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Study of Residual Stress State of Massif During Rock Destruction by an Explosion at The Limit Contour of a Quarry

Zairov Sh. Sh.
Head of the Sector of Scientific Research, Innovations and Training of Scientific and Pedagogical Personnel of the AF NIT "MISIS", Doctor of Technical Sciences, Professor;

Gaibnazarov B. A.
Deputy Dean for Youth Affairs of the Mining Faculty of the Almalyk Branch of the Tashkent State Technical University named after Islam Karimov, Doctor of Philosophy (PhD) in Technical Sciences

Fatkhiddinov A. U.
Associate Professor of the Department of General Professional and Economic Disciplines of the Almalyk branch of the Tashkent State Technical University named after Islam Karimov, Doctor of Philosophy (PhD) in Technical Sciences

Abstract
The paper studies the residual stress state of the rock mass caused by the blast, which changes the residual stress-strain state and physical and technical properties of the rock mass outside the crushing zone. The paper presents the parameters of drilling and blasting operations, the main characteristics of destruction, the geological and mining factors that affect them, and also studies the physical picture of the explosive destruction of the rock mass.

Keywords: Rock blasting, quarry limit contour, stress waves, problems in drilling and blasting operations, residual stresses, rock mass deformation, distance from the blasted block, Hooke's law, stress-strain state.

Introduction

The action of the explosion of borehole charges of explosives (HE) on the marginal contour of a quarry can be characterized by a number of force and kinematic parameters: the amplitude and duration of stress waves, the velocity of displacement of the medium behind the stress wave, the impulse and energy of stress waves in the medium, and the parameters of the shock wave.
The values of impulse and energy transferred during the explosion of a charge of explosives to the rock mass on the marginal contour of a quarry more fully characterize the action of the explosion, since they take into account not only the force and kinematic parameters, but also the time of the explosion, i.e. they are integral parameters.
The intensification of technological processes in quarries has led to the emergence of a whole range of problems in the conduct of drilling and blasting operations (BW) in the near-margin zone of a quarry. These problems acquire particular importance at deep horizons, where the negative

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effects of mass explosions are intensified due to the complexity of geological and mining conditions.
In Fig. 1 shows the parameters of the blasting operation, the main characteristics of the destruction, as well as the geological and mining factors influencing them [1].

