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CHAPTER-1

INTRODUCTION TO GEOLOGY

Introduction

Geology is the branch of science that includes the study of its origin, history of development, materials it is made up of and all the processes that take place on the interior as well as the exterior surface of the earth that leads to the modification of its features. It can simply be referred to as the "earth sciences" i.e the science that deals with the various aspects of the earth.

In short: Geo + logos = Geology

(earth) (the study of)

Application of geological Sciences in the field of Engineering so that the various geological factors and phenomenas occurring on the earth do not hamper the successful planning, designing, execution, construction and maintenance of engineering structures is called **Engineering geology**. Any engineer, be it civil, mining or metallurgical, must have some knowledge of geology.

1.1 Engineering Geological System (EGS)

1.1.1 Engineering Geological System and Various Parameters for Evaluation of EGS:

The various components and features that form the earth constitute the engineering geological system. It includes: rocks, soil, faults, folds etc. The various parameters for the evaluation of Engineering Geological System are as follows:

A. Rocks:

Rock is a naturally formed hard and compact mass of aggregate of minerals or mineraloids. It may contain some petrified matters also. It forms the earth and may be found exposed on the surface or may extend several kilometers below the surface underlying the soil. Based upon the strength of the rock it may be classified as follows:

i) **Hard Rocks:** The Rocks that have high strength and do not break up on applying pressure by hands are called Hard Rocks. examples: granite, quartzite etc.

Hard rocks are used in the foundation of structures and also as building construction material.

ii) **Soft rocks:** The Rocks that have low strength and break even on the application of pressure by hand are called soft rocks. examples: phyllite, cyst etc.

The soft rocks are less resistant to high pressure. Hence they can't be used for foundation purposes. However, they can be used in the roofing and flooring purposes and also to beautify the houses.

B. Geological structures:

The structural features or architectural patterns that are developed on the rocks are called geological structures. Formation of these structures is a result of stresses that act on the rocks. They make the rocks weak and hence must be evaluated properly and carefully.

Based upon the mode of formation; the geological structures are of three types:

i) **Primary structures:** The structures that are developed at the time of formation of rocks are called primary structures. stratification (bedding), lamination, cross bedding, graded bedding, ripple marks, mud cracks, rain Prints and tracks and trails for under this category.

ii) **Secondary structures:** Those structures that are developed on the rocks after their formation as a result of compression and stretching are called secondary structures. Structure is usually formed by the modification of original structures.

Foliation, ~~food~~ Fould, faults, joints etc fall under this category.

iii) **Compound structures**: Those structures that are formed by the combination of events is called compound structures. Example: unconformities.

A civil engineer must always check for the presence of any geological structure. The presence of such structure is always unfavorable for any civil engineering project because the geological structures are always formed due to the deformation and are always considered as unstable zones.

C. Soil Type:

All engineering structures are built on the soil. Hence soil is of great importance to an engineer. The soil must be properly evaluated before carrying out any construction and checked for its bearing capacity, rate of erosion and settlement.

D. Weathering Grade:

Weathering is the process of decay, disintegration and decomposition of rocks as a result of which the rocks get gradually worn out. Weathering grade represents the weathering condition of a rock.

Based on weathering grade we have:

i) **High grade**: The presence of large amount of soil indicates that the Rock is weak and there is high weathering. High grade denotes that the Rock is weak and is unfavourable for the project.

ii) **Medium grade**: The presence of rocks and soil in almost equal proportion indicates medium grade. Several precautions and soil improvement techniques must be carried out.

iii) **Low grade**: The presence of soil in very less amount indicates low grade. The rock is strong and is favourable for construction purpose.

E. River Morphology:

River is defined as a water body which flows from higher relief to lower relief and carries sediments along its flow.

There are three types of river:

i) **Straight river:** The river which flows in a straight path is called Straight River.

Proper care must be taken while carrying out construction in such areas as the river causes intense scouring effects. Run off type hydropower and Arc Bridge is applicable in Straight River. Stone pitching and plantation must be done to prevent the problems of scouring.

ii) **Meandering river:** The river that follows a Zig Zag pattern or path is called meandering river. While constructing a bridge in such rivers, stable, narrow bend must be selected so that the length of the bridge is short and the construction work can be completed in lower cost. The run off as well as Reservoir in the meandering river can be provided based upon the site conditions.

iii) **Braided rivers:** The river that has many channels and is formed due to the overloading of sediments carried by the river is called braided river. The construction materials like stones, Sands, gravels etc. are found in this river and can be used for construction purpose. Bridges with large spans are required in this type of river. Hydropower projects are not possible in this type of river.

F. Ground water:

The water which exists below the ground surface is called groundwater. The encounter of groundwater is always unfavorable for any civil engineering project except for water supply engineering.

G. Landforms:

Landforms are natural features on the Earth's surface like Hills, valleys, mountains etc. The Earth's surface comprises of many such landforms and Hence a thorough study must be carried out. Each landform must be briefly considered in any civil engineering project.

H. Geological setting:

Geological settings give the location of where we are or in other words it gives our current position.

I. Attitude(slope):

The 3D orientation of some geological features of rocks like beds, joints, foliations etc is called attitude. A civil engineer must always check the relationship between the rock slope and the natural slope before carrying out any construction activity.

Based upon the relationship between the rock slope and natural slope; slopes are of two types:

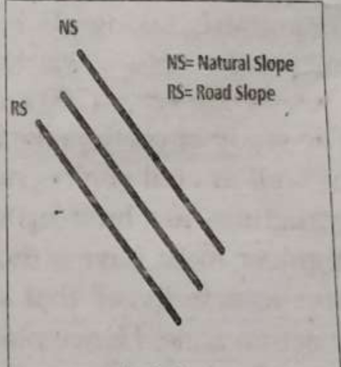


Fig:Dip Slope

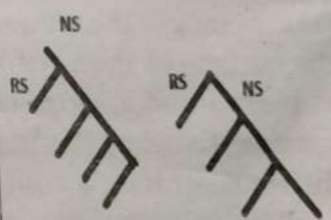


Fig: Counter dip Slope

i. **Dip slope:**

If the rock slope and natural slope are parallel to each other then it is called dip slope.

ii. **Counter dip slope:**

If the rock slope and natural slope are perpendicular to each other or at any angle then it is called counter dip slope

Note: Counter dip slopes are always stable than Dip slopes.

1.1.2 Hydrogeology:

Hydrogeology is the branch of science that deals with the study of water on the surface as well as below the surface of the Earth. It also deals with the study of quality and quantity of water in rocks and the various hydrological properties of rocks.

1.1.3 Geomorphology

The branch of science that deals with the study of various landforms and features on the surface of the earth and their structure and development over a period of time is called geomorphology.

1.1.4 Earthquake and Seismicity:

Seismic activity is one of the most important source that provides gives the information of the interior of the earth. Disturbance are continuously taking place on the interior of the earth. Most of the natural earthquakes take place on the lithosphere of the earth (200 km from the surface of the earth).The study of earthquake is very important for geologists as well as civil engineers. Since most of the engineering structures are built up on soil and rock stratas; a civil engineer must have a thorough knowledge about the systemic activity of that region. Nepal falls in a seismically active zone. Hence planning, designing and construction of Engineering structures must be done in such a way that the structures can resist the seismic waves as far as possible and provide safety for human life during earthquake.

