

Destruction of Rock by Explosives

Blasting in rock is performed by placing explosives in blast holes and initiating them. The energy of the explosion is transferred into the rock mass and causes its fracture in the zone where tensile stresses are greater than the tensile strength. In doing so, the previously explained fracture criterion, presented in earlier texts, was used:

$$\sigma_t = \frac{\nu}{1 + \text{tg}\varphi} \cdot \sigma_1 - \sigma_3$$

On a 2D model, using the finite element method, a borehole with a diameter of 0.1 m was modeled. The model is initially unloaded, all stress components are zero. The model boundaries are sufficiently distant from the borehole and all nodes on the contour are fixed. I assumed that the tensile strength of the modeled rock was 5 MPa, so this is the tensile stress zone of interest. A compressive load of 2000 MPa was applied to the borehole wall, Figure 1.

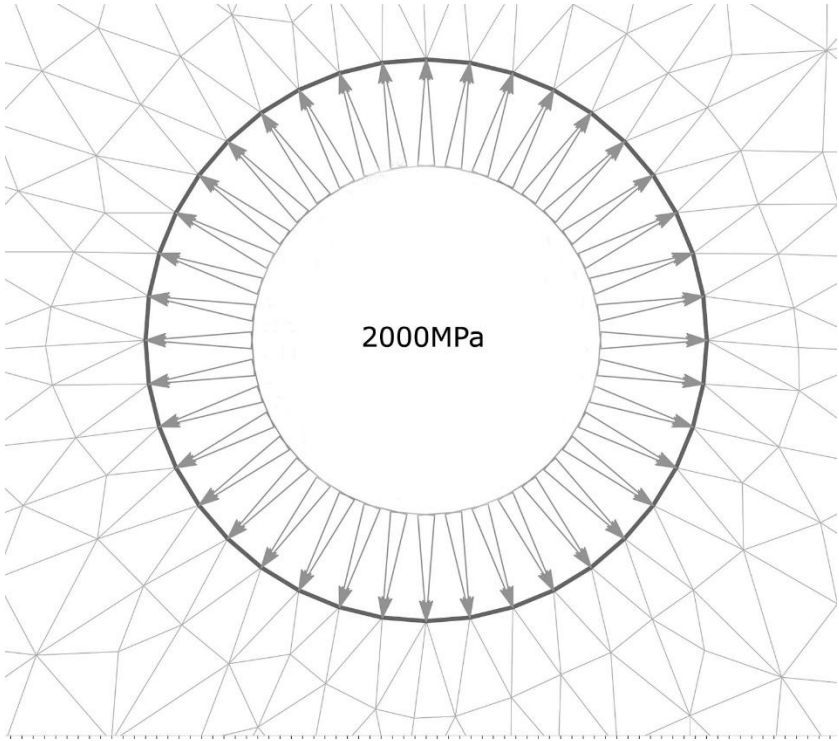


Figure 1. Compressive load on the borehole wall

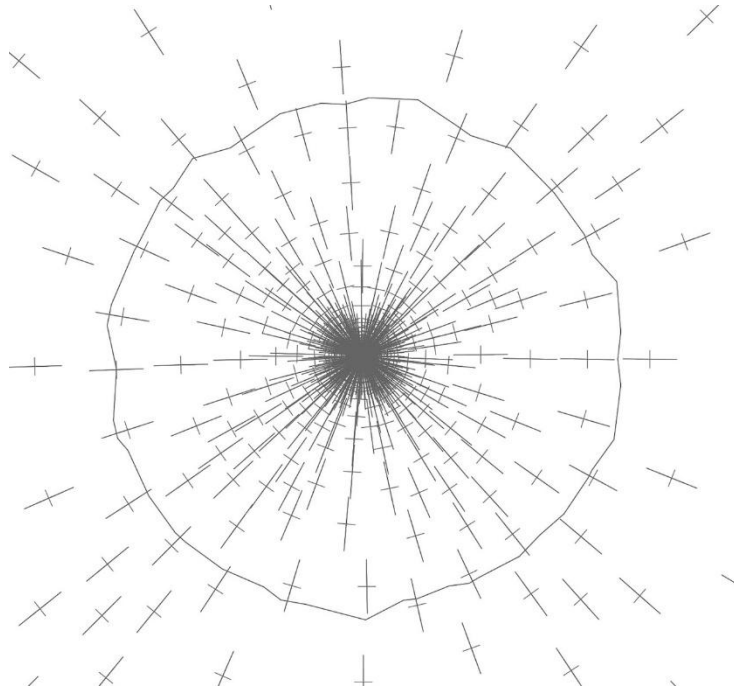


Figure 2. Directions of maximum principal stresses and the zone of tensile stress greater than the tensile strength of the rock during the primary compressive wave

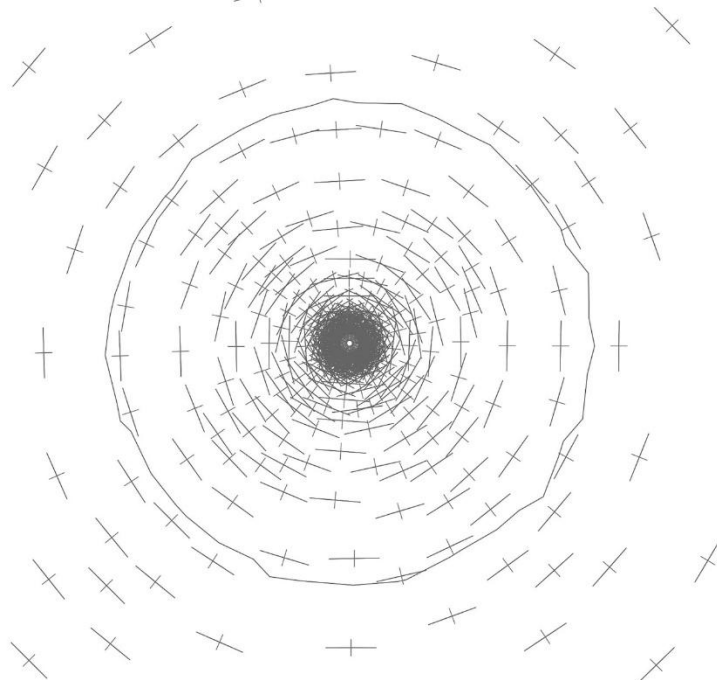


Figure 3. Directions of maximum principal stresses and the zone of tensile stress greater than the tensile strength of the rock during the return compressive wave

By applying the above formula, the values of tensile stress were calculated. As explained in previous texts, particles move apart in the direction of the minimum principal stresses, i.e. cracks are formed in the direction of the maximum principal stresses in the zone where tensile stresses are greater than the tensile strength (5 MPa), Figure 2. The application of load to the borehole wall

