

## C H A P T E R - I

## INTRODUCTION

1.0 General:

The material rock is the product of perpetual natural process spread over extremely large time scale. The mechanical behaviour of rock is too complex and a lack of clear understanding prevails among scientists and engineers. Only recently owing to imperative need to evaluate the stability of structures particularly in the field of mining and civil engineering attention has been focussed on understanding the failure mechanism in rocks. From whatever data and information available on mechanical behaviour of rocks it is evident that an independent approach is necessary to be developed ofcourse keeping in view the existing theoretical background and experimental investigations. The material rock cannot be identified to evince either elastic or plastic or viscoelastic characteristics and is not amenable to the theoretical analysis purely on the basis of classical theories of elasticity or plasticity. It has been recognised that the failure in rock is largely as a consequence of stresses locked in during the process of formation. In general rock fail at the proportional limit of the elasticity or some what beyond it, very near to its yield point. If rocks deform plastically before failure it is referred to as 'ductile' failure while if it fails with no previous plastic deformation it is referred to as 'brittle' failure. The term 'fracture' implies the brittle failure with

complete loss of cohesion across the surface. Most rocks exhibit fracture, therefore the plastic deformation and the degree of plasticity is relatively very small. One of the inherent characteristics of rocks is the presence of microcracks which under stress triggers the failure process in rocks. The approach to delineate the mechanics of failure in rock should therefore be centered around the stresses locked in the cracks and their initiation and propagation.

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### 1.1 Rock as a material:

Rock is a material constituted of an aggregate of crystals and amorphous particles of minerals jointed by cementitious material. The composition of most rocks is non-homogeneous, delineation of which is attempted through the study of crystals. Deformation of the crystals provide evidence concerning the deformation to which rock is subjected. However the overall mechanical properties of rock depends upon varieties of structural features like cracks, joints, bedding planes at different orientations. Notwithstanding the properties of the individual particles may differ widely from one particle to another, but they and their grain boundries between them interact sufficiently in random manner to produce average homogeneous properties. These average properties are not necessarily isotropic because the processes of rock formation and alteration often align the structural particles so that their interaction is random with respect to size, composition and distribution but not with respect to their anisotropy. Nevertheless the rock reveals gross anisotropic properties which can be regarded as homogeneous. The loads applied to the rock mass are generally due to

gravity and compressive stresses are encountered more often than not. Under these conditions the most important factor in connection with the properties and continuity of a rock mass is the friction between surfaces of cracks and joints of all sizes in the rock. If conditions are such that sliding is not possible on any surfaces the system can be treated to a good approximation as continuum of rock with average properties. If sliding is possible on any surfaces the system can be treated as a system of discrete elements separated by the surfaces and with frictional boundary conditions over them.

#### 1.1.1 Origin and formation of rock:

The term 'rock as used in engineering geology means a compact, semihard to hard mass of natural material composed of one or several minerals. Geologists have classified the earth rocks on the basis of origin in to three major groups: Igneous, Sedimentary and Metamorphic. Igneous rocks are products of melts called 'magma' generated at some unknown number of miles below the earth's surface. Magma rises from the zone of origin and may escape through conduits to the surface and spread outward as a 'lavaflow' until cooling solidifies the entire mass. At depth much magma is injected in to the surrounding rock where it stagnates and crystallizes in homogeneous masses of varying shapes and dimensions. Rocks developing under each of these conditions are recognised by their distinctive texture and more predominantly by their structure. When the products of disintegration and decomposition of any rock type are

transported, redeposited and partly further consolidated or sedimented in to a new rock type, the resulting material is classified as sedimentary rock. This classification also includes those rocks which result from chemical precipitation or deposition of organic remains in water. Deposits laid down by sedimentary action usually can be recognised by their layered (stratified) structures as contrasted to the usual massive structure of igneous rocks. Besides both animal and plant fossils are commonly found in sedimentary rocks whereas they are non-existent in igneous rocks. Rocks formed by the complete or incomplete recrystallization i.e. change in shape or composition of igneous or sedimentary rocks by high temperatures, high pressures and or high shearing stresses are called metamorphic rocks. A platy or foliated structure in such rocks indicated that high shearing stresses have been the principal agency in their formation. Foliation is not always visible by naked eye but individual grains may exhibit strain lines under the microscope. Metamorphic rocks formed without intense shear action have massive structure.

#### 1.1.2 Structure of rock:

Structure is a distinctive feature of all rocks as it supplies certain characterizing aspects which are independent of the rock's composition and texture. All regions in rocks are separated by boundaries and it is these boundaries in particular that defines the structure in a body of rock. The term 'structure' is used in more than one sense and is applied to relatively large scale features which are produced during the development of the rock as well as to the

deformed attitude of strata. There are igneous and metamorphic structures as well as those which are typical sediments. They are characterizing attributes identifying some aspect of the environment which produced the rock, not to be associated with those developed through later deformations.

#### 1.1.2.1 Primary structure of rock:

Primary structures consist of features known to be produced under special conditions during the initial development of the rock or sediments. They are the indicators of certain environmental conditions identifying the nature of the rock body in terms of flow lines, pillow structures, tubular vessicles, columnar jointing, ripple mark, mud crack and relict structures etc.