Terminologies:

Focus(hypocenter): *The point where the energy is first released is called focus. The Waves originate from this point and propagate in all directions causing vibrations.*

Epicenter: The energy waves originated from the focus reach the surface of the earth. The point on the surface of the Earth which is the first to experience the wave and is nearest to the focus is called epicenter.

Seismology: The study of earthquakes and assessment waves produced by it is called seismology.

Seismograph: The device used to record the earthquake is called seismograph.

Seismicity: The occurrence of frequency of earthquake in a given area is called seismicity.

1.1.5 Evaluation of EGS with reference to the different phases of infrastructure development project.

Most of the civil engineering structures are built upon soil or different rock strata. The engineering geological investigations are a must for a success of any civil engineering project. It provides information's regarding the physical and geological properties of rocks and soil strata, about the groundwater conditions and the suitability of the site for the proposed project. It ultimately saves us from investing excessive time and money unnecessarily.

The different phases of the evaluation of egs are as follows:

A. Planning phase:

This is the first phase of evaluation of EGS. in this phase, a proper concept about project is established. An existing database is obtained so that information can be gathered. In this phase, all the information that are available are collected.

The information to be collected are as follows:

i) Site plan
ii) Probable soil condition of the area
iii) The type of structure to be built
iv) Permeability characteristics of soil and rocks
v) Topographic maps

vi) Still photographs of the area
vii) Behavior of existing structure at the site
viii) Information regarding the seismicity of the area
ix) Ground temperature conditions
x) Information regarding the aquifers and ground water tables ,geological setting ,terrain etc.

B. Investigation phase:

This phase provides further information to an engineer about the soil condition at a given site by directly obtaining sample from the site. This phase uses the existing maps to gather information. This phase helps in estimating the various engineering and Mechanical properties of the rocks and soil based on the various site test and lab tests . Some information can also be obtained based on experiences and the data obtained from the lab test is recorded for further use. The surface and subsurface geotechnical information is obtained either by one of the following

i) Direct: Test pits, trenches
ii) Semi direct: boring
iii) Indirect method: sounding and penetration

C. Design phase: This phase should include the optimal foundation design keeping in mind all the information obtained from the investigation and planning phase. Geological maps must be prepared. All the salient features of the area are mapped. In this phase further detailed investigation regarding the stability of the rock is carried out if the information obtained from previous phases are not sufficient and finally an appropriate design of a project is prepared. The design must take into consideration all the existing geological conditions and comment on the site issues that may arise in the future.

D. Construction phase:

In this phase, Site is prepared for construction and construction building materials are gathered. Construction works are carried out under the supervision of expert. If encountered with any abnormalities during the

construction then further studies must be carried out and the design must be modified necessarily. Continuous supervision by an expert must be done for better results.

E. Maintenance phase:

Regular inspection and monitoring must be carried out after the construction. If any stratigraphic and geological problems arise then immediate actions must be taken.

1.1.6 Geotechnical Category of the Projects:

It is divided into three categories:

Category 1: It only includes small and simple structures. It must be possible for those structures that the fundamental requirements would be satisfied ~~on the basis~~ of experience and geotechnical investigations.

Category2: It includes conventional type of structures and foundation with exceptional risk or difficult soil or loading conditions. It must include qualitative data and analysis to ensure that the fundamental requirements are satisfied.

Category 3: It includes structures or parts of structures which fall outside the limits of category 1 and category 2.

1.2 Important Rock Forming Minerals and Their Significance

There are more than 3000 species of minerals ore known in nature more than 99% rocks of the earth's crust are made up hardly of about 20 or so minerals which mostly occur in combination of two to three minerals in a rock. The minerals which are common to make up the bulk of the rocks of the earth's crust have been named as rock forming minerals. There are two types of mineral, essential minerals which are constituents of more than 50% of the rock and those which occur in small quantity are Accessory mineral.

On the basis of chemical composition there are two groups based on silica content. They are (i) silicate minerals and (ii) Non silicate

[A] Silicate Minerals: The mineral which contains silica tetrahedrons are called silicate minerals. The base unit of silicate mineral is $[SiO_4]^{-4}$. Silicate minerals are further divided into following group:

(i) Feldspar group: Feldspar is the most abundant minerals of the earth's crust and they consist of frameworks of SiO_4 and AlO_4 tetrahedral with ions of potassium, sodium or calcium occupying the appropriate place in the structure. E.g.: Orthoclase, Microcline, Plagioclase, Oligoclase, Sanidine.

Generally, Feldspar group minerals are light in colour due to absence of Fe and Mg. They have lower specific gravity generally around 2.6 and double cleavage and hardness varying between 6-6.

(ii) Pyroxene group:

They are Ferro-magnesium silicates with calcium, sodium, aluminum and lithium. They are generally dark in colour, their hardness varies between5 to 6. They are generally short and stout with sp. gravity 3-3.3. E.g:Hypersthene, Augite, Aergirine etc.

(iii) Amphibole group:

This group has similar properties like pyroxene group. They are dark in colour and hardness varies between 5 to 6 and sp. gravity 2.8 to 3.6. They differ from Pyroxene group only in the arrangement of SiO_4 tetrahedral. Pyroxene group has single chain structure while amphibole has double chain structure. Also, amphiboles are elongated, slender and fibrous in nature.

(iv) Mica group:

Mica group are characterized by the presence of micaceous structure by virtue of which these can be split into very thin sheets along a direction. They are mainly silicates of aluminum and potassium containing one or more of Hydroxyl group, Magnesium, Sodium, Iron etc. They have low hardness between 2 to 3. E.g: muscovite, Biotite.

(v) Miscellaneous group:

All the remaining silicates fall under this group. E.g.: Quartz, Garnet, Topaz, Tourmaline, etc.

[B] Non- Silicate Minerals:

Non silicates mineral are those which don't contain silica tetrahedron. They are generally classified according to chemical composition. The main groups are enlisted below:

(i) **Oxides:** The oxides mineral contains oxygen as dominant group and further divided into simple oxides, Hydro oxides and multiple oxides. Example: Corundum, Magnetite.

(ii) **Carbonate:** The carbonate minerals are those in which anionic group is carbonate $[CO_3]^{-2}$. They react with acid so distinguish from non carbonates. E.g. Calcite, Dolomite.

(iii) **Sulphate: The** sulphates minerals are those which have main anion sulphate $[SO_4]^{-2}$. E.g.: Gypsum.

(iv) **Phosphate:**The phosphate minerals are those which have $[PO_4]^{-3}$ unit as anion. E.g.: Apatite.

(v) **Halide:** The halide, minerals are those minerals which contain halogen as main anion group. E.g.: Fluorite.

(vi) **Sulphide:** The sulphide minerals are chemical compoun of one or more metals or semi-metal with sulphur element of sulphur group. E.g.: Cinnabar, galen sphalerite.

(vii) **Native Mineral:** This mineral group contains nativ metals, semi metals, non-metals and various alloys an solid solution.

E.g. Gold, Graphite, Diamond, Sulphur.

Engineering Significance of Rock forming Minerals

(a) Clay minerals like Kaolinites swells with water an therefore creates hazardous site for engineering structures.

(b) The rock containing silicates are generally resistant towar weathering.

(c) The rock forming minerals like calcite and dolomit dissolves in water with evolution of CO_2 gas and develop hollow inside ground. So, they may result internal drainag problem and collapse.

(d) Feldspar is used in manufacture of proclein glass, sanitar ware and enameled brick.

