2

Rocks

2·1. Rocks

Since the details of Rock properties are available in geologists's literature and their language, it is necessary that a rock engineer should have an information about the rock qualities, as observed by the geologist, to evaluate numerical conclusions. It is necessary to know about formation, qualities properties and defects of rocks. Hence, in this chapter these topics will be dealt with in brief so that a rock engineer may be acquainted with rocks fully.

Geologists define rocks as naturally occuring aggregates of minerals or mass of mineral matters constituting an essential part of the earth's crust.

2·2. Minerals

A mineral is a natural inorganic substance of a definite structure and chemical composition such as Calcite, Quartz, Chlorite, Hematite etc.

Minerals are generally identified by their colour, streak, hardness, cleavage and fracture, tenacity, crystal form, specific gravity and lusture.

If a mineral is rubbed over an unglased porcelain or China plate, a coloured or white streak of minute mineral particles is left on the plate. The colour of the streak is compared with a standard colour chart available, which gives an idea of characteristics of the mineral. If struck with a sharp object, a mineral breaks along a definite plane which is parallel to a crystal face and is know as cleavage plane. It is usually a smooth surface and appears to be polished. The cleavage plane also helps in identifying a mineral.

If a sharp blow is given to a mineral block it breaks into irregular surfaces known as fracture. Along this failure planes, fresh mineral particles can be observed by microscope or simply by eye, depeding on the size of the grains, and they can thus be identified.

The ability of a mineral to withstand crushing, shearing or bending is its tenacity. They are described as brittle, malleable, flexible and elastic. If it can be powdered easily it is brittle ; malleable when it can be hammered into thin sheets. If it bents but does not return to its original shape after bending when the force is released then it is known as flexible, where as it will be known as elastic if it returns to its original shape after the removal of a bending force.

Every mineral has a definite crystal form bounded by several or many crystal faces and belongs to a definite crystallographic system. The crystal forms may be Monoclinic, Hexagonal, Rhombohedral etc.

By keeping the mineral in hand, (just for preliminary identifications) its heavyness will give an idea of the specific gravity of the mineral. Feeling of more heaviness will represent more specific gravity of the mineral. However measurement of specific gravity can be done in the laboratory, and an exact value can be known for proper identification of mineral.

Most minerals exhibit a certain characteristic appearance (luster) under reflected light. The luster may be metallic, non-metallic or sub-metallic.

Hardness of a mineral is also a good scale for its identification. The hardness of a mineral is expressed by its number in Mohs scale of hardness. A mineral listed in a particular scale can scratch all minerals of smaller numbers.

2·3. Structure of Earth

Before discussing 'rocks' in details, a brief idea of the Earth structure is given for reference to the readers.

Due to high pressure and temperature at the Inner most part of the earth the minerals contain very high density. This inner most part of the earth crust is known as *Inner core* and consists of solidified heavy metals such as iron and nickel. It is estimated to be about 850 kilometres thick.

The inner core is surrounded by outer core which is estimated to be 2100 km thick. Composition of outer core is similar to that of inner core. However, the inner core is in more fluid state as compared to the outer core.

The outer core again is surrounded by a layer which is estimated to be 2900 km thick and is known as Mantle. The materials in mantle are about two to three times as dense as those at the surface of the earth. By sismic observations, it has been found that a major change or discontinuity occurs at the boundary between the Mantle and the outer Core.

Outside the Mantle, the portion of the Earth upto the surface is known as crust. The crust consists of two parts.

(*a*) Inner annulus also known as Sima or Basaltic Layer.

(*b*) Outer annulus also known as Sial or Granitic Layer.

Sima or Basaltic Layer is made up of dense, dark-coloured material which is rich in magnesia and it is similar to those which comes out of the Volcanoes.

Sial or Granitic is composed of less dense materials. It is rich in silica and alumina and has got similartiy in composition of rock granite.

The depth of crust which includes Basaltic as well as Granitic layer is about 40 kilometres in the continental areas, whereas the depth of Bastic layer, which forms the floor of ocean under the oceanic areas, is about 6 km. The prime constituent of basaltic and granitic layers is considered to be molten silicate material or magma. From time to time, the magma comes to the surface of the earth, in the form of lava, through the mouths of Volcanoes.

