Energy evaluation of de-stress blasting

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Vyhodnotenie energie pri protiotrasových trhacích prácach

V článku sú prezentované teórie koncepcie napäťovo-pretvárnych stavov horninového masívu a komponenty uvoľnenej energie z geofyzikálneho hľadiska pri protiotrasových trhacích prácach. Pri týchto trhacích prácach je možné z priebehu premiestňovania energie dedukovať celý rad základných seizmických princípov.

Key words: rock massif, seismicity, de-stress blasting, potencial energy.

Introduction

De-stress blasting has been used for a number of years to overcome problems of highly stressed ground and rockbursts. It is generally considered that the blast fractures the rock, reducing its deformation modulus, and transfers the stress the adjecent rock structures.

De-stress blasting was first systematically used in South African gold mines in the 1950 to create a fractured zone in front of a longwall face (Roux et al., 1957). It was successful in reducing the number and severity of rockburst incidents. Also, there was a reduction in the number of casaulties and lost days` prroduction, hanging wall conditions improved, and there was a significant decrease in the number of bursts occuring on shift. However, the practice was discontinued apparently due to difficulties in drilling relatively long holes and loading explosives in highly stressed ground. Later it was reported that the energy liberated in a de-stress blast was no greater than the energy in the explosive itself (Cook et al., 1966). Seismic recordings of rockbursts had indicated that two-thirds of the liberated energy was in the vertical shear wave component. Similar recordings of de-stress and conventional blasts indicated that most of the energy was in the radial compresion wave and a negligible amount in the verticalshear wave.

In North American mines de-stressing is more widely practised and apparently more successful. De-stressing of sill pillars is done on a regular basis in the mines in the Coeur d`Alene district of northern Idaho. Normally, de-stressing takes place when the sill pillars have been reduced to 10÷12m thickness and are highly stressed. Another concept is rock preconditioning where drilling and blasting is done before stoping takes place, and hence the rock is under its lowest stress condition. It has been reported that preconditioning significantly reduced seismic activity during mining (Blake, 1982).

In Canadian mines de-stressing is normally practised in sill pillars in thin, steeply-dipping orebodies (Cook et al., 1983). Other applications of de-stressing techniques are in development openings including shafts and access openings.

In Czecho-Slovakia de-stressing is used in the hanging wall of the coal layers in the Ostrava coalfield. A de-stress blasting is applied in the extreme geological and tectonical deposite conditions for a purpose of the coal-gas-burst prevention (Lát, 1988; Protistresovy boj v OKR, 1980).

Rock mechanics concepts of de-stressing

Although de-stress blasting is successfully practiced in various mines in the world, there is very little theoretical background on what actually happens to the stress, displacement and energy during the blast. There is a general consensus that de-stressing softens the rock and reduces its effective elastic modulus. There are conflicting views on the importance of reducing stress and the stored strain energy within the de-stressed rock.

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Conditions of stress and strain, before and after de-stressing, were investigated by (Crouch, 1974). He postulated subcritical, critical and supercritical degrees of de-stressing as illustrated in *Fig.1*.

After de-stressing the final equilibrium stress-strain position is dependent on the intersection of the de-stress modulus line with the slope of the local mine stiffness. If its intersection lies within the stress-strain envelope (i.e., subcritical) the de-stress blast will ineffective. However, if the intersection lies outside the envelope (i.e., super-critical) excess energy will be released and eventually an equilibrium is achieved along the residual strength curve. From it follows that de-stressing is most effective when the pillar is near its point of failure and the excess energy released in a de-stress blast, or a rockburst is derived from the change in potential energy of the rock mass, not the stored strain energy in the pillar.

These studies have looked at the before and after effects of de-stressing, and not what happens during the blast itself. When an explosive is detonated in a borehole, a ressure or shock wave, radiates outwards producing radial fractures around the hole. Expanding gases open and extend these fractures and physically displace (i.e., throw) the rock fragments. In a de-stress blast the explosive is confined and a free face is normally some distance away. under these conditions the shock wave is the major source of rock fragmentation and most of the gases are probably vented through the borehole collar. Generally, the seismic energy in the shock wave is 5÷10% of the total chemical energy in the explosive.