- Calcite is used for manufacture of cement.
- Gypsum is used for production of plaster of paris.
- Sheet mica is used as insulating material in manufacture of electrical apparatus and fireproofing material.
- Quartz is used as gemstones or ornamental material.

1.3 Application of Engineering Geology in Various civil Engineering Projects:

The knowledge of engineering geology is a must for a success of any civil engineering project. It provides information regarding the physical and geological properties of rocks and

Kaolinites

soil strata, about the groundwater conditions and the suitability of the site for the proposed project.

In the context of Dam and reservoir site:

In the history, many incidents of failure of dam and reservoir structures like Teton dam, Malpsset dam, Baldwin Hills reservoir etc. have been observed. These failure are solely due to geological factors like pervious rocks, subsidence, rock fault, rock folds ,pressurization of rocks and pressure of abutment rocks(in the case of reservoir)etc. Soluble rocks in the foundation causes seepage problems in the dams and reservoirs.

All these problems can be minimized and to some extent be avoided with the help of engineering geology. A proper site investigation by an engineering geologist prior to the designing phase helps to gain a proper idea about the proposed area and its engineering characteristics. It provides an idea about the proper design of the dam structures in the given geological context. Dams must be constructed on hard solid rocks. If hard rocks are not available then grouting must be done in order to increase the strength.

In the context of Road:

In recent years we have been hearing about the failure of roads just after a very short time of construction of roads .This is due to the geological reasons.

In most of those cases of road failure; the main cause is the presence of weak zones that challenge the stability of the roads. Fractured basements, faults etc. below the proposed road leads to the failure. Hence the knowledge of engineering geology provides a clear idea on how to ensure safety and stability of the engineering structure economically. Engineering geolog indicates the problems that may arise in the near future an warns the engineer to make the designs accordingly. It geolog provides knowledge about the geological hazards that exist i that area like landslides, floods, rock fall, rock toppling etc.

In the context of tunnels:

Tunnels are underground passages. Some examples tunnel failure are: Umin Barapani stage 1 tunnel, Ramgang diversion tunnel etc.

Geological factors like incompetent rocks, faults, fold porosity, and permeability hamper the stability of the tunne Engineering geology provides an idea about these problen and helps to design the tunnel properly and effectively. provides the knowledge about the prevailing ground wate condition at the given site and prevents us from investing tim and money unnecessarily.

In the context of Irrigation system:

Engineering geology provides us information about th engineering problems associated with irrigation like the chang in moisture content of the soil or of the ground water regim etc.

It helps in proper designing of the project.

1.4 Engineering Geological Maps: Their Classification and Preparation Engineering Geological maps:

A map provides the best impression of a geologica environment and the existing geological conditions, individua

components and their interrelationships. Engineering geological map is a type of geological map that provides basic information about the geological condition of the site for the use in planning, designing and construction and maintenance of engineering structures. It should fulfill the following requirements:

i) It must be easily understood by a professional user who may not necessarily be a geologist.
ii) It should potray the basic information necessary to evaluate geological features involved in Planning and selection of site.
iii) It should represent the geomorphological condition, dynamic phenomena, important landscapes, information on seismic phenomena, volcanic activity, prevailing faults and folds etc.
iv) it should provide basic information regarding the character of Rock and soil in that area and their distribution and lithology.
v) Hydrological distribution which includes what a bearing soil and rocks must be shown. depth of water table must also be shown.
vi) Region of confined aquifers must be shown if possible.
vii) Location of construction material must be shown.
viii) Previous hazard location must be shown.

According to the purpose of map:

i) Special purpose map: It provides information on one special aspect. It is also known as single purpose map.
ii) Multipurpose map: It provides information on more than one aspect. It provides information on various factors which is useful for planning and designing.

According to the content:

i) Analytical map: the map that evaluates individual components is called analytical map. example: geological hazards map, weathering grade map, jointing map etc.

ii) Comprehensive map: It is of two types:

a) The map that depicts all the principal components of Engineering geological environment.

b) The map that evaluates and classify individual territorial units.

According to the scale of maps:

i) large scale: 1:10000 and greater

ii) medium scale : 1:100000 <x<1:10000

iii) small scale :<1:1 0000

Preparation of maps:

Maps are prepared after detail field investigation. The physical and Mechanical properties of rocks and soils must be represented on a map. The content and the amount of details shown is determined by the purpose and scale of mapping.

The map is prepared by adopting the following:

i) Different type of rocks and soil can be shown by the use of colour or colourful patterns. rocks and soils on the surface is represented by colours and the underlying rocks are shown by using distinguish and colourful patterns

ii) The topography of the surface is shown by contours.

iii) Statically determined Rock and soil properties may be indicated in the legend.

iv) The actual boundaries of geological features can be shown wherever possible by giving some appropriate symbols.

v) Lines at 1 m intervals can be used to represent the hydrogeological condition with known fluctuations shown numerically.

vi) Data on groundwater chemistry should be shown numerically or by symbols.

vii) Various symbols are used to locate the bore holes.

viii) The Legend must contain the description about the various symbols used.)

ix) Other features can be represented by strike and dips.

x) The map must be accompanied by explanatory texts.

xi) The name of the organization that carried out the investigation along with the date and location must be provided.

Uses:

The various uses of engineering geological maps are as follows:

i.

ii. It is used to get a general idea about the geological history of that area. It includes the information related to plate tectonics, climatic changes, sea level changes etc.

iii. It is used to gain the information on the groundwater development and protection.

iv. It is used in selecting a tentative alignment of road projects, railways etc.

v. It helps to gain information regarding the availability of energy resources like oil, radioactive materials etc.

vi. It is used in identifying the geological hazards prevailing in that area i.e. hazard assessment.

vii. It helps in determining the faulting zones and hence locates the warm springs.

viii. They are used in land planning.

ix. They are used in waste disposals.

x. They are used by security persons in national defense.

xi. They are used in zoning.

EXERCISE

1. How is Engineering Geological Map prepared? Mention the components of Engineering Geological Map. [2074 Bhadra]

Ans: For first part see 1.4

Geological Map consists of following Components:

1. The map
2. The legend
3. Geological cross section of the map area
4. Explanatory texts
5. The title of the map
6. Table including the date and location of the project

2. Mention the Engineering Geological study with reference to the different phases for Evaluation of EGS.[2073 Magh]

Ans:see 1.1.5

3. Describe the Engineering Geological Map. Mention Engineering Significance of quartz mineral w.r.t to of rock forming minerals.[2073 Bhadra]

Ans: For first part see 1.4

About 75-80% of sediments in the rivers of Nepal is composed of hard minerals like quartz. It is very resistant to weathering as it has a hardness of seven in Mohr's hardness scale. It is chemically inert and is highly stable. But is not desired in the hydropower projects .This is because quartz causes the wearing or erosion of the turbine and its components because of its hardness.

4. Write main tasks for EGS in detailed design phase of Civil Engineering Projects. [2072 Ashwin]

Ans: see 1.1.5

5. Write down Parameters of Engineering Geological system. [2072 Magh]

Ans: see 1.1.1

6. What are the Major Engineering Geological tasks for Evaluation of Engineering Geological System in detail design phase? Define Rock forming mineral. [2071 Magh]

Ans: see q no.4

For second part see 1.2

7. Describe about the preparation of Engineering Geological Map in the field? [2071 Bhadra, 2069 Bhadra]

Ans: see 1.4

8. Describe the Engineering Significance of the Rock Forming Minerals.[2070 Bhadra]

Ans: see 1.2

9. Write the scope of Engineering Geology in the field of Civil Engineering.

Ans: Geology has scope in different field. Some of the important fields are listed below:

Civil engineering: Geology provides necessary information about the site of construction materials used in the construction of buildings, dams, tunnels, tanks, reservoirs, highways and bridges. Geological information is most important in planning phase (stage), design phased construction phase of an engineering project.