Although geologists often call 'rock' to all constituents of the earth crust, engineers devide the earth crusts into rocks and soils.

The hard and compact natural materials of the earth crust are known as rocks and their derivatives due to weathering etc. are termed as "soils".

As discussed earlier the subject which deals with the laws of hydraulics and mechanics applied to Rocks is known as Rock Mechanics whereas the subject dealing with laws of hydraulics and mechanics applied to "Soils" is known as "Soil Mechanics".

2·4. Rock for Engineers

A better definition of rock may now be given as "Granular aelotropic, heterogeneous technical substance which occurs naturally and which is composed of grains of varied poly-crystalline or non-crystalline materials which are cemented together either by "glue" or by mechanical bond, but ultimately by atomic, ionic and molecular bonds within the grains and glue and at every interface of the boundary".

Thus by "rock", an engineer means a firm and coherent substance which normally cannot be excavated by manual methods alone. Thus like any other material a rock is frequently assumed to be homogeneous and isotropic. But in most of the cases, it is not so.

A homogeneous substance is one in which a small element has the same property as that of the whole substance and a hetrogeneous substance has different properties of the elements within the body.

An isotropic material is one that has the same physical properties in every direction at any point whereas an anisotropic or aleotropic material is one in which certain property may vary in a particular direction at a point in the substance.

In a small scale, a Rock may be homogeneous and isotropic but when considered at a large scale it may not be so. Therefore, for large engineering projects these difficulties are overcome with introduction of finite element method techniques and solving the problems with the help of computers.

2·5. Rock as a Construction Material

Rock is used as a construction material in two ways.

(*a*) Rocks with which constructions are done.

(*b*) Rocks over which constructions are done.

For the first category, rocks are brought from quarry etc. and used in place where construction is done.

For example :

(1) For making breakwaters and other such structures.

(2) For protective blanketing of earth dams and other earth works against erosion by water in the form of riprap.

(3) For putting as ballast to support railway sleepers.

(4) As a base and sub-base and top course for roads, and airfield runways.

(5) As a coarse aggregate for concrete.

(6) As facing stones for building, bridges and hydraulic structures to protect such structures from weathering and to improve their elevations.

(7) As building blocks for putting them in foundation as well superstructures of buildings.

A few examples for (*b*) category are :

(1) To support massive structures such as dams, weirs, multistoreyed building etc.

(2) For construction of tunnels for vehicular transport and sometimes water transportation also.

(3) For making shafts.

SOLUTION

2·6. Classification of Rocks

Some of the classification systems of rock are :

(*a*) By origin or genesis.

(*b*) Geological or lithological classifications.

(*c*) Engineering classification of intact rock.

(*d*) A combination of these.

2·6·1. By Origin or Genesis

Based on genesis or mode of origin rocks are grouped into three major groups.

Igneous rocks
Sedimentary rocks
Metamorphic rocks.

2·6·2. Igneous Rocks

Igneous Rocks are those rocks which are formed by the solidification of molten magma originating in the interior of the Earth. Magma is a "fluid" consisting of molten silicates, water vapour and volatiles. If a rock is formed by the cooling and solidification of magma at depth (*i.e.* below the surface of earth) the rate of solidification is relatively slow and consequently a coarse grained structure is formed. If a rock is formed from the solidification of lava on the surface, (which mainly comes due to irruption of volcanoes) the rate of cooling is faster and rapid solidification takes place. In such cases, fine grained materials are formed.

Igneous rock which are formed at a depth, are known as plutonic igneous rocks and those formed from lava and formed mainly at the surface, are known as volcanic igneous rocks.

Classification of igneous rock depends upon the composition of the parent magma and its textural classification will depend upon the environment in which it solidifies.

Thus the chemical composition of magma, rock is sub-divided into four parts :

(*i*) Acidic
(*ii*) Intermediate
(*iii*) Basic
(*iv*) Ultrabasic.

In an igneous rock if quartz and feldspar are predominant it will be acidic in composition whereas if ferromagnesian minerals are predominant the rock will be having basic composition.

The acidic igneous rocks are generally light coloured whereas basic one are dark coloured due to the presence of ferromagnesian minerals.