lasts several microseconds, after which the gas pressure in the borehole is maintained for several milliseconds. Since they have lost support, the particles return to their initial position, but they do not remain there; due to inertial forces they continue moving radially toward the center of the borehole. This causes a change in the stress state in the rock around the borehole. The tensile zone around the borehole remains the same but becomes somewhat smaller due to entropy in the process of energy transformation. The minimum and maximum stresses exchange places and, in the return compressive wave, cracks are formed perpendicular to the cracks generated during the primary compressive wave, Figure 3.

The previous analysis was carried out for the case where the rock mass is not loaded, that is, all stress components are zero or close to zero. In the rock where blasting is performed at some location in the Earth's crust there is always an initial stress state. Very rarely, or almost never, are the maximum and minimum stresses equal; rather, there are differences, sometimes considerable ones.

In the next analysis, an initial stress state was modeled with maximum principal stresses of 5 MPa and minimum principal stresses of 2 MPa. Immediately adjacent to the borehole, where stresses are several thousand MPa, this initial state has no influence. However, in the zone where the boundary of the tensile zone greater than the tensile strength is located, where stresses are several MPa, it has a significant influence. In Figure 4 it can be seen that the 5 MPa tensile zone is not circular but elliptical. The longer axis of the ellipse has the direction of the initial maximum principal stresses. Figure 5 shows the 5 MPa tensile zone under the action of the return compressive wave. The tensile zone is again elliptical, but the longer and shorter axes of the ellipse have exchanged places.