Mining: Geology is useful to know the method of mining of rock and mineral deposits on earth's surface and subsurface.

Water resource: Resources development geology is applied in various aspects of resources and supply, storage, filling up of reservoirs, pollution disposal and contaminated water disposal.

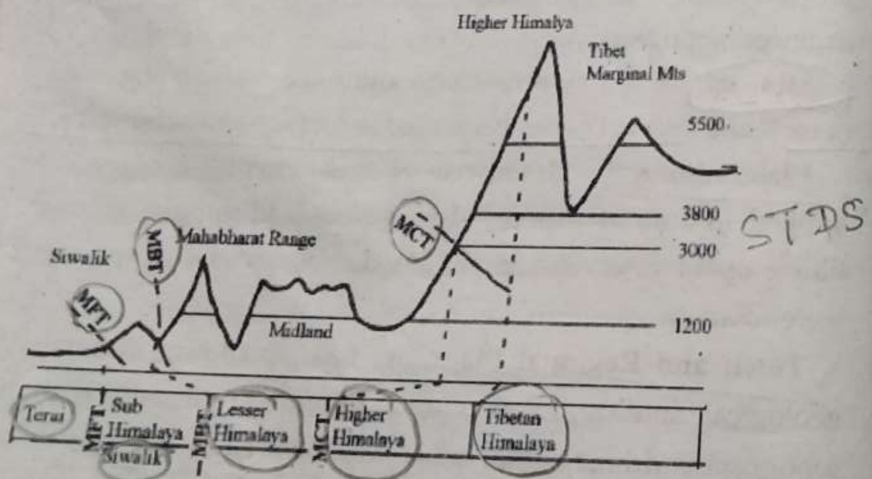
Town and Regional Planning: town planning also needs geological studies because they provide information about topography, drainage that is network of streams, ground water availability etc.

CHAPTER-2

ENGINEERING GEOLOGY IN THE HIMALAYAS

The Himalayan range is considered as one of the youngest mountain system in the world. The Himalayas are formed as a result of collision between the plates. The Himalayas has a span of nearly 2400km and extends from the Punjab Himalayas in the west to Arunachal Pradesh in the East. The Himalayas are regarded as the most fragile, active and highly stresses mountain range in the world.

Nepal Himalayas occupy the central part of the Himalayan belt. Nepal Himalayas undergo highly dynamic physical processes and hence are always at a risk of earthquake or any seismic disasters. Due to its instability, the implementation of any project is very difficult in such condition and hence proper and effective methods of designing, construction and implementation must be adopted.



2.1 Major Discontinuities System of the Nepal Himalaya and Their Engineering Significance

2.1.1Discontinuity: A discontinuity is a zone within the earth which marks a change in physical or chemical properties of the earth. For example change in velocity of earthquake wave occurs as the waves proceed.

It marks the boundary between different layers. It can be a joint, a foliation, a fracture etc.

The major discontinuities system of the Nepal Himalaya is as follows:

i) Main Frontal Thrust(MFT)

ii) Main Boundary Thrust(MBT)

iii) Main Central Trust(MCT)

Tibetan Tethys zone

—— —— —— —— STDS

Higher Himalaya

—— MCT ——

Lesser Himalaya

—— MBT ——

Siwalik

—— MFT ——

Terai

In MCT, MFT, MBT;"T" represents "thrust". Thrust is a low angle fault. A fault is defined as a parallel surface where the relative displacement between two rock blocks has taken place. There, thrusts are seismically active and dipping towards the north. Besides these many local faults, folds and joints are encountered along the Nepal Himalaya.

The discontinuities are described below:

i) **Main Frontal Thrust(MFT):** It is also known as the Himalayan Frontal Thrust .It is regarded as the youngest structure and is considered to be very active. It is located at the interface of terai and siwalik. It lies in the southern part of the Himalayan belt. It is assumed to have originated around 1.6 million years ago. The maximum potential of this fault is 6.5 magnitudes.

ii) **Main Boundary Thrust(MBT):** MBT is a major structural plane that separates siwalik from the lesser Himalaya and is assumed to be noticeable throughout the length of the Himalayas. It is regarded as a north dipping fault. It is still active and has been a source of very large earthquakes in the past. It is found to fatten with depth. The maximum earthquake noted is 8 magnitudes.

iii) **Main Central Thrust(MCT):** It is another major geological fault which separates the lesser Himalaya from the higher Himalaya. It is a north dipping fault. It has been reactivated, deactivated and again reactivated several times in the history. However, it is considered to be less active than MBT. The maximum earthquake noted is of 7.5 magnitudes.

IMP

2.1.2 Significance of the discontinuities

The major significance of the discontinuities are as follows:

i) The thrusts are seismically active zones. They are north dipping and hence are at a high risk of earthquakes. The violent and continuous shaking of the earth may cause the collapse of the structure.. Hence large engineering projects are avoided in such areas.

ii) Mass movement occurs in this zone which is a huge threat to the projects.

iii) It is a zone of high porosity and is always at a risk of slips and sides.

iv) The thrust has many cracks and causes severe seepage problems.

v) The thrust is very prone to landslides. Hence if construction is carried out in such areas then it may result in failure of the project. Proper civil engineering structure must be constructed to prevent from landslides

vi) It causes instability of the water table.

An alternate site must be looked for as far as possible. However, if alternate site is not present or small project is to be constructed then stabilization methods and other prevention must be applied.

2.2. Major Engineering Geological problems of the Terai, Siwalik, Lesser Himalaya and higher Himalaya and Their Mitigating Measures

The different geological divisions with their problems and mitigating measures are as follows:

A. Geology of Terai zone:

Terai zone extends from Indo Nepal border in south to the base at Churia or Siwalik hills in the north. Its altitude ranges from 100 to 200 masl and having a subtropical climate. It's width varies from 10 km to 50 km nearly continuous belt from east to west, exceptions being along the Chitwan and Rapti valleys. It is composed of alluvium deposits consisting of coarse sediments in the north and finer sediments like silt, clay in the south. The age of rock is recent. Itis further divided into sub divisions:

i) Bhabhar zone (Northern) Terai ii) Middle Terai

iii) Southern Terai

This zone is separated from Siwalik zone in north by Main Frontal Thrust (MFT) or Himalayan Frontal Thrust.

