rocks, when fed with water, are potentially a source of local landslides. Subsidence is observed during the filling of dumps and temporary slip roads, which are based on clay rocks. Sometimes slopes occur in the form of slumps. They are typical for clay rocks saturated with water.

Conclusions. Taking into account the above brief analysis of possible slope deformations, it can be concluded that one of the main technological tasks at the quarry is to ensure the stability of the rock mass and prevent its destruction from a certain type of deformation. It is not always possible to eliminate the main cause of deformation (e.g., landslides or local cave-ins). In this case, it may be advisable to take measures to reduce the effects of slope deformation. In particular, it is necessary to clean the safety berms in case of accumulation of rock slides, install barrier walls, use artificial strengthening of weakened areas of rock masses, create buttresses, etc.

In cases where the structural structure of the rock masses, their physical and mechanical properties, the degree of watering, etc. are studied in detail, it is necessary to develop special measures to manage the stability of quarry slopes. These may include drainage of massifs; turning slopes concerning identified weakening surfaces; development of special technology for drilling and blasting operations in quarries when placing the sides on the design contour; the controlled collapse of rock ledges and formation of artificial landslides of clay rocks; ensuring the required size of the safety platform when filling dumps, etc.

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АНАЛІЗ ПРИЧИН ДЕФОРМАЦІЇ СХИЛІВ У ВІДКРИТОМУ КАР'ЄРІ

Анотація: *Встановлені основні причини виникнення деформаційних явищ на укосах гірських масивів. Наведено короткий аналіз можливих видів деформацій укосів на кар'єрах. Для забезпечення стійкості гірського масиву та попередження його руйнування від певного виду деформації запропоновано проводити заходи щодо зменшення наслідків деформацій укосів.*

При детальному вивченні структурної будови гірських масивів та їх фізико-механічних властивостей, а також можливого ступеня обводненості запропоновано розробляти спеціальні заходи з управління стійкістю кар'єрних укосів. До таких заходів належать осушення масивів, розвертання укосів у плані відносно виявлених поверхонь ослаблення, розробка спеціальної технології ведення буропідривних робіт на кар'єрах, кероване обрушення уступів скельних порід та утворення штучних зсувів глинистих порід, забезпечення необхідного розміру запобіжного майданчика при відсипанні штучних насипів.

Ключові слова: *кар'єр; гірський масив; деформації укосів; осипи; обвалення; зсуви; просідання; спливання.*