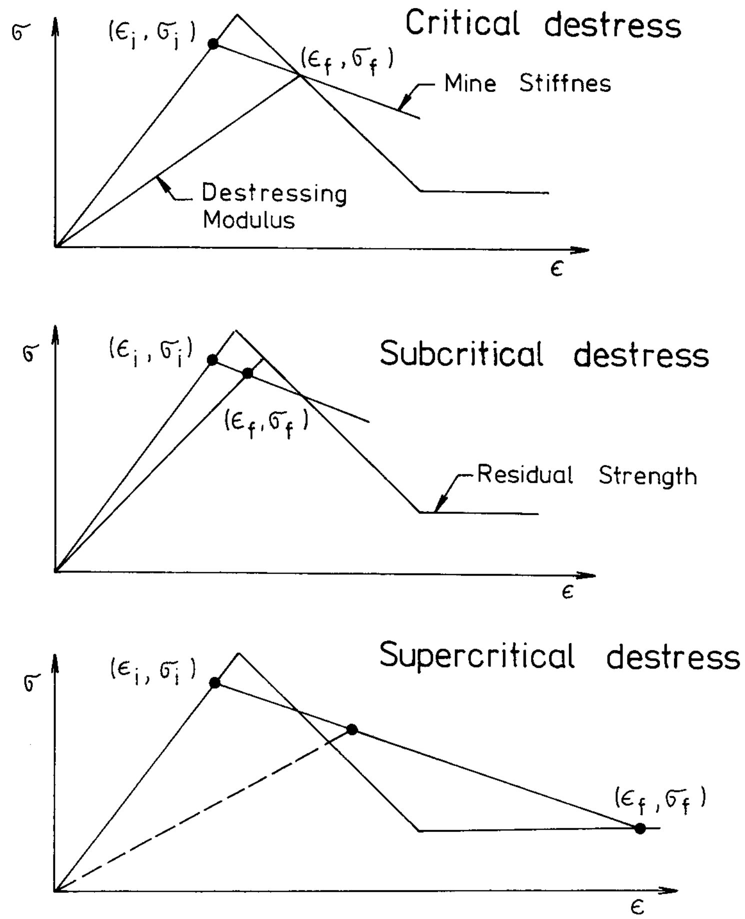


Fig.1. Different degrees of de-stressing.

In an elastic medium the increase in radial stress, σ_r, can be expressed by equation

$$\sigma_r = P\,(r/R)^2\,, \qquad (1)$$

where P is borehole pressure, r is borehole radius and R is distance from the borehole.

For commercial explosives the borehole pressure is in the range of 200 to 8 000MPa (Coates, 1981). Equation 1 indicates that the change in radial stress decreases rapidly away from the borehole. When $R = 10r$ the change in stress is only 1% of the borehole pressure. For typical hardrocks the power coefficient is more likely to be 2.5 than 2, indicating greater attenuation of the shock wave.

The change in radial stress can also be expressed by equation

$$\sigma_r = \rho\, c_P\, v\,, \qquad (2)$$

where ρ is rock density, c_P is pressure wave velocity and v is particle velocity.

The velocity of crack propagation is only about 15 to 40% that of the pressure wave velocity (Coates, 1981). Hence, initially the pillar only experiences an increase in stress without a reduction in alastic modulus due to fracturing, which occurs later.

The imposition of a dynamic load due to explosives on top of a statistic load can now be looked at in terms of stress-displacement on a pillar as shown in *Fig.2*. *Fig.2a* shows the pressure wave radiating from the de-stress boreholes. By the time these waves hit the hanging wall and footwall they have probably coalesced into a straight front. *Fig.2b* shows the mechanical equivalent of a de-stress blast with a thin flat jack at mid-pillar height which can be instantaneously pressurized. This is not an exact duplication since the explosive pressure wave is transient. *Fig.2c* shows the stress-displacement history of the hanging wall or footwall.