The major geological problems of Terai and their mitigating measures are given below:

PROBLEMS	CAUSES
a) **Flooding**: Most of the rivers of Nepal reach the Ganga River in India through the Terai. Hence, Terai is always at a risk of flooding.	a) Excessive rainfall Low relief and flat area
b) **Subsidence**:The lowering of a land is called a subsidence.	b) Presence of unconsolidated sediments High movement of groundwater
c) **Scouring or river erosion**:It is the process of removal of sediments.	c) High velocity of the flowing rivers Presence of meandering river
d) **Excessive deposit of sediments**:It is the process of accumulation of sediments carried by the river as it flows.	d) Flow of suspended particles in a river
e) **Earthquake**:Sudden vibration of land accompanied by the release of energy is called earthquake.	e) Plate tectonics Active tectonic structures
f) **Liquefaction**:It is the phenomena in which the solid soil behaves like a viscous liquid temporarily.	f) Travel of s waves in water saturated ,unconsolidated soil
g) **Channel shifting of river**:It is the lateral shifting of river channel.	

settlement

Mitigating Measure

i) **Construction of buildings at high foundation level:** If buildings are constructed with their foundations at higher level than that of flood line, ~~then the flooding~~ can be prevented to some extent

ii) **Improvement of soil:** Various methods of soil improvement like grouting of soil, pre-loading, addition of admixtures, dynamic compaction etc. must be carried out in order to improve the quality of soil and made it compact and fit for construction

iii) **Earthquake resistant buildings:** As Nepal is always at a risk of earthquake; buildings must be constructed by adopting suitable building codes and made earthquake resistant. The buildings must be strong enough to sustain human life during the crisis period.

iv) **Use of proper civil engineering structures:** Civil engineering structures like wire meshes should be used at the side of the river. Gabion walls must be used as retaining structures wherever necessary.

v) **Proper drainage management:** Proper floodways must be constructed in order to divert the flood flow.

vi) **Detail study:** For phenomena like liquefaction, detail study must be carried out and the action must be taken accordingly.

B. Geology of Siwalik or churia or Sub Himalayan zone:

Siwalik rises from northern part of plains of Terai zone and forms southernmost mountain range of the Himalaya. It is narrow belt of 10-50 km in width, Siwalik Hills typically ranging in altitude from 200-1000 m and rises to 1300 m in many places. This zone is composed of loose to consolidated north dipping sedimentary rocks like conglomerate, sandstone, silt stone, mudstone and marls. The Churia hills are the youngest mountain range of the Himalayan formed in mid-

Miocene to Pleistocene age. They are further divided into three zones.

Upper Siwalik - consists of conglomerates
Middle Siwalik - consists of coarse sediments
Lower Siwalik - consists of fine sandstone, mudstone

This zone is separated from Terai zone in the south by Main Frontal Thrust (MFT) and Lesser Himalaya zone in the north by Main Boundary Thrust (MBT).

The major geological problems of Siwalik and their mitigating measures are given below:

PROBLEMS	CAUSES
a) **Mass movement:** The movement of large portion of land is called mass movement	• Presence of cracks in the rocks. • Heavy rainfall • loose soil • High slope • Rapid melting of snow
b) **Gully erosion:** The process of removal of soil along the drainage lines by surface runoff is called gully erosion.	• continuous and heavy rainfall • Deforestation and lack of vegetative cover • High slope • Unstable soil along the drainage
c) **Earthquake:** Sudden vibration of land accompanied by the release of energy is called earthquake.	• Plate tectonics • Active tectonic structures
d) **Scouring or river erosion:** It is the process of removal of sediments.	• High velocity of the flowing rivers • Presence of meandering river
e) **Creep:** It is a slow downward movement of particles.	• due to alternate freezing/thawning/drying of soil particles.
f) Debris flow: The process of rushing down of mass of soils laddened with water is called debris flow.	• Heavy rainfall and loose soil

Mitigating Measure

a) **Earthquake resistant buildings:**
As Nepal is always at a risk of earthquake, buildings must be constructed by adopting suitable building codes and made earthquake resistant. The buildings must be strong enough to sustain human life during the crisis period.

b) **Use of proper civil engineering structures:**
Civil engineering structures like wire meshes should be used at the side of the river. Gabion walls must be used as retaining structures wherever necessary.

c) **Proper drainage management:**
Proper flow ways must be constructed in order to divert the flood flow.

d) **Detail study:**
Detail study must be carried out and the action must be taken accordingly.

e) **Bio engineering:**
It is highly cost effective and ecofriendly method. When it is used in combination with civil and social engineering means, it reduces the overall cost of mitigation of various hazards.

f) **Slope treatment:**
Slope stability may be carried out by grouting of rocks and also carrying out rock Bolting in the rocks

C. Geology of Lesser Himalayan zone: Lesser Himalayan zone lies to the north from the Siwalik in between the Sub-Himalayan and Higher Himalayas separated by Main Boundary Thrust (MBT) and Main Central Thrust (MCT). It has width 60-80 km and has complicated geology due to folding, faulting, and thrusting. They are divided into ~~three~~ Two physiographic units - the Mahabharat, Midlands and Fore

Himalaya. The zone is made up of mostly unfossiliferou sedimentary and meta-sedimentary rocks such as shal sandstone, limestone, dolomite, slate, phyllite, schist an quartzite ranging in age from Precambrian to Eocene. Low t medium grade rocks are found in this zone. In some region magnetic intrusions like granite, pegmatites etc. are als found.

The major geological problems of Lesser Himalaya and the mitigating measures are given below:

a) **Mass movement:** The movement of large portion of landmass is called mass movement.	• Presence of cracks in the rocks. • Heavy rainfall • Loose soil • Steep topography • Rapid melting of snow
b) **Debris flow:** The process of rushing down of mass of soils laddened with water under the effect of gravity is called debris flow.	• Heavy rainfall and loose soil
c) **Earthquake:** Sudden vibration of land accompanied by the release of energy is called earthquake.	• Plate tectonics • Active tectonic structures
d) **Flash flood:** A flash flood is a sudden rapid flooding of an area.	• Heavy rainfall • Narrow and steep flowing river. • When the hard surface like roads and concrete don't allow the draining of water ,then it result in overflow leading to flash flood
e) **Weathering:** It is the process of decay, disintegration and decomposition of rocks as a result of which rocks gradually get worn out. It leads to mass wasting.	• Alternate rainfall and sunshine
f) **Toe cutting:** It is one of the action caused by rivers.	• High velocity of the flowing rivers.
g) **Rock fall and rock toppling:** It is the falling down of rocks of different sizes.	

Mitigating Measure

a) **Earthquake resistant buildings:**

As Nepal is always at a risk of earthquake; buildings must be constructed by adopting suitable building codes and made earthquake resistant. The buildings must be strong enough to sustain human life during the crisis period.

b) **Use of proper civil engineering structures:**

Civil engineering structures like wire meshes should be used at the side of the river .Gabion walls must be used as retaining structures wherever necessary.

c) **Proper drainage management:**

Proper floodways must be constructed in order to divert the flood flow.

d) **Site investigation:**

Proper site investigation must be carried out and the design must be made accordingly.

e) **Bio engineering:**

It is highly cost effective and ecofriendly method. When it is used in combination with civil and social engineering means; it reduces the overall cost of mitigation of various hazards.

f) **Slope treatment:** Slope treatment may be carried out by grouting of rocks and also carrying out rock bolting in the rocks.

g) **Afforestation:**

Plantation of tress must be done

D. Geology of Higher Himalayan Zone:

This zone lies in the north from the Lesser Himalaya zone and is separated by Main Central Thrust (MCT). This zone is of 10-12 km thick and consists of succession of high grade metamorphic rocks known as Tibetan slab. High grade metamorphic rocks like gneisses, marbles, schist, quartzite etc. in association with high grade index minerals like Kyanite, garnet etc. are found in this zone. This zone consists of high snow covered mountain chain and has extremely high relief, steep topography, rocky cliff and outcrops with little soil cover terrain.