Textural subdivisions are done as :

(*i*) Coarse grained also known as Plutonic
(*ii*) Medium grained also known as Hypabyssal
(*iii*) Fine grained also known as Volcanic.

Table 2·1 gives an idea of classification of some important Igneous Rocks as discussed by Krynine and Judd.

Table 2·1

Classification of Igneous Rocks

Structure	*Composition*			*Remarks*
	Acidic	*Intermediate*	*Basic*	
Coarse to medium grained (Plutonic)	Granite (L.C)	Syenite (L.C)		
	Granodionite (L.C)	Diorite (D.C)	Gabbro (D.C)	
Medium to Fine Grained (Hypabyssal)	Microgranite	Microsyenite		L.C→Light Coloured
	Quartz-porphyry (L.C)			D.C→Dark Coloured
	Micro granodiorite (L.C)	Microdiorite (D.C)	Dolerite (D.C)	
Fine Grained and Glassy (Volcanic)	Rhyolite (L.C)	Trachyte (L.C)		
	Pitchstone			
	Dacite (L.C)	Andesite (D.C)	Basalt (D.C)	

2·6·3. Sedimentary Rocks

Sedimentary Rocks are derived due to weathering and decomposition of earth crust or from any rock type.

When a rock or earth crust is weathered or decomposed and transported and redeposited, and subsequently consolidated and cemented partly or fully, then the new product formed is known as Sedimentary Rocks.

The size of weathered products and the degree of consolidation and cementation determine the strength of the sedimentary rocks.

The type of sedimentary deposit formed in any area depends upon :

(*a*) The nature of sediment carried into the area

(*b*) The physical environment within the area.

The material from which sedimentary deposits are formed are derived in the following ways :

(*i*) Mechanically

(*ii*) Organically

(*iii*) Chemically.

Mechanically. Weathering agents act on the surface of a pre-existing rocks which may be igneous, sedimentary or metomarphic. These weathered products latter become constituents of the new sedimentary rocks.

The weathering agents are :

(*a*) **Atmospheric agents**—Rain, frost, wind and temperature changes.

(*b*) **Gravity**—The rock disintegration during landslide.

(*c*) Rivers

(*d*) Seas

(*e*) Ice

(*f*) **Organic agents**—such as animals and plants.

Organically—Sediments are formed from the remains of plants and animals.

Chemically—Sediments are formed due to chemical decomposition.

Sedimentary Invironments.

Invironments which cause sedimentations are mainly :

(*a*) Continental,

(*b*) Intermediate,

(*c*) Marine.

Continental. In such cases the agents are rivers, lakes, glaciers, and wind. For example deposits transported and deposited by wind are Aeolian, deposited by rivers—Fluviatile and deposited by glaciers are Glacial.

Intermediate. Deposits formed in deltas are Deltaic and deposits formed in estauries of rivers are Estuarine.

Marine Environments. Deposits formed along coastlines—Shore, deposits formed under great depth of water—Abyssal.

The shape of grains in a sediment depend upon :

(*a*) The original shapes of the materials supplied by the disintegration of pre-existing rocks. For example—weatherings from granite will be sharp angular quartz and from feldspars it will be irregular mica flakes.

(*b*) The amount and nature of transport : The greater the distance of transportation the more will be the rounding of the grains. Wind transported sediments will be rounded of up to the maximum extent, water causes some degree of rounding whereas ice will cause the least rounding off.

Generally sedimentary rocks occurs in well defined beds. They are known as bedding planes or stratification.

Classification of sedimentary Rocks.

As a broad classification, sedimentary deposits are classified in two categories.

(*i*) Unconsolidated Sedimentary Deposits;

(*ii*) Consolidated Sedimentary Rocks ;

In fact due to further consolidation and cementation of sedimentary deposits sedimentary rocks are formed. To the engineer group (*i*) constitutes the engineering soils and group (*ii*) is the rock.

From an engineering view point, the most important sedimentary rock are sandstones, shales and limestones.

The size of grains in sandstones varies from fine grained type to coarse grained type. The structures are massive, horizontally bedded or cross-bedded. Sandstones are having good bearing capacity. However presence of some weak materials in the mass make it weaker.