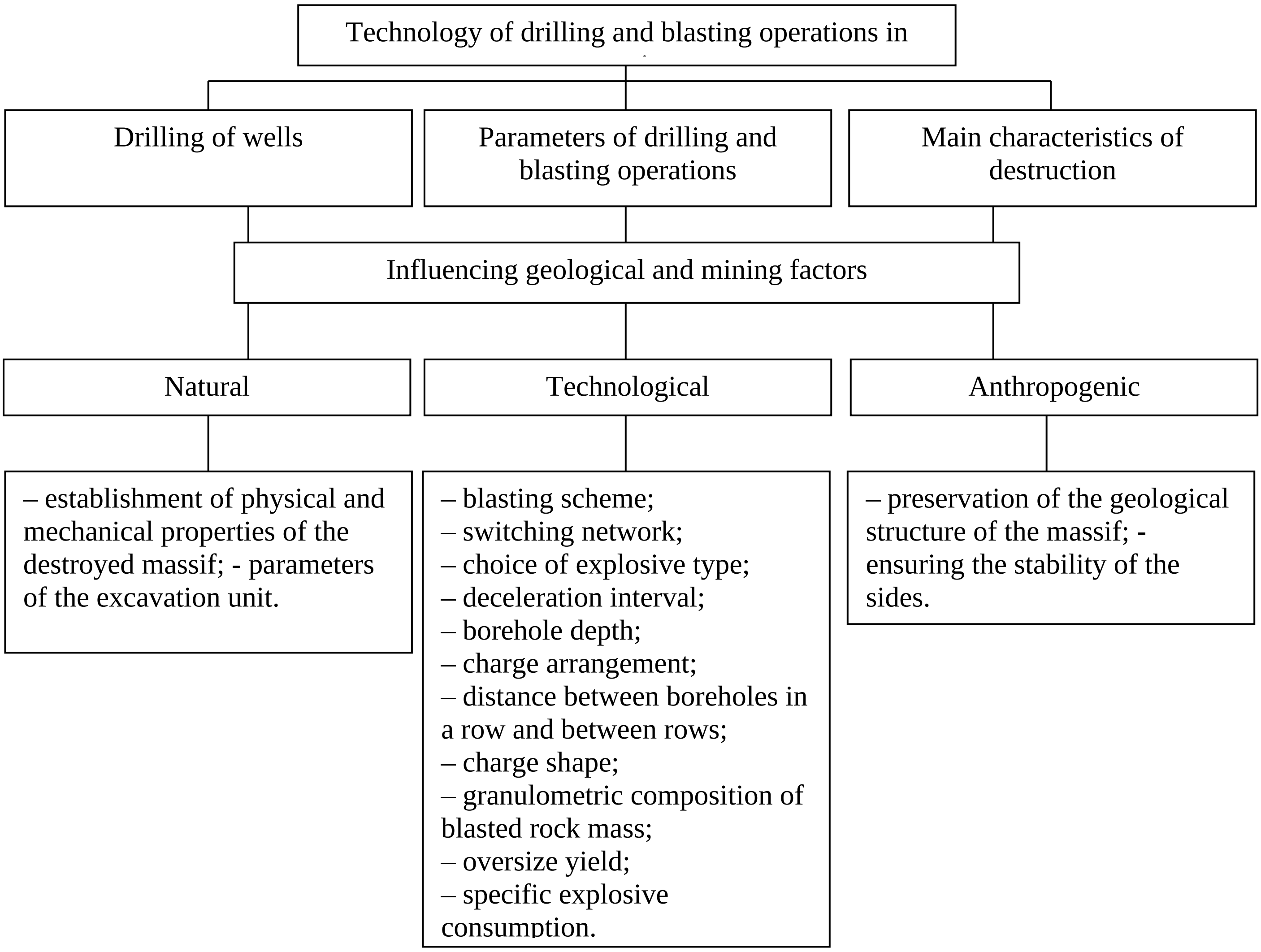
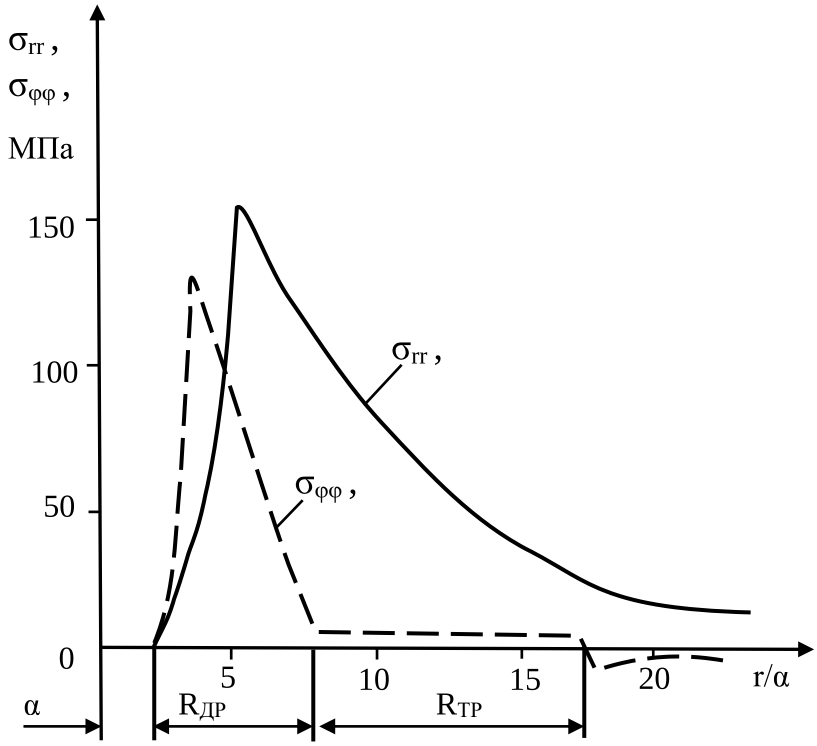


Fig. 1. Parameters of the blasting operation, main characteristics of destruction, as well as geological and mining factors influencing them

After a mass explosion, internal (residual) stresses arise in the rock mass, which are mutually balanced within the mass without the participation of external loads. Residual stresses have a significant impact on the processes of deformation and destruction, as well as on the strength and deformation characteristics of rocks [2].According to studies [3, 4], residual radial and azimuthal stresses are mainly located within the crushing zone (Fig. 2).



a – charge radius; Rdr – radius of crushing zone; Rtr – radius of radial crack zone

Fig. 2. Distribution of residual radial (σrr) and azimuthal (σφφ) stresses in rock after blasting with distance (r/a)

Analysis of the studies performed [5-9] indicates the presence of residual deformations of the massif at a distance of up to 70 m from the site of the mass explosion and depends on the strength properties of the massif, the explosion energy, etc. The magnitude of the deformations of the massif after a series of mass explosions is [5]: at a distance of 10 m - 0.1-0.35 m, at a distance of 50-70 m - 6-10 mm. Fig. 3 shows the dependence of the deformations of the cracked massif on the distance from the blasted block [3].

