Faults are shear failures in the Earth's crust, many mechanical aspects of which can be dealt with by Coulomb-Mohr's theory of brittle shear failure in a regime of compressive effective stresses.

In this chapter we present the principles of the theory, including the effective stress control, the condition for the onset of faulting, the orientation of the fault planes, and the 'double gliding model'. Furthermore, Anderson's fault classification, the curvature of faults, the segmentary development of faults, and the contemporaneous formation of multiple fault sets are discussed in terms of Coulomb-Mohr's theory. The chapter concludes with an assessment of the range of applicability of the theory.

4.1 The critical state of stress

In the preceding chapter we discussed the modes of shear failure observed in the laboratory and noted that the formation of sample-size shear fractures or shear bands required that the differential stress $\sigma_1 - \sigma_3$ (i.e., twice the maximum shear stress $\tau_{max}$) attains a certain critical value. In the brittle regime, this value is not a material constant; it still depends, for a given rock, on the total pressure $\sigma$, the pore fluid pressure $p$, and, to some degree, on the intermediate principal stress $\sigma_2$. Effects of variations in the rates of straining or loading may be neglected in the brittle regime — at least as long as these variations remain within a reasonable range. Therefore, the formation of shear fractures or shear bands under brittle deformation conditions requires that the stresses satisfy a limit condition of the general form:

$$|\tau_{max}| = (\sigma_1 - \sigma_3)/2 = f(\sigma, p, \sigma_\Pi) \quad (4.1)$$

where

$$\sigma = (\sigma_1 + \sigma_\Pi + \sigma_3)/3 \quad (4.2)$$

In reviewing the failure types observed in rock tests (Section 3.3), we did not specify $\sigma$ and $p$ as separate parameters controlling the shear strength $\tau_{max}$ but related the shear strength to a single pressure parameter — Terzaghi's effective mean pressure (Eq.1.20):

$$\sigma' = \sigma - p \quad (4.3)$$

By replacing the total intermediate principal stress $\sigma_\Pi$ by the effective stress $\sigma'_\Pi$, the limit condition (4.1) is reduced to

$$|\tau_{max}| = (\sigma_1 - \sigma_3)/2 = f(\sigma', \sigma'_\Pi) \quad (4.4)$$

where $f$ is a monotonically increasing function of the effective pressure $\sigma'$. 

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The Effective Stress Principle. The failure criterium (4.4) implies that the pressure of the pore fluid has no influence on the shear failure of a fluid-saturated rock and thus behaves as a truly neutral stress which has to be subtracted from the total rock pressure. This is known as the Principle of Effective Stress. It was found to account remarkably well for the shear strength of a great variety of fluid-saturated rocks that were tested over a wide range of effective confining pressures in laboratories all over the world. Based on this experimental corroboration, the concept of Terzaghi's effective stresses controlling the shearing strength of rocks has found wide acceptance. And yet our understanding of the mechanical basis of this concept is still unsatisfactory, in spite of much research effort since the principle was first stated by Terzaghi (1923) in soil mechanics. Nevertheless, the principle can be proven for at least two idealised rock types: rocks with a solid skeleton consisting of grains with intergranular point contacts and rocks with a continuous uniformly elastic skeleton.

We consider, in both cases, a volume element of the porous rock, the dimensions of which are very large compared to the dimensions of pores, grains or other characteristic dimensions of the microstructure of the skeleton. The element, which is very schematically shown in Fig.4.1, is bounded by planar surfaces which cut the skeleton at random. The parts of the boundary that lie inside the solid material are denoted by ss (solid/solid), the fluid portions by ff (fluid/ fluid), and the huge internal surface of the skeleton by fs (fluid/ solid). The total load on the element may be considered as being applied by closely fitting plates, of which only the top plate is shown in the figure. The total loading stress vector $\sigma$ has a normal component $\sigma_\perp$ and a shear component $\tau$.

![Fig.4.1 Total stress load on a porous volume element](image)