The groups of sedimentary rocks formed by clay minerals are shales. A shale is laminated sedimentary rock frequently dark in colour and composed of mainly clay sized particles (Finer from 0·002 mm size particles). Sometimes small percentage of sand and silt may occur. It has got laminations which can easily be observed. But the shale has got variable hardness depending upon its consolidation. A good shale gives a clear ring if struck with a hammer.

Limestone. It is primarily composed of calcium carbonate and has got crystalline structure. The grains are fine. It may be considered as a good foundation material unless it has got cavities.

Another important type of rock which may be considered in the sedimentary category, is the Conglomerate. It is a rock composed of very coarse (6 mm to 75 mm) particles which are rounded off. Sometimes well graded particles with good percentage of fines are there in the materials. The well graded materials make such type of rock as good bearing surface. Some of important sedimentary rocks are given in Table 2·2.

Table 2·2
Classification of Sedimentary Rocks

Group	*Unconsolidated Sediments*	*Consolidated Rocks*
Rudaceous (Pebbly)	Gravels Fragmented rock	Conglomerates Breccias
Arenaceous (Sandy)	Sands	Sandstones Ferruginous sandstone—iron Cement : Seliceous sandstone—siliceous cement. Calcareous sandstone-Calcareous cement. Greywocke—composed of mixture of rock fragments.
	Silts	Siltstones—a consolidated rock of silt grade.
Argillaceous (Muddy)	Muds, Clays, Brick earth	Hard clays, shales, mudstones, fine clay, marl.
Calcareous (Limey)	Shell sand, Coral reef, $CaCO_3$ precipitate from solution	Lime stones Shelly limestones Siliceous limestone Ferruginous Limestone Chalk.
Carbonaceous Peat		Coals Lignite Anthracite Cannel
Ferruginous		Clay ironstone Blackband ironstone
Siliceous	Silica gel	Flint, Chert

2·6·4. Metamorphic Rocks

Due to high pressure, high temperatures and temperature gradings as well as high shearing stresses on existing igneous or sedimentry rock masses, under the earth crust, recrystallisation of rocks takes place and the resulting complete or incomplete recrystallised mass is known as metamorphic rocks. Due to recrystallisation a new rock mass evolves due to changed environments.

The process which brings out changes in the rocks is known as metamorphism.

The agents which are active for metamorphism are :

(*a*) Temperature

(*b*) Pressure

(*c*) Stress

(*d*) Chemically reactive substances.

These agents may act separately, or combined together depending upon conditions to bring the changes in the rock mass. During recrystallisation, the action of directed pressure or stress on the rock mass causes a change in the orientation of the mineral grains or crystals. The nature of metamorphic rocks not only depends upon a particular agent as listed above but it also depends on the extent to which they are in action to bring metamorphism.

The mineralogical composition of a metamorphic rock is dependent upon two factors.

(*i*) The initial composition of the rock

(*ii*) The degree of metamorphism (*i.e.* change) undergone by the rock mass.

Limestone which consists of calcium carbonate is changed into marble due to metamorphism and sandstone which contains silica is changed to quartzite.

A shale under low grade of metramorphism is changed to slate whereas under high grade of metramorphism, it is converted into phyllites.

Igneous rocks are formed under a condition of falling temperature and pressure and hence, the minerals crystallise in descending order of their melting points. In case of metamorphic rocks, there is commonly a rise in temperature which brings out new reactions depending upon the degree of temperature and all the constituent minerals are formed simultaneously when cooling takes place. Then the minerals which occur in a metamorphic rock are known as anti-stress minerals if they have been formed under uniform pressure whereas they will be known as a stress-minerals when formed under a directed pressure or stress *i.e.* when pressure or stress in a particular direction was more than the other directions. Anti-stress minerals are generally equidimensional whereas stress minerals are flaky or laminar.

Some of the important metamorphic rocks which are used by engineers are marble, slate, schist, Gneiss, Quartzite, Hornfels etc.

Marble results from recrystallization of lime stones. Slate is formed by metamorphism of fine grained sedimentary rocks. Cleavage planes are highly developed.

Schist results from mica, chlorite, talk and hornblende minerals. They are of medium to coarse grained size.