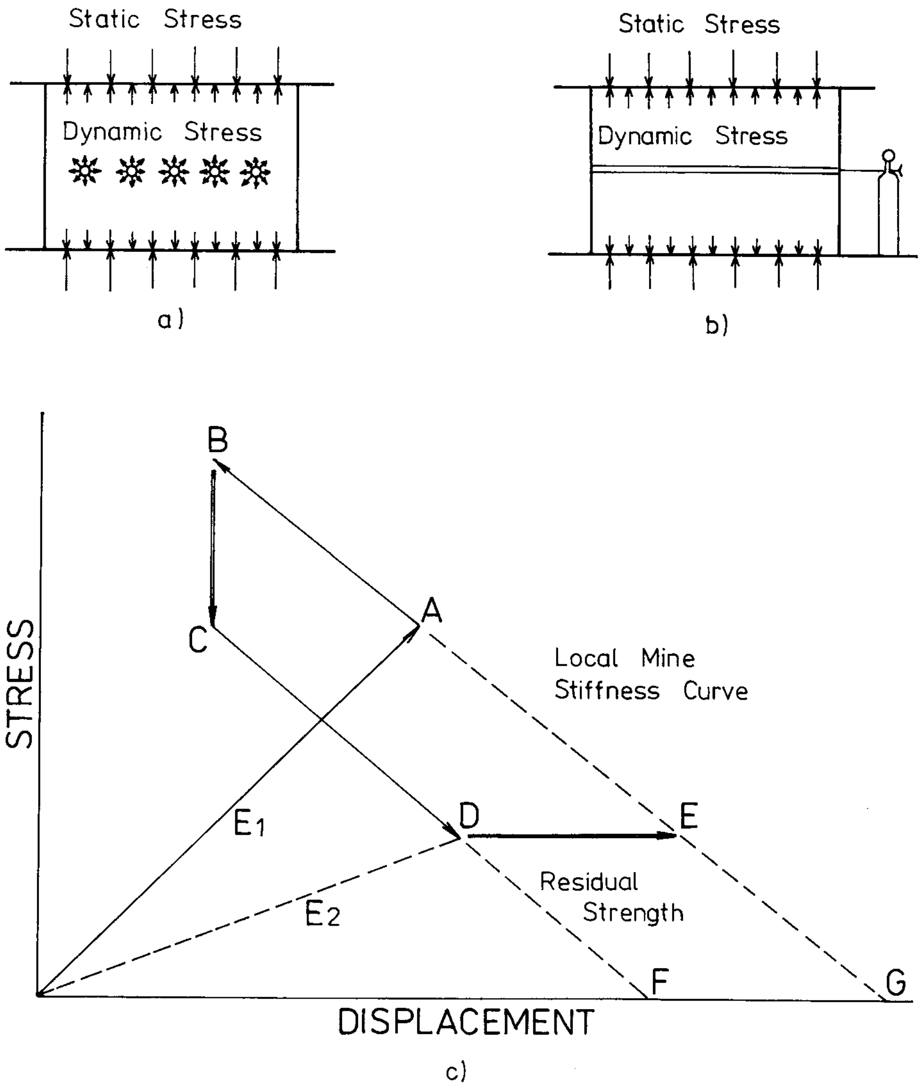


Fig.2. Stress-displacement history of a pillar during a de-stress blast.

The sequence of events during a de-stress blast are probably as follows (Sedlak, 1993):

a) Just before the blast the pillar is under static stress-displacement conditions at point *A* with an elastic modulus E_1.

b) After detonation the pressure wave radiates outwards and increases the stress on the hanging wall and footwall, similar to that obtained by pressurizing the flat jack. This internal pressure will force the hanging wall or footwall apart along the line *AB* which is the slope of the local mine stiffness curve.

c) Fracturing occurs after the pressure wave, similar to rupturing of the flat jack. There will probably be a sudden stress drop to point *C* after the pressure wave passes through, of magnitude probably equal to the increase in stress due to the explosive.

This will be followed by a further stress reduction as the hanging wall and footwall converge. The pillar will have a reduced elastic modulus E_2 due to fracturing which is reached at point *D*.

d) Equilibrium has not yet been reached and displacement will continue along the residual strength curve until it intersects the local mine stiffness curve at point *E*.

e) If it was a production rather than a de-stress blast, then unloading would continue along line *DF* until zero stress is achieved. However, again, equilibrium is not reached until the hanging wall and footwall converge to point *G* which is the intersection with the local mine stiffness curve.

Energy evaluation

The energy components involved in the de-stress blast can be examined. The energy balance due to mining can be expressed by equation (Salamon, 1974)

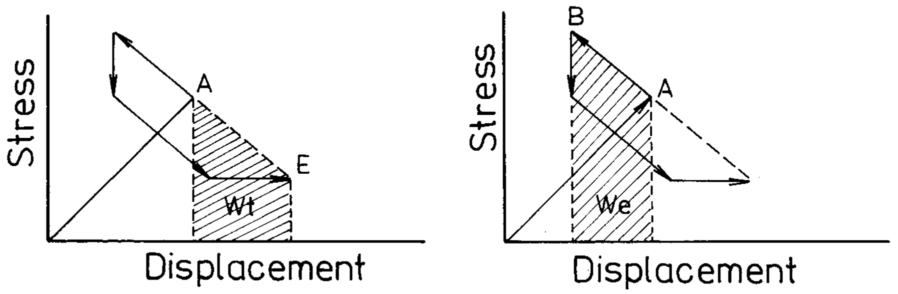
$$W_t + U_m = U_c + W_r \ , \qquad (3)$$

where W_t is change in potential energy, U_m is stored strain energy in mined material, U_c is increased strain energy in surrounding rock and W_r is realised energy.