According to Hooke's law [10], the stresses σ arising in a deformed body are directly proportional to the relative deformation ε, i.e. residual deformations are proportional to the stresses:

$$\varepsilon = k\sigma, \tag{1}$$

where k is the coefficient of elasticity.

Thus, it can be assumed that the massif has a modified residual stress state caused by the explosion, which ensures a change in the residual stress-strain state and the physical and technical properties of the massif outside the crushing zone. The stress-strain state and physical properties of the rock mass determine its impact hazard, stability, drillability and blastability.

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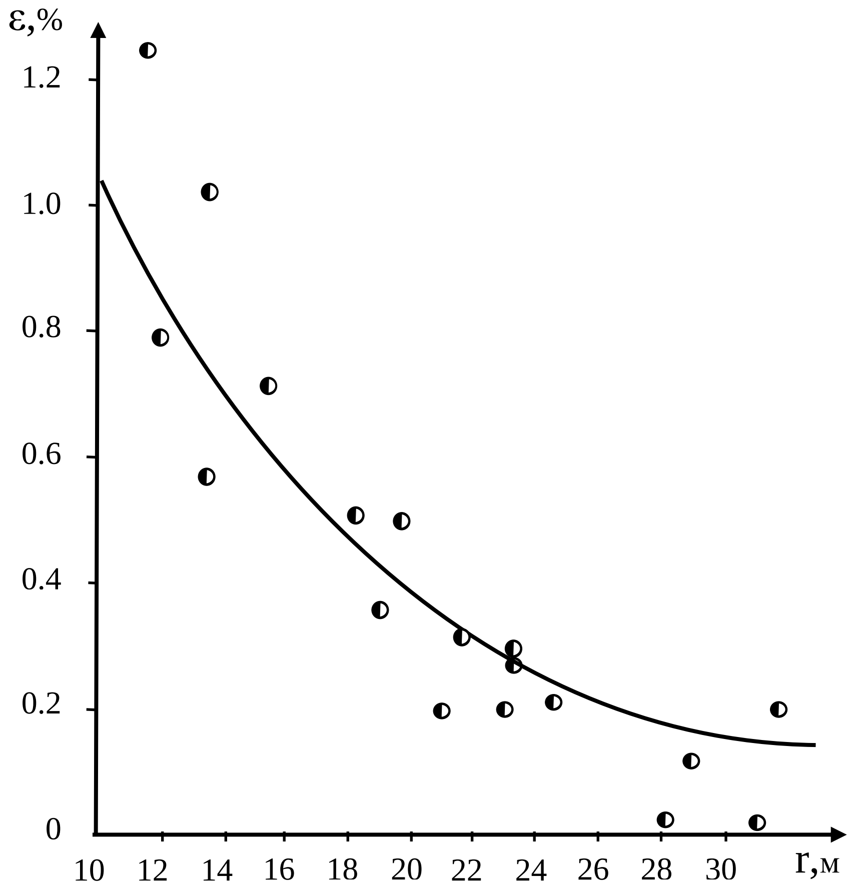

Fig. 3. Dependence of deformations of the fractured massif (ε) on the distance (r) from the blasted block

Research [5-9] has established that the work spent on plastic deformation is not completely transferred to the rock, but only by 80-90%. The remaining 10-20% remains in the rock in the form of residual stress energy. Rocks in which residual stress acts can be considered as being under the influence of a long-term load. As a result of its action, plastic deformation and, consequently, cracking of the rocks are possible over time.

The authors of [11-13] identified “the phenomenon of abrupt release of residual stresses in rocks, which consists in the fact that during static compression of a rock with residual stresses, along with smooth longitudinal compression and transverse tension, an abrupt and alternating change in deformations occurs, caused by the violation of the equilibrium of existing residual stresses by an external load and their interaction with stresses generated by the action of external forces.” The classical physical picture of explosive destruction of a rock mass is shown in Fig. 4

In the work [3], the analysis of the grid of the location of borehole explosive charges, measurements of the distance from the explosive charges to the boundary of the chipping zone, as well as reference measurements, showed that in fractured rock massifs, 3 deformation zones are formed (Fig. 5):