The major geological problems of Higher Himalaya and their mitigating measures are given below:

PROBLEMS	CAUSES
a) ***Mass movement:*** *The movement of large portion of landmass is called mass movement*	• Presence of cracks in the rocks. • Heavy rainfall • loose soil • steep topography
b) ***Earthquake:*** *Sudden vibration of land accompanied by the release of energy is called earthquake.*	• Plate tectonics • Active tectonic structures
c) ***Wind erosion:*** *It is the process of removal of loose rock particles by the action of wind and produces many changes on the surface of the earth*	• Presence of dry and small fragments of rocks and soil particles • Wind speed large enough to lift the particles • No vegetation cover
d) *Glacier Lake Outburst Flood(GLOF):* When a dam or any structure that binds the glacier fails then GLOF occurs.	

e) **Snow avalanche:** It is common in steep slopes. The snow in huge bulk falls under gravity causing serious problems.	• Vibration • Human activity like snow sports
f) **Rock fall:** It is falling of rocks under the influence of gravity.	• weak and fracture rocks • heavy rainfall
g) **Weathering:** It is the process of decay, disintegration and decomposition of rocks as a result of which rocks gradually get worn out. It leads to mass wasting.	• Alternate rainfall and sunshine

Mitigating Measure

a) **Earthquake resistant buildings:**

As Nepal is always at a risk of earthquake; buildings must be constructed by adopting suitable building codes and made earthquake resistant. The buildings must be strong enough to sustain human life during the crisis period.

b) **Use of proper civil engineering structures:**

Civil engineering structures like wire meshes should e used at the side of the river. gabion walls must be used as retaining structures wherever necessary.

c) **Proper drainage management:**

Proper floodways must be constructed in order to divert the flood flow.

d) **Site investigation:**

Proper site investigation must be carried out and the design must be made accordingly.

e) **Bio engineering:**

It is highly cost effective and ecofriendly method. When it is used in combination with civil and social engineering means; it reduces the overall cost of mitigation of various hazards.

f) **Slope treatment:**
Slope treatment may be carried out by grouting of rocks and also carrying out rock bolting in the rocks.

g) **Afforestation:**
Plantation of tress must be done.

h) Proper Locating of glaciers and lakes must be done.

i) Avalanche zoning must be done.

j) Artificial deepening of the natural sillway can be done in order to prevent GLOF.

E. **Geology of Tibetan – Tethys zone:**

This zone lies to the north of Himalayan zone. This zone is composed of fossiliferous sedimentary rocks like shale, limestone, sandstone etc. This zone has lower relief and ruggedness than Higher Himalayan zone. This wide valley is covered with thick glacial and fluvial-glacial deposits along with recent alluvium. These deposits are very loose and fragile. Steep slopes are dominated at places. The sedimentary rock found in Tethys sea is found in this zone.

The major geological problems of Tibetan Tethys zone and their mitigating measures are given below:

Problem	Causes
a) **Earthquake:** Sudden vibration of land accompanied by the release of energy is called earthquake.	•Plate tectonics •Active tectonic structures
b) **Wind erosion:** It is the process of removal of loose rock particles by the action of wind and produces many changes on the surface of the earth.	•Presence of dry and small fragments of rocks and soil particles •Wind speed large enough to lift the particles •No vegetation cover

c) **Rock fall:** It is falling of rocks under the influence of gravity.	•fractures of rocks •heavy rainfall • week rocks
d) **Debris avalanche:** The process of rushing down of mass of soils laddened with water is called debris avalanche.	

Mitigating Measure

a) **Earthquake resistant buildings:** As Nepal is always at a risk of earthquake; buildings must be constructed by adopting suitable building codes and made earthquake resistant. The buildings must be strong enough to sustain human life during the crisis period.

b) **Use of proper civil engineering structures:** Civil engineering structures like wire meshes should be used at the side of the river .Gabion walls must be used as retaining structures wherever necessary.

c) **Site investigation:** Proper site investigation must be carried out and the design must be made accordingly.

d) **Afforestation:** Plantation of tress must be done.

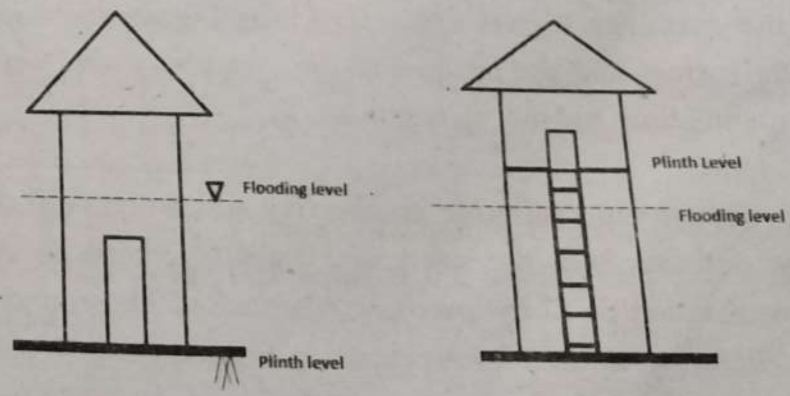


Fig: Construction of buildings with high foundation level

2.3. Importance of Engineering Geological Information System in Nepalese context:

Nepal is a country which is situated in a region of active plate tectonics. It is characterized by complex structural deformations, geo hazards, highly dynamic physical processes and instabilities. Hence carrying out any civil engineering structure is very difficult and challenging. Itrequires highly advanced techniques and innovative approaches .Hazards like flooding and scouring is famous in the terai area of Nepal whereas the problems of landslides, rock falls rock toppling is common in the Himalayas. They give rise to serious threats to the civil engineering projects. Problems of faults, folds are common throughout Nepal and must be evaluated properly. GLOF and snow avalanches create more difficulties in implementing the projects. Hence engineering geological system is very important in the context of Nepal. It helps in proper analysis of these problems and provides proper and sound solutions to them. It helps in carrying out proper studies keeping in mind all the past problems and the future problems that may arise. It gives a clear idea to an engineering regarding the terrain and the features of the area and saves him from wasting time and money unnecessarily.

It helps in producing an effective and economical design that satisfies both the safety and stability criteria. If proper consideration of all the problems like faults,folds,groundwater condition etc. is not done,especially in a country like Nepal then all the engineering structures will fail, immediately after the completion of construction.

EXERCISE

1. State the major Geotechnical Problems in Lesser Himalaya. [2068 Magh].
   Ans:See 2.1.1
2. What are the Geological problems of lesser Himalaya and terai zone? What are the preventive measures for landslide? Describe[2074 Bhadra]
   Ans:For first part see2.2(i)&(iii)
   Preventive measures:
   - Retaining structure
   - Drainage structure
   - Rock bolting
   - Bio-engineering Technique
3. Explain the Engineering Significance of Major discontinuities system in the Nepal Himalaya. [2069 Poush]
   Ans: see 2.1.2
4. Highlight the Major discontinuities system of Nepal Himalaya and their Engineering Significance. [2069 Bhadra]
   Ans: see 2.1.1
5. Explain the Engineering Significance of Major discontinuities System of the Nepal Himalaya. [2070 Magh]Ans: see 2.1.2
6. What are the different type Engineering Geological problems in the Terai zone of the Nepal Himalaya? [2070 Bhadra]
   Ans: see 2.2(i)

CHAPTER -3

HYDROGEOLOGY

Introduction

Hydrology: Hydrology is the branch of science that basically deals with everything related to water. It includes the study of its origin, occurrence, movement, its transport from the atmosphere to the earth and vice versa, its forms and other hydrological phenomena that take place.

hudour (water) + logos (science) = hydrology

Hydrogeology:

The branch of geology that deals with the study of occurrence, movement and quality of water beneath the earth surface is called hydrogeology.

