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On the dilatant behavior of rocks under general triaxial compression conditions

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The phenomenon of dilatancy in rocks is of considerable practical importance since it is associated with possible premonitory signs for earthquakes, mining-induced rock-bursts and mine collapses. In the field, dilatancy is manifested by excessive crustal deformation (rapid uplift rates, anomalous ground tilts), changes in density of the earth and in the gravity field. It also is responsible for acoustic emission, changes in the velocity of seismic waves, seismic anisotropy, changes in pore pressure and flow rate, lowering of the groundwater level, emission of radon and other gases, and changes in the magnetic field and electrical resistivity of the earth.

In the 1970s Mogi was the first to reveal the effect of, independently, confining pressure, intermediate principal stress and minimum principal stress on the differential stress-axial strain characteristics of rocks. The ultimate goal of the present studies was to reveal the effect of confining pressure, the effect of σ_2 and the effect of σ_3 on the volumetric deformation mode and the dilatant behavior of rocks. There is no doubt that volumetric strain is a quantity that provides much more information about the mechanical behavior of rocks than the axial strain alone.

Samples of four fine- to coarse-grained sandstones were subjected to loading and unloading tests to and from different levels of differential stress $(\sigma_1 - \sigma_3)$ in the pre- and post-peak stage under uniaxial compression (UC), conventional triaxial compression (CTC) and true triaxial compression (TTC) conditions. The CTC tests were carried out at confining pressures (p) equal to 12.5, 25.0, 37.5, 50.0 and 62.5 MPa. In the TTC tests the minimum principal stress (σ_3) was equal to 25.0 MPa and the intermediate principal stress (σ_2) was 1.5, 2 and 2.5 times higher than σ_3, or the intermediate principal stress was equal to 62.5 MPa and the minimum principal stress was equal to $0.4\sigma_2$, $0.6\sigma_2$ and $0.8\sigma_2$. In all the tests rectangular parallelepiped (prismatic) samples of the dimensions 35 mm $\times$ 35 mm $\times$ 70 mm were used. The triaxial tests were carried out using a Mogi-type servocontrolled true triaxial compression apparatus. In the triaxial cell of the apparatus, three principal stresses can be generated in rock samples independently. The maximum and intermediate stresses are each induced by a pair of rigid pistons, while the minimum principal stress is induced by oil pressure.

As a result of experimental studies, the threshold of absolute dilatancy, ultimate strength, stress at faulting, stress drop accompanying faulting, ductility, volumetric strain at the threshold of dilatancy and volumetric strain at the peak stress have been determined and dependence of these characteristic stress levels and strain quantities on confining pressure, intermediate principal stress and minimum principal stress has been determined. In addition, the relationship between permanent volumetric strain and differential stress below and above the threshold of absolute dilatancy has been determined.

Based on the TTC test results it has been shown that contrary to the effect normally observed when confining pressure is increased in CTC tests, increasing the intermediate principal stress leads to a decrease in the ductility of rocks. The effect of dilatancy was strongly hampered too. Rock samples behaved in a highly brittle manner and underwent faulting just at the peak differential stress or at a very early post-peak stage. Faulting was very violent, accompanied by a release of a great amount of the elastic strain energy, a very strong acoustic effect and a large stress drop.

The behavior of the rocks tested under axisymmetric triaxial stress conditions (CTC tests) was totally different. In the pre-peak stage, the rocks showed ductility that was much higher than under asymmetric stress conditions. After strength failure they continued to deform, at a slightly decreasing differential stress, without gross-fracturing, while at the same time undergoing a significant increase in volume. Faulting occurred in a well-advanced post-peak region. It was accompanied by a small immediate stress drop. No audible acoustic effect could be detected.

The effect of intermediate principal stress and minimum principal stress on ultimate strength and threshold of absolute dilatancy is similar; both σ_2 and σ_3 cause some increase in these two characteristic stress levels. However, the effect of σ_2 and σ_3 on the deformational properties is different. While an increase in σ_2 causes the rock to behave in an increasingly brittle manner, an increase in σ_3 causes, just as confining pressure does, an increase in ductility. Higher ductility manifested itself also in smaller values of the faulting ratio and smaller immediate stress drops during faulting.