# In-Situ Measurements in Jointed Rock Masses as a Means to Study their Failure Behaviour

L. Müller-Salzburg and H. P. Götz

The strength of rock masses, in which we carry out engineering constructions is much lower than we generally believe. Fracturing and undesirably large deformations occur frequently. This has been demonstrated by a number of recent catastrophic failures. Research on rock fracture is therefore a central aspect of rock mechanics.

Due to inhomogeneity and the anisotropic nature of rock masses, their large number of discontinuities and the large dimension of constructions in rock fracturing of such rock masses shows essential differences in comparison to other materials.

Slopes for example fail through progressive fracturing (Fig.1) associated with relatively large deformations. The foundation of a dam cannot only be regarded as case of simple loading, but involves also load redistribution in a material which has already highly been stressed in its history. In tunnelling no external load is applied, nevertheless fracturing can be very intense. A primary triaxial state of stress is altered and a secondary essentially biaxial stress field results.

Rock is a material of highly complex mechanical behaviour. None of the known fracture theories can exactly describe its failure characteristics. Some of the theories may apply to a solid rock element, but are not very useful with regard to the larger rock mass. An investigation of the mechanical rock properties tells us very little about the mechanical behaviour of rock masses. Those differences are due to the presence of discontinuities such as joints, bedding planes and shistosity. They split the rock mass up in a large number of individual elements with more or less planar boundaries. The partial movements which characterize the internal kinematic of such a system are orientation dependant. This determines the highly anisotropic nature of the jointed medium with regard to all its mechanical properties. The fact, that the joints are in most cases filled by water further complicates the picture, as the solid and the liquid phase in this two phase system are in constant mechanical interaction.

The discontinuities of this strange medium are the results of a long geological history during which the rock mass has been deformed and fractured through the action of tectonic stresses above its strength. To test the jointed rock mass at the large scale, necessary for statistical validity the testing machine has, for example, be taken into the tunnel. Because it is only there where we can test a sample several cubic meters in size. By carrying out such in situ tests we obtain stress-strain curves (Fig. 2), which are indeed only the last portion of a more complete curve, expressing the long deformation history of the material.

Most engineers working with other materials have little interest in the fractured material. Their main interest besides determination of yield points etc. is the load capacity. If, however, the rock mechanics engineer wants to determine under which mechanical conditions his construction in rock will fail than we have to look for failure criteria for the already highly fractured material which we find in nature. These criteria are vastly complex and little known.

The separation of the rock mass , in bodies of cubic or rhombic shape, so-called rock elements, give the material its large inner mobility; its modulii of elasticity and deformation, and its strength are much lower than the same properties of a single rock element. Its strength is only a residual strength - the strength of a system of blocs, which is mainly a cause of friction between adjoining elements. The strength of a rock mass may therefore be called an apparent strength, as its elastic modulus is a fictitious modulus. Plasticity and creep in reality are pseudo-plasticity and pseudo-creep determined by relative movements of the single rock elements. Characteristic

for rock masses in their failure through simultaneous flow and fracture. In rock elements which are small in comparison with the scale at which the material properties change it is possible to regard this type of deformation as a space continuous process. In rock mechanics therefore the laboratory experiment has to be replaced by large scale in-situ testing (Fig. 3). For the same reasons all measurements in rock masses have to be at a large scale of usually several tens of meters (Fig. 4) so that measuring techniques had to be developed.

The stress distribution in such a three dimensional mosaic of joint blocs must be really chaotic. Only at a larger scale can average stresses reasonably be defined, but seldom be measured. Due to this complex behaviour the measurement of deformations assumes a larger role in rock mechanics than stress measurements. We, therefore, intend to use deformations rather than stresses in our failure criteria, because those can more readily be measured in nature or in buildings . Such criteria predict failure without knowledge of material strength and loading conditions.

We try to establish such empirical laws by model tests on regularly jointed model bodies. Those tests reveal rather interesting relationships.