Hydrological Cycle:

The cycle that represents the flow of water from the surface or below the surface to the atmosphere in the form of vapour and back to the surface of the earth in the form of precipitation and the conveyance of precipitated water to oceans is called hydrological cycle. The basic processes that place are evaporation, transpiration, interception, infiltration, runoff, precipitation etc.

3.1 River Channel Morphology

River is defined as a water body which flows from higher relief to lower relief and carries sediments along its flow.

There are three types of river:

i) Straight river:

The river which flows in a straight path is called Straight ri[ver]. The velocity of this type of river is very high. The high stren[gth] of river results in higher erosional rates. Deep scouring alo[ng] the path of river is higher than side cuttings. Hence proper ca[re] must be taken while carrying out construction in such areas, the river causes intense scouring effects. Run off typ[e] hydropower and arc bridge is applicable in straight river. Ste[ep] pitching and plantation must be done to prevent the problem of scouring.

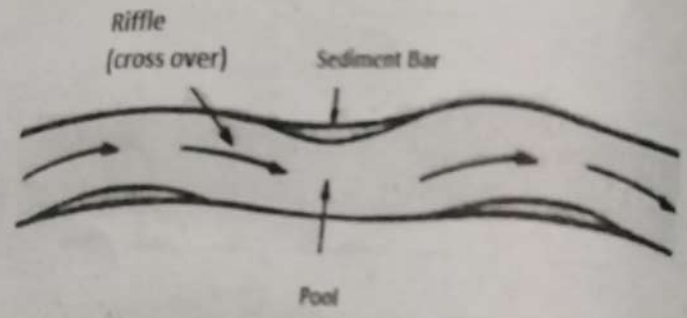


Fig: Straight River

(ii) Meandering river:

The river that follows a Zig Zag pattern or path is called meandering river. It is characterized by gentle gradient and the rate of erosion and deposition is almost equal .The side cutting of the river is higher than deep scouring along the path of the river. While constructing a bridge in such rivers, stable, narrow bend must be selected so that the length of the bridge is short and the construction work can be completed in lower cost. The run off as well as Reservoir in the meandering river may be provided based upon the site conditions.

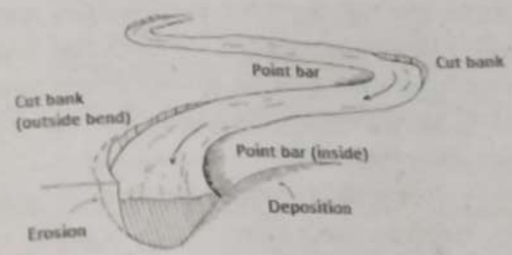


Fig: Meandering River

(iii) **Braided rivers:** The river that has many channels and is formed due to the overloading of sediments carried by the river is called braided river. This type of river has low velocity. The depositional rate is higher than the erosional rate.

The construction materials like stones, Sands, gravels etc. are found in this river and can be used for construction purpose. Bridges with large spans are required in this type of river. Hydropower projects are not possible in this type of river.

Fig: Braided River

3.2 Origin, Type and Movement of Ground Water, Porosity, Permeability and Hydraulic transmissibility of Different Rocks and Sediments

3.2.1

Groundwater: The water that is available below the ground surface and exists in pore spaces and rock fractures is called ground water or subsurface water.

The water after falling on the earths surface infiltrates the ground and produces groundwater. The encounter groundwater in any engineering project except water sup engineering is considered unfavourable. The major sources groundwater are as follows:

1. **Springs:** A spring is a natural outflow of groundwa through rock fractures , rock pores, joints or faults at a regio where the water table intersects the ground surface.

It can be classified into two categories:

a) **Gravity springs:**

The springs that result from gravitational forces are calle gravity springs.

Depression springs, contact springs and artesian spring fall under this category.

i) **Depression springs:**

The springs formed due to the outflow of water where the ground surface intersects ; the water table due to topographic undulations is called depression springs. It may be seasonal and depends mostly upon the rise and fall of water table.

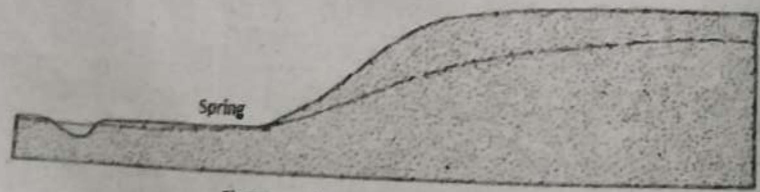


Fig:Depression Spring

ii) **Contact springs:**

The springs that are formed where a permeable rock overlies a rock of low permeability are called contact springs. The lithological contact is usually marked by a line of springs.

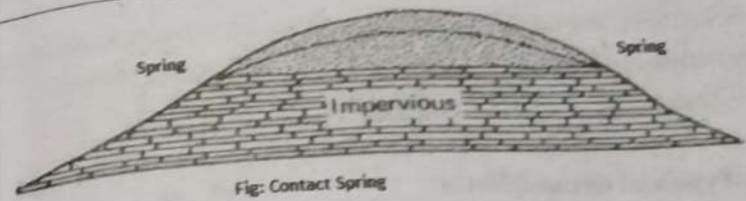
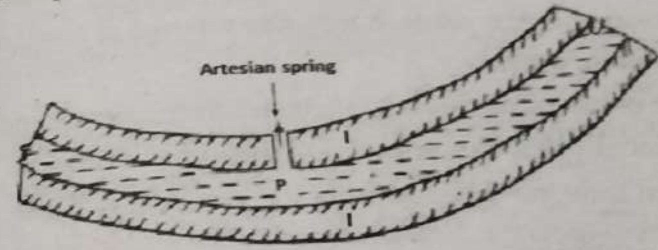


Fig: Contact Spring

iii) **Artesian springs:** The springs that are formed due to the release of water from confining beds under pressure are called artesian springs. The amount of water available in such springs depends upon the catchment area.



P- Pervious layer
I- Impervious layer   Fig: Artsian Spring

b) **Non-gravity springs:** The springs that result from non-gravitational forces are called non-gravity springs. Fracture springs and volcanic springs fall under this category.

i) **Fracture springs:** The springs that are formed due to the existence of fracture extending to greater depths in the permeable zones are called fracture springs. The springs are formed where the fracture intersects the land surface.

ii) **Volcanic springs:** The springs that are formed due to volcanic eruptions and are associated with volcanic rocks are called volcanic springs.

2. **Wells:**

A well is a hole or shaft that is made on the ground by the excavation of soil inorder to get the underground water. It is usually vertical. The wells can be dug into various types of rocks and the quality and quantity of water avail depends on the various rock types. It can be of two types

(i) Open wells (ii) Tube wells

3.2.2.Types of Groundwater:

The various types of groundwater available are as follows:

i) **Connate water.**

The water that is trapped in the pores of the rock dur the formation of the rocks is called connate water. M connate water is saline. It may also referred as fossil wate

ii) **Meteoric water:**

The ground water which originates from rainfall and oth forms of precipitation such as hailstorms and snow fall called meteoric water. Most of the groundwater falls und this category.

iii) **Juvenile water.**

It is also referred to as magmatic water. .It is the water th is formed in the cracks due to the condensation of stear emitted from hot molten magmas. It usually has hig mineral content.

iv) **Confined water:**

The water that is confined between the aquicludes an aqifuge is called confined water.

v) **Unconfined water:**

The water that lies below the water table and can mov freely in upward or downward direction is calle unconfined water.