Gneiss results from metamorphism of igneous or sedimentary rocks. Minerals are arranged in irregular bands. Common minerals are feldspar, quartz, mica or hornblende. Quartzite is formed due to recrystallization of sandstones under heat and pressure Dominant mineral is quartz.

Hornfels are formed by thermal metamorphism of muddy rocks, such as shales. Minerals present are feldspar, biotite and quartz.

Table 2·3

Classification of Metamorphic Rocks

Structure and Texture	*Composition*	*Rock name*
Massive Banded, consisting of alternating lenses	Various tabular prismatic and granular minerals (frequently elongated)	Gneiss
Granular, consisting mostly of equidimensional grains	Calcite, dolomite quartz in small particles	Marble or quartzite
Foliated or platy	Various tabular and/or prismatic minerals (generally elongated)	Schist, slate phyllite

2·7·1. Geological or Lithological Classification

The lithology of a rock is the study of its physical character. It includes the study of mineralogical composition, texture, colour, physical appearance etc. It helps in the selection of a particular rock for engineering purpose. Generally engineers are mainly concerned with strength properties of the rock material. Hence if an engineer is conversant with the lithological or geological classification of rocks he can select the rocks primarily for his purpose. For example if he has to use a building block, he will be using marble where external exposure is required, whereas he will use granite when the rock has to be used as foundation blocks.

When he refers the name of granite, limestone, sandstone, mica shist, quartzite he gets an idea of the physical property of the rock and he ascertains whether a particular rock will be suitable for a specific purpose.

To ascertain the engineering properties of rocks it is to know the following rock properties which can be ascerta visual examinations to make a preliminary inference about the ability of a particular rock for a particular purpose. For example, granites, lime stones and other rocks may exist in a very hard and strong state to a completely decomposed and weak state. Hence if simply rock type is described the informations may not be sufficient. Hence in order to describe the rock fully for a particular engineering purpose it is necessary to describe following properties :

(*i*) Texture

(*ii*) Structure

(*iii*) Composition

(*iv*) Colour

(*v*) Grain size.

2·7·2. Texture

Rock materials may be of any of the following textural group.

(*i*) Crystalline

(*ii*) Indurated

(*iii*) Crystalline-indurated

(*iv*) Compact

(*v*) Cemented.

Crystalline rock materials are composed of visible interlocking crystals or crystal grains. When scratched by the blade of a penknife, particles do not come out of the rock mass. If particles come out due to scratching, the rock will not be taken in crystalline group.

Indurated rock materials are those in which interlocking crystals and crystal grains are not visible by naked eye. Grains are fine. But the rock is strong as particles do not come out of the rock mass when scratched by the edge of a knife.

Crystalline-indurated rock materials fall between crystalline and indurated rock materials. Its individual crystal grains or crystal aggregates are finer than crystalline structure but coarser than indurated. Rocks of this type of structure are hard because the grains do not come out when scratched by the edge of a knife.

In compact rock materials, the particles are held together purely by tightness for grain packing. Grains are finer. Particles or powder come of the rock mass when scratched by the edge of a knife.

mented rock materials are medium to coarse-grained rock g grain to grain bonding by some cementing materials. Grains re visible to the naked eye and particles come out from the rock mass even when scratched with a finger nail.

2·7·3. Structure

Structures refers to placing of various textures within the rock material. It also refers to fractures or any preferred mineral orientation within the rock mass.

The various types of structures are as follows :

(*a*) Homogeneous

(*b*) Lineated

(*c*) Intact-foliated

(*d*) Fracture foliated.

Homogeneous. If the grains and crystals are having random orientation the structure will be called homogeneous. By visual examinations only the homogeneous structures in a rock mass can be ascertained.

Lineated. If the mineral particles are having a preferred orientation in a particular linear direction/directions the structure will be known as lineated.

Intact-foliated. When the minerals in the rock mass are having a preferred orientation of a planer nature.

Fracture-foliated. When the planer structure is having closed or incipient fracture such as bedding planes or cleavage planes.

Generally the lineated structures pose problems because propertics of rock mass is not the same in all directions in such cases. The mass is known as aelotropic or non-isotropic.