It is interesting for example, that under certain conditions in a material which is not completely separated by the joints, the strength can be lower than in a material separated completely by throughgoing joints. In such a case stress concentrations at the edges of joints are an important factor. Fracturing may partially occur along existing discontinuities, but they also cause separation of the material bridges. Therefore we may differenciate between joint steps, joint steps and fractures, and joints substituting another set of joints (Fig. 5). Another curious experience is the fact, that rock material is much more sensitive to unloading than to additional loading during stress redistribution.

Depending on the direction of loading the same rock material may show ductile or brittle behaviour, this means that failure may be preceded by large deformation or not.

Transverse expansion only offers a limited criteria for approaching fracture or yielding; more reliable indicator in this respect is a version of transverse expansion measured normal to existing joint sets rather than directions of principal stresses. In the discontinuum the directions of largest and smallest deformations do not correspond with the directions of the principal stresses.

The ratio of largest and smallest expansion can yield a further criteria. This ratio will be close to 0,5 if the stress-strain curves is reaching the yield point, which we would rather like to define as a stiffness limit. This expresses dilatation of the jointed mass which is what ROS and EICHINGER have been calling the material damage.

On two examples measuring systems will now be discussed which monitor deformations necessary to guarantee the safety of constructions.

It should be a principle to start deformation measurements early even before begin of construction work, to study the influence of different construction phases (e.g. the excavation). The figure showing the deformation measuring system for a dam is generalized , in practice it has to be related to the local joint pattern, shistocity and fault orientations. The measurements are carried out within the rock mass of the foundation at a large scale with extensometers measuring parallel to the bore-hole axis and with chain deflectometers measuring in a normal direction to the bore-hole axis.

The measuring system in underground openings yields a radial field of deformations obtained by the use of extensometers and chain deflectometers; pressure cells register the stresses developing in the lining. The results are used to study not only the failure behaviour, but also for the economical dimensioning of the lining in tunnels constructed according to new tunnelling methods.