In these models, the influence of the explosion on the stress state of the rock mass was simulated under conditions without a free surface. In all blasting operations for the excavation of underground openings and in production

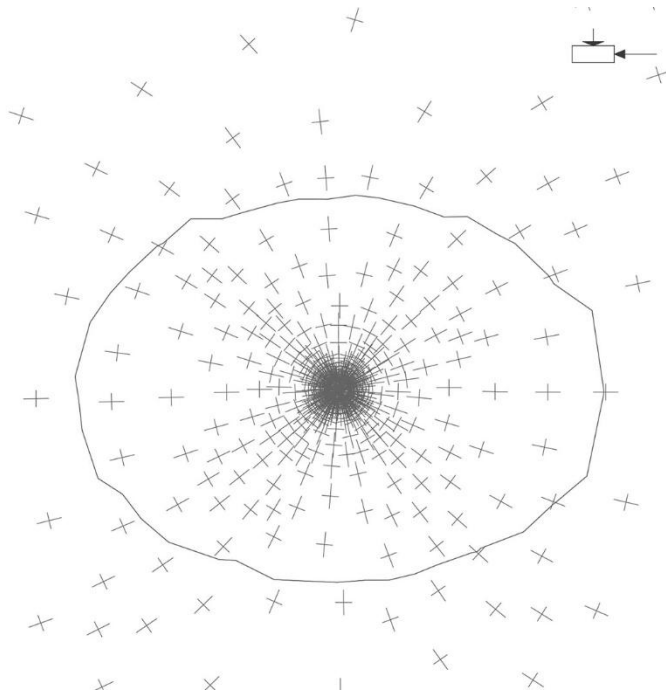


Figure 4. Directions of maximum principal stresses and the zone of tensile stress greater than the tensile strength of the rock during the primary compressive wave with an initial stress state

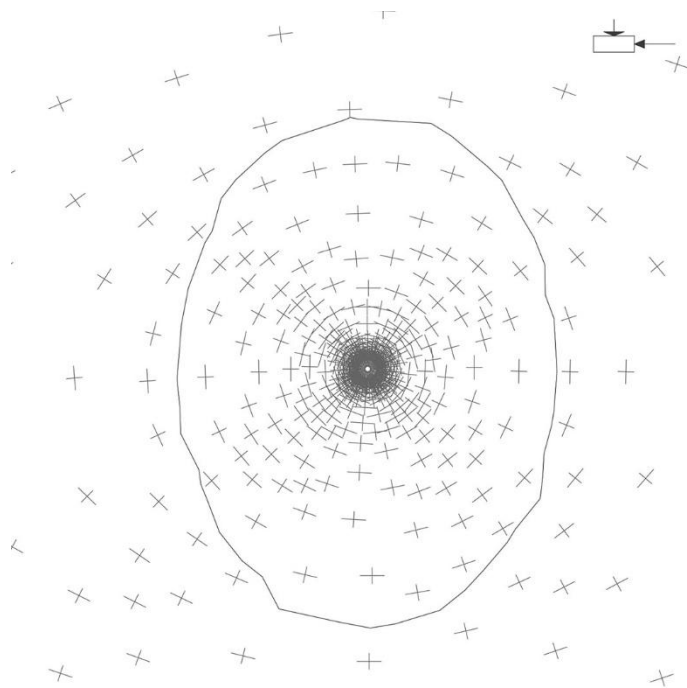


Figure 5. Directions of maximum principal stresses and the zone of tensile stress greater than the tensile strength of the rock during the return compressive wave with an initial stress state

blasting, a free surface exists as a basic prerequisite for successful blasting. Also, there is always an initial stress state that must be taken into account.