#### 1.1.2.2 Secondary structure of rock:

The structures which are secondary in origin developed under circumstances which were brought about after the solidification of the rock mass are designated as secondary structure. Principal among such secondary structures are those which result from the application of stress against the rock mass viz joints, folds, faults, fractures, cleavage and schistosity. Other secondary structures appear to be produced through chemical activity or erosion viz veins, solution caves, stylolites, geodes and unconformity etc.

#### 1.1.3 Failure in rock:

The failure in polycrystalline materials like rocks is predominantly different than crystalline materials

or metals as the former is having anisotropic particles and later having isotropic particles. The brittle fracture in rocks is the outcome of the energy stored in the particles of the material. It takes place at microstructural level i.e. on a plane dependent on microstructure.

Microstructure is the fundamental criteria for failure in rocks. The microstructural behaviour at failure can be understood by the packing of the particles. The post elastic limit behaviour shows that when densely packed particles move over densely packed particles high concentrations develop at points due to rotation and sliding of the particles. The rotation of the particles are predominant in brittle materials while sliding in ductile materials. Due to rotation of the particles and their shapes the contacts are becoming lower causing high stress concentrations. The rotation of the particles in elastic materials requires space to rotate in. Either it is provided by inherent crack or is created out of its rotation. It is interesting to note that in elastic material there is no loss of energy until the time comes there is a burst of energy stored causing rupture or fracture at a plane of weakness. In general the failure starts at a moment when at a certain point of a body a particular combination of parameters such as stress, strain etc. reaches a definite critical value.

## 1.2 Mechanical characteristics of rock material :

The mechanical characteristics of rock material depends on composition and constitution of minerals forming rock as also on structural and textural features of rock material. Interpretation of these characteristics envisages investigation of the state of stress, stress-strain behaviour and failure conditions in the rock.

### 1.2.1 State of stress in a rock mass:

The natural state of stress that exist at a point within a rock mass is a function of all the previous geologic processes that have acted on the mass. It is impossible to know with any degree of accuracy the stresses in a rock mass from the knowledge of geology. It is therefore conventional to regard the state of stress as virgin stresses. The virgin stresses include component of gravitational stresses and latent stresses. The virgin state of stress is also altering owing to variety of natural and environmental processes. The latent stresses which may have originated in processes such as crystalization, metamorphism, sedimentation, consolidation and dehydration and some may have originated due to tectonic forces and crustal movements. Thus the state of stress is extremely variable in magnitude and direction.

### 1.2.2 Stress-strain characteristics:

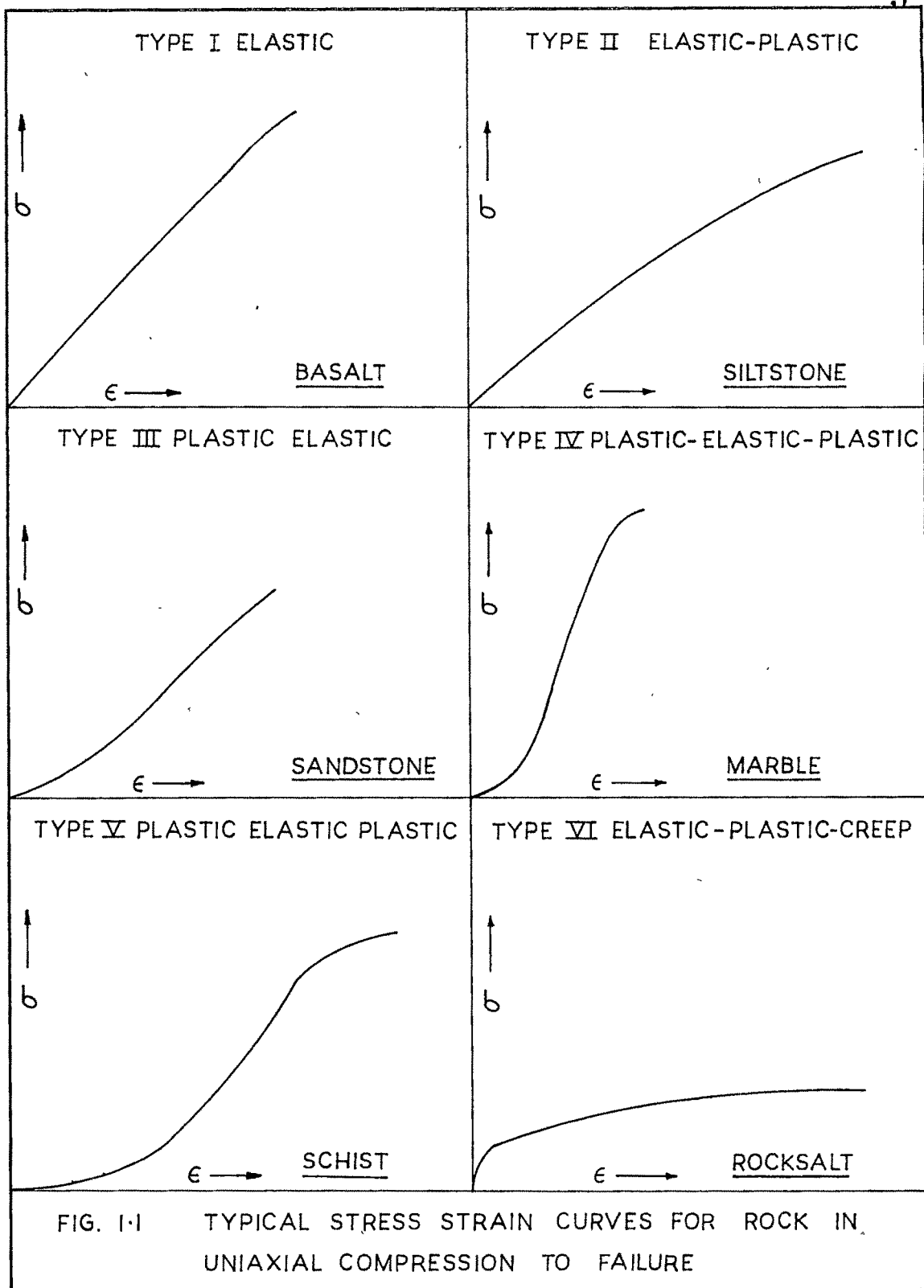
The understanding of the mechanical behaviour of any material is possible if the nature of strain caused due to the application of the stress is known. Whence the strain