In the absence of any support, such as backfill, the released energy consists of the stored strain energy in the mined material, U_m, and seismic energy W_k, which vibrates the rock mass. In a de-stress blast there will be additional energy components and equation 3 becomes

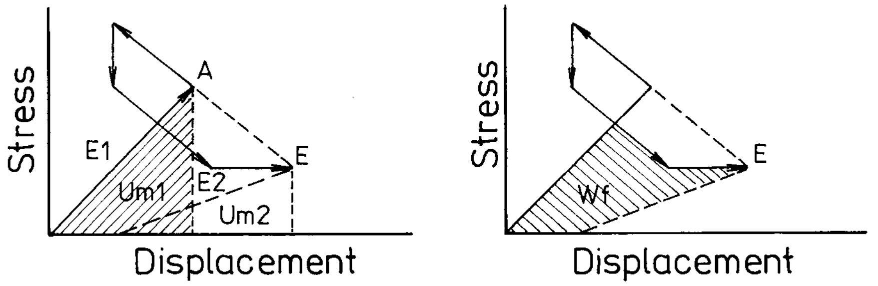
$$W_t + U_{m1} + W_e = U_c + U_{m2} + W_f + W_k \ , \qquad (4)$$

where U_{m1} is stored strain energy before de-stressing, U_{m2} is stored strain energy after de-stressing, W_e is explosive energy and W_f is energy nosumed in fracturing the rock.



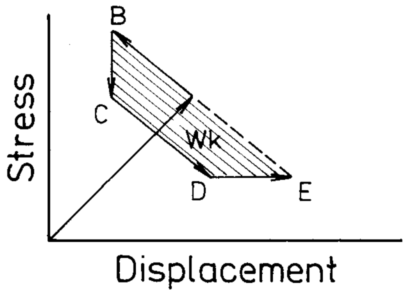
a) Net change in potential energy.

b) Explosive energy to push back walls.



c) Stored strain energies before and after destressing.

d) Energy consumed (excluding explosive) to facture pillar.



e) Seismic energy released.

Fig.3. Energy components during a de-stress blast.

These energy components are illustrated in *Fig.3*. The net change in potential energy is the area under the *AB* line as shown in *Fig.3).* Explosive energy used to push back the hanging wall and footwall is the area under the *AB* line as in *Fig.3b.* There is an additional explosive energy, such as in heat expanding gases, which is not accounted for and does not effect the energy balance. Stored strain energies before and after de-stressing are shown in *Fig.3c* and represent the stress and elastic modulus at points *A* and *E*, respectively. The energy consumed in fracturing the rock is the area under the stress-displacement envelope minus the stored strain energy remaining in the fractured pillar as shown in *Fig.3d.* The seismic energy released is the area outside the stress-displacement envelope as shown in *Fig.3e.* It includes two components: that due to the explosive which pushed back the hanging wall or footwall, and that due to the change in potential energy of the rock mass.

Conclusion

Although this is a simplistic view of what happens during a de-stress blast a number of fundamental deductions can be made from the stress-displacement history in *Fig.2* and the energy components in *Fig.3*.

a) The major function of de-stressing is to reduce the potential energy of the surrounding rock mass, (Crouch, 1974). This is achieved by reducing the modulus and stress on the pillar. In *Fig.2c* and *3a* the reduction in potential energy is from point *A* to point *E*. A further reduction in potential energy will occur when mining the de-stressed pillar until point *G* is reached. The closer point *E* is to point *G* the more effective is the de-stress blast, although this must be balanced against the practical difficulties of mining extremely fractured ground.

b) Irrespective of whether the pillar is de-stressed then mined, or is removed by production blasts, or has failed due to a rockburst, the endpoint is always the same, namely point *G* in *Fig.2c.*

c) The stored strain energy in the pillar is used in the fracturing process and is not released as seismic energy.

d) The explosive as well as initiating the fracture process is used in pushing back the hanging wall or footwall.

e) The seismic energy released is partly due to the explosive and partly due to the change in potential energy. It is released during the latter part of the cycle.

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