In the next experiment, with all other conditions remaining the same, a free surface was placed at a distance of 1 m from the blast hole, Figure 6. It is clearly visible that the free surface, by one of its parts, limits the zone with tensile stress greater than 5 MPa. The figure also shows the trajectories of potential tensile cracks. In the part where the free surface forms the boundary of the tensile zone greater than 5 MPa, radial tensile cracks reach the surface.

Having lost support, the particles return to their initial position, but they do not remain there; due to inertial forces they continue moving radially toward the center of the borehole. Figure 7 shows the modified zone with tensile stress greater than 5 MPa. The figure also shows the trajectories of potential tensile cracks, which in this phase are perpendicular to the cracks formed under the action of the primary compressive wave. After this, the marked area is divided into trapezoidal blocks which, in the zone bounded by the free surface and the first cracks on both sides that reach the surface, are ejected from their position by the action of the gases.

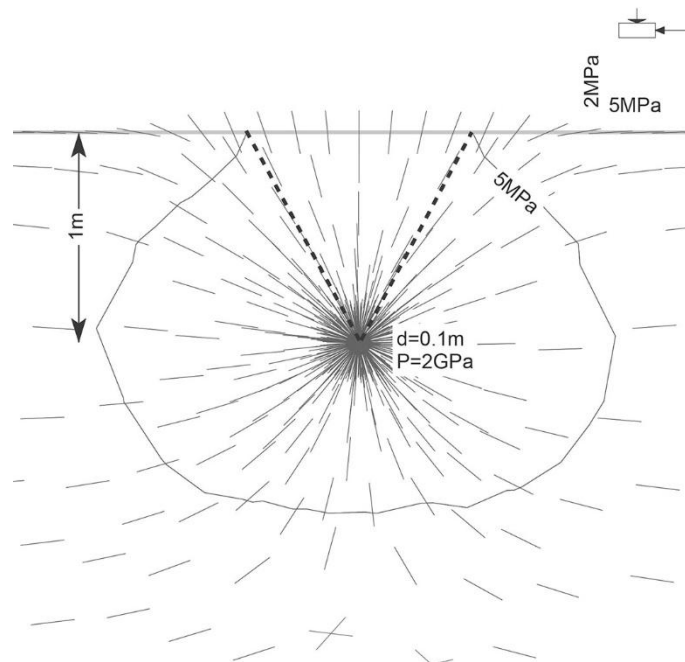


Figure 6. Trajectories of potential cracks and the zone of tensile stress greater than the tensile strength of the rock during the primary compressive wave with a free surface

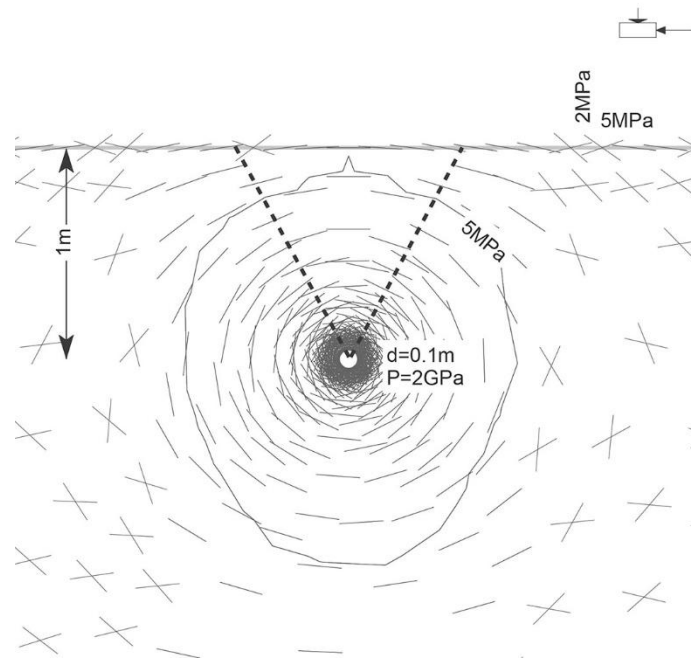


Figure 7. Trajectories of potential cracks and the zone of tensile stress greater than the tensile strength of the rock during the return compressive wave with a free surface