is infinitesimal statical analysis of stress and strain follow same principles. In general six types of stress-strain curves are identified from compressive series of tests (Fig.1.1).

- Type - 1      Straight line behaviour until a sudden explosive failure occurs. This behaviour is typical of intact basalts and can be roughly characterized as elastic.
- Type - 2      Stress-strain curve show elastic-plastic characteristics which is found in silt stones.
- Type - 3      Stress-strain curve is typical of sand stone and roughly resembles to plastic-elastic characteristics.
- Type - 4      S shaped stress-strain curve characteristic of plastic-elastic-plastic behaviour, seen in metamorphic rocks like marble.
- Type - 5      S shaped curve characteristic of schist showing high compressibility.
- Type - 6      Stress-strain curve with a small initial straight line portion followed by increasing inelastic deformation and continuous creep. This curve represents elastic-plastic creep behaviour as seen in case of rock salts.

Type 3-4 & 5 curves are all characterized by initial concave upwards portion which became steeper as microcracks or foliation surfaces close up. The initial portion is followed by definite linear portion which gradually shows varying





Type - 3 rocks do not yield significantly and have brittle type of failure similar to Type - 1 rocks.

Failure criteria:

definite relationship characteristic of the material.

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is satisfied. This relationship is called the 'criterion of failure' and its geometrical representation gives a surface which is called the 'failure surface' or limiting surface of rupture.

### 1.3 Fracture in rock materials:

The rock material contains large number of randomly oriented zones of potential failure in the form of grain boundaries. It is generally believed that fracture initiates from the boundary of a crack when the tensile stress on this boundary exceeds the local tensile strength of the material.

#### 1.3.1 Crack formation:

Igneous rocks are probably in a state of hydrostatic stress just before solidification from a melt. By the time the solid rock is exposed at the surface of the earth, two major changes occur; the temperature is reduced several hundred degrees and the pressure several kilobars. Because rock consists of mineral phases which have different mechanical properties such changes produce intergranular stresses. Cracks are formed when intergranular stresses exceed the strength of the material. At microscopic level the atomic bonds get ruptured in tension and shear across preferred crystallographic planes. These orientation defects and inhomogenities collectively constitute the microstructure of the material and principally influence the formation of cracks.

#### 1.3.2 Crack propagation:

There are three basic mode of crack propagation namely opening mode, sliding mode and tearing mode. Out of these three modes the opening mode is the most pertinent to crack propagation in rocks. The approach which deals with

crack development requires to investigate the aspects at microstructural level thoroughly. Further the atomic or molecular level is the ultimate decisive factor which determines the resistance to the propagation of a crack. It is particularly true in brittle materials where the critical rupture process is confined to an atomic scale zone about the crack tip. While the atomic approach provides physical insight in to a problem nevertheless it involves greater complications in analysis. Hence the possible approach is limited to the computation of the displacement as a function of the crack length.

### 1.3.3 Fracture phenomenon:

In rock material the fracture could be either transgranular or intergranular or both. In a polycrystalline materials the grains are crystallographically misoriented with respect to one another. A crack intersecting the boundary between two grains may traverse the boundary and thereby continue the propagation through the second grain with relatively minor adjustments to the crack plane. This phenomenon is called as transgranular fracture. Further grain boundaries constitute relating planes of weakness in a crystal. There is an increasing tendency for cracks to propagate around instead of through grains as the angular misorientations between crystallites increase. This phenomenon is called intergranular fracture.

#### 1.4 Concluding remarks:

Thus the rock is a material of complex nature and it is not possible to classify so as to fit in the realm of a ideal material. Hence the current research in rock mechanics is centered around aspects which can explain clearly the mechanics of failure of a rock.