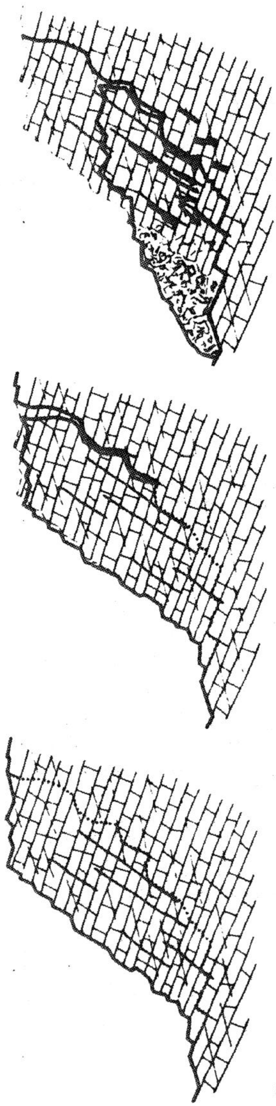

FIG.1 PROGRESSIVE FAILURE IN ROCK

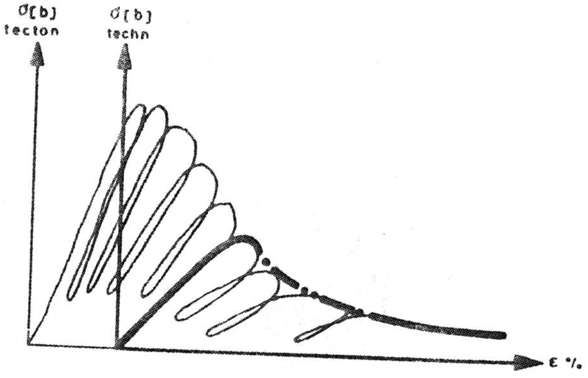

FIG. 2 STRESS-STRAIN CURVE

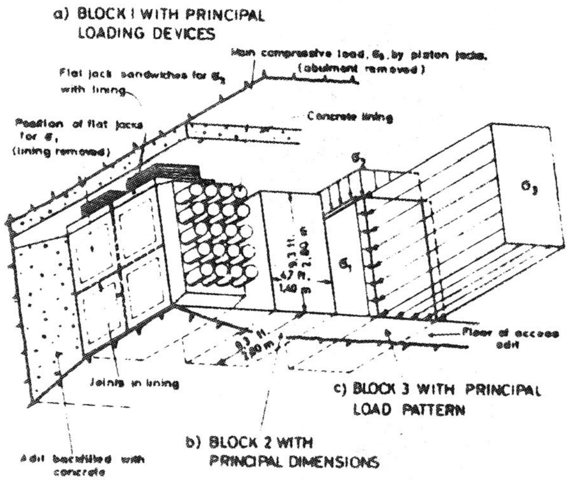

FIG. 3 IN-SITU TRIAXIAL COMPRESSION TESTS ON ROCK MASS

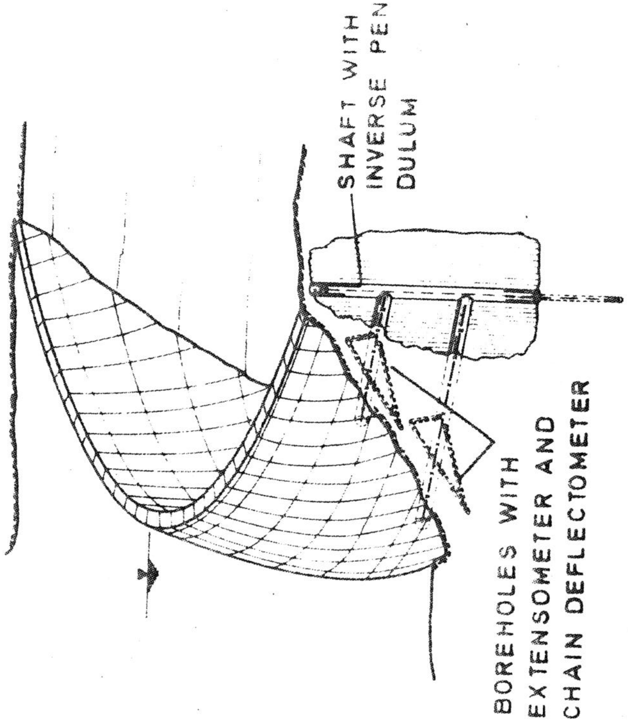

FIG. 4 MEASUREMENT SYSTEM IN AN *ABUTMENT OF O DAM*

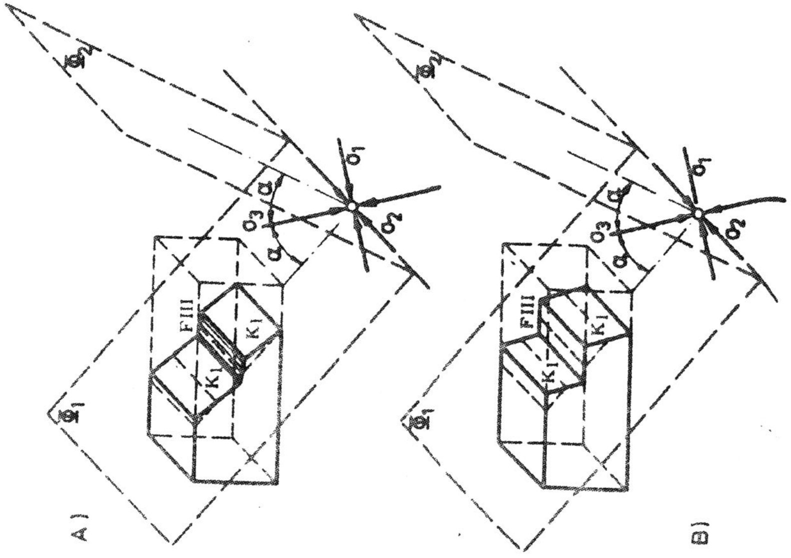

*FIG. 5 A) JOINT STEP AND FRACTURE*
*B) JOINT STEP*