2·7·4. Composition

Presence of calcite is of prime importance when considering mechanical and physical characteristics of rock mass. The important sub-divisions are :

(*a*) Noncalcareous

(*b*) Part-caleareous

(*c*) Calcareous.

Non-calcareous. Rock materials are those in which calcium carbonate is absent.

Part-calcareous. The rock contains mainly non-calcareous materials. The calcareous material is present as a bond between the grains.

Calcareous. The rock materials which are mainly composed of calcite.

2·7·5. Colour

If the rock is of basic nature, it will be of dark colour whereas acidic rocks are of light colour. Light-coloured rocks are generally feldspathic whereas dark coloured rocks generally contain ferro-magnesiun minerals. Calcarrous rocks, which contain impure materials, are dark in colour whereas pure calcareous rocks are light.

2·7·6. Grain Size

Sometimes classification of rocks is done on the basis of their grain sizes. In such cases origin or type of rock is not so important.

The rock material is classified in three groups—Coarse, Medium and Fine grained.

Coarse-grained—When the particles are larger than 2 mm in diameter.

Medium grained—When particles size lies between 2 mm and 0·1 mm.

Fine grained—Particles of less than 0·1 mm size and invisible to the natural eye.

2·8. Engineering Classification

The problems of Rock mechanics are mainly associated with intact rocks. Hence it is necessary to classify the rock based on insitu properties. The behaviour of rock mass subjected to change in stress due to change in physical conditions due to construction of some superstructures or excavation of tunnels etc. is governed by mechanical properties of the intact rock mass and number and nature of geological discontinuities present in the mass. Hence, in rock classification these two items are taken separately. In addition to these, rocks are also classified sometimes according to their degree of weathering. Because this also gives an important information about the load bearing capacity of the rock mass. While making a classification as per degree of weathering rocks are classified as grade I, II, III etc.

Table 2·4 gives the classification based on degree of weathering of the rock mass as suggeted by Geological Society of London.

Table 2·4

Classification based on degree of weathering of rock mass

Term	*Description*	*Grade*
Fresh	No visible sign of material weathering.	IA
Faintly weathered	Discolouration on major discontinuity surfaces.	IB
Slightly weathered	Discolouration indicates weathering of rock material and discontinuity of surfaces. All the rock material may be discolured by weathering and may be somewhat weaker than in its fresh condition.	II
Moderately weathersd	Less than half the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a contineous frame work or as core stones.	III
Highly weathered	More than half the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones.	IV
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is largely intact.	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

The basis of engineering classification of rocks is uniaxial compressive strength and modulus of elasticity. Based on uniaxial compressive strength the rock is classified as Class A, B, C, D and E. The compressive strength value is based on the results of the specimen having length diameter ratio of atleast 2. It may be observed from the table that strength of different classes follow a geometric progression. Deer and Miller (1966) has given Table-2·5, for classification of rocks in different categories.

Table 2·5

Engineering Classification of Intact Rock (After Deer and Miller, 1966)

Class	*Description*	*Uniaxial Compressive Strength kg/cm²*	*Rock Material*
A	Very High Strength	Over 2250	Quartzite, diabase, basalts, Majority of igneous rocks, Strong metamorphic rocks.
B	High Strength	1125—2250	Weakly cemented sand stones, hard shales, majority of lime stones, dolomites
C	Medium Strength	562·5—1125	Many shales, porous sandstones, and limestones, schistose varieties of metamorphic rocks.
D	Low Strength	281·25—562·5	Porous low-density rocks, friable sandstone, truff.
E	Very low Strength	Less than 281 25	Clay shales, weathered and chemically altered rocks of any lithology.

Table 2·6 shows the engineering classification of intact rock on the basis of modulus ratio,

$$M_R = E_{t\,50}/\sigma_{ult}.$$

where E_{t50} = tangent modulus at 50% ultimate compressive strength of rock and
σ_{ult} = unaixial ultimate compressive strength.

Table 2·6

Engineering Classification of Intact Rock (After Deer and Miller, 1966)

Class	*Description*	*Modulus ratio*
H	High	More than 500
M	Average (medium)	200—500
L	Low	Less than 200

On the basis of above two tables engineering classification is done like *AM*, *BH*, *CM*. etc. (*e.g. CM* means medium strength and average modulus ratio).