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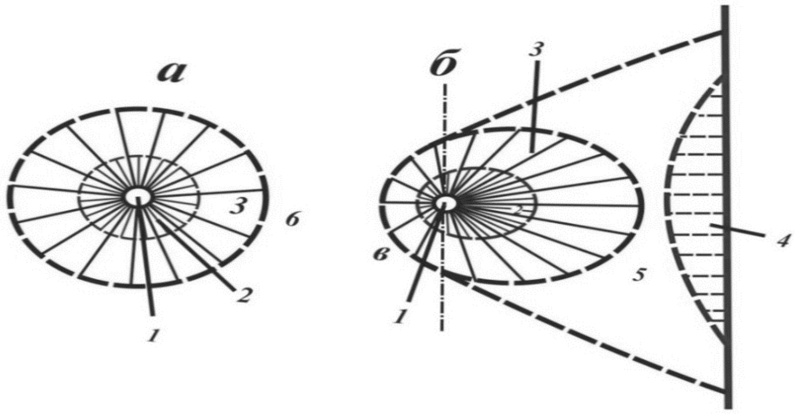


1 – borehole; 2 – crushing zone; 3 – radical crack zone; 4 – crack zone developing from the free surface; 5 – zone of cumulative destruction; 6 – undestroyed zone

Fig. 4. Destruction of a rock mass during an explosion in an infinite medium (a) and near a free surface (b)

– the crushing zone, in which dynamic impact and crushing of individual parts into parts occurs

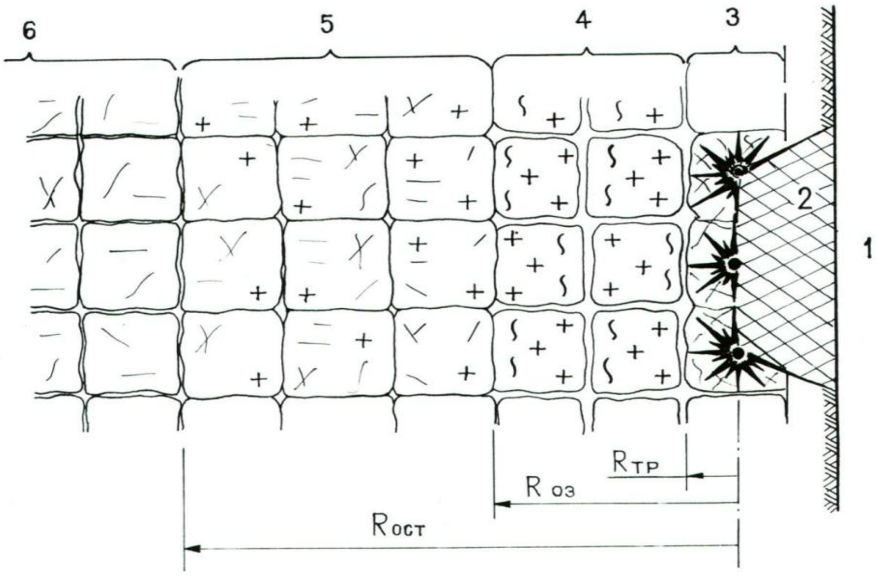
$$R_{тр} \leq (10 \div 15) d_з; \qquad (2)$$

– zone of elastic-plastic deformations (zone of chips), in which deformations occur on the edges of cracks and elastic deformations in individual parts without their destruction, the elastic component of dynamic deformations ensures the movement of individual parts to the loading cavity with the formation of chips

$$15 d_з \leq R_з \leq 50 d_з; \qquad (3)$$

– зона остаточных напряжений, в которой происходит закрытие трещин и упругие остаточные деформации в отдельностях массива

$$50 d_з \leq R_{ост} \leq 150 d_з . \qquad (4)$$



1 – mined-out space; 2, 3, 4 and 5 – respectively, zones of ejection, crack formation (crushing of individual parts), unloading (chippings), residual deformations (stresses); 6 – zone of natural state of the massif; Rtr, Roz, Rost – radii of crack formation zones, chippings and residual stresses

Fig. 5. Zones of deformation of a stressed fractured massif by an explosion

The sizes of crack formation zones, chips and residual stresses depend on the diameter of charges, type and specific consumption of explosives, well arrangement grid, charge design, blasting sequence, deceleration intervals, degree of mass fracturing and rock strength. Thus, residual stresses are non-uniform and structurally connected to the level of the crystal lattice, as a result of which, with known unloading methods requiring the formation of a new surface by drilling a well, residual stresses, due to their internal structural connectivity, are not completely unloaded. In this regard, it is recommended to determine residual stresses by unloading methods or radiography in rock cores in all directions and then calculate the stresses acting in the rock mass. By determining the residual stress state of the massif, it is possible to predict and prevent landslides by unloading dangerous stresses in these areas with low-power explosions.

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