3.2.3 Occurrence of Groundwater :

The groundwater is found to exist in two zones:

i) **Saturated zone/Groundwater zone/Phreatic zone:**

It is also known as water extraction zone. All the pores and fractures are saturated with water. There is very little or no downward movement of water in this zone.

ii) **Vadose zone/Zone of aeration/Water unsaturated zone:**

As the name implies, it is the zone in which the pores and fractures are not saturated with water but rather are filled with air and water. The water can't be extracted from this zone. This zone is further divided into 3 zones:

a) soil water zone

b) intermediate zone

c) capillary zone

3.2.4 Factors controlling the occurrence and movement of groundwater:

The occurrence and movement of groundwater depends upon various factors. Some of the factors are listed below:

A. Climate:

Climate is one of the factor controlling the occurrence and movement of groundwater. In is found that about 5cm rainfall in one hour facilitates more runoff and results in less filtration. However, a rainfall of about 5m in 24 hours facilitates less run-off and more infiltration. In area where the climate is humid ,more water is lost due to evaporation and transpiration and hence very less amount of water will infiltrate resulting in less amount of groundwater.

B. Topography:

The area with steep topography has more runoff of the precipitated water and results in less infiltration. In contrary to it, the areas with gentle topography facilitates more infiltration and less runoff. In areas with horizontal land or depressed land, there is negligible amount of runoff and almost all wa infiltrates into the ground.

C. Porosity:

Porosity is defined as the ratio of volume of voids to t total volume. In simple words, Porosity is the amount of emp space in the aquifer that is available to hold water.. It is usual expressed as a %.

Mathematically it is written as:

porosity(n) = (Volumes of volds (Vv) * 100) / Total volume(V)

There are two types of porosity:

a. **Primary porosity:** The porosity that is developed durin the decomposition of sediments.

b. **Secondary porosity:** The porosity that is developed afte the formation of rocks such as joints, racks etc.

Well sorted sediments have greater porosity than poorl sorted sediments.

Sedimentary Rocks	
Rock Type	**Porosity (%)**
Sandstone	14 - 49
Siltstone	21 - 41
Claystone	41 - 45
Shale	1 - 10
Limestone	7 - 56
Dolomite	19 - 33

Crystalline Rocks	
Rock Type	**Porosity (%)**
Basalt	3 - 35
Weathered granite	34 - 57
Weathered gabbro	42 - 45

Material	**Porosity (%)**
Soil	55
Clay	50
Sand	25
Gravel	20
Limestone	20
Sandstone (unconsolidated)	11
Granite	0.1
Basalt (young)	11

C. Permeability:

Permeability is a measure of how easily water can pass through any material. flows quickly through materials that have high permeability and flows very slowly through material that have low permeability. For example if we pour water into a bucket of gravel, the water will flow around the stones rather quickly but If you pour water over a bucket of sand however, the water will move more slowly. A bucket of gravel has a higher permeability than a bucket of sand, hence the water passes through the material more easily.

D. Hydraulic Gradient:

The ratio of head difference between two points and the distance between two points is called hydraulic gradient.

$$\text{Hydraulic Gradlent (I)} = \frac{hl}{L}$$

where,

hl=head loss between two points

L=distance between two points

E. **Hydraulic conductivity:**

Hydraulic conductivity is defined as the flow velocity per unit hydraulic gradient.

Sedimentary Rocks Rock Type	Hydraulic Conductivity (m/sec)
Karst and reef limestone	1×10^{-6} to 2×10^{-2}
Limestone, dolomite	1×10^{-9} to 6×10^{-6}
Sandstone	3×10^{-10} to 6×10^{-6}
Siltstone	1×10^{-11} to 1.4×10^{-8}
Salt	1×10^{-12} to 1×10^{-10}
Anhydrite	4×10^{-13} to 2×10^{-8}
Shale	1×10^{-13} to 2×10^{-9}

F. **Hydraulic transmissivity:**

Transmissibility is most simply defined as the effective hydraulic conductivity of an aquifer or other water-bearing unit multiplied by the thickness of that unit.

G. **Geological formations:**

Geological formations like aquifer, aquiclude, aquifuge alter the transmission of water.

H. **Vegetation cover:**

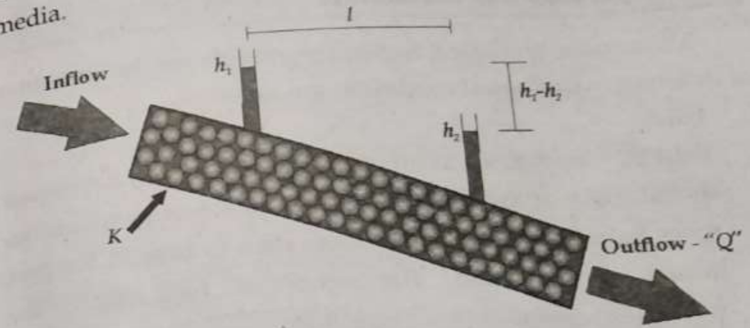
If there is a presence of vegetative cover, then most of the water gets intercepted by the vegetation and hence results in more infiltration of water. More infiltration of water means that more water will reach the ground water table.

3.2.5 Movement of ground water

Water moves from a region of higher elevation to lower elevation. The movement of ground water is governed by Darcy's Law.

Darcy's Law: A French engineer Henri Darcy , in 1856 formulated a relationship between the rate of flow of water through a porous medium to other parameters. The rate at which groundwater moves through the saturated zone depends on the permeability of the rock and the hydraulic gradient. It is

the basic law which governs the fluid flow through porous media.



Assumptions:

The following are the "Darcy's law" assumptions.

i) Soil is saturated.
ii) The Flow through soil is taken as laminar.
iii) The stable and continuous flow is considered.
iv) Total cross sectional area of soil mass is considered.

It is states that; **the rate of flow is directly proportional to the difference in hydraulic head between two points and inversely proportional to the distance between those two points.**

This law is explained by using following equation.

$$Q = KiA$$

$$\frac{Q}{A} = Ki$$

$$V = Ki$$

Here, q is flow rate, A is total cross sectional area of soil mass, i is hydraulic gradient $\left(\frac{h}{L}\right)$, k is Darcy's Permeability coefficient of, and v is velocity of flow.

3.3 Geological Factors for Formation of different Hydrological Conditions

The various geological factors responsible for the formation of different hydrological conditions are as follows:

i) **Folds:**

Fold may be defined as an undulation or a bend develops in the rocks of the earth as a result of stress to which the rocks have been subjected to from time to time in the past history of the earth. The nature of fold affects the availability of water.

ii) **Faults:**

A fault is a rupture developed in the rock mass along which there has been a relative displacement of two sides parallel to the fracture plane. Fault is a result of brittle deformation due to tensional and compressive forces. They are porous and weak zones. If the fault zone consists of finely ground rock and clay (gouge), the material may have a very low hydraulic conductivity. Significant differences in groundwater levels can occur across faults.

iii) **Unconformities:**

Unconformity is a contact between two rock units in which the upper rock is younger in comparison to the underlying rock. It

iv) **Geological formations:**

The major types of geological formations are as follows:

- **Aquifer:**

An aquifer is a geological formation that contains layer of water bearing permeable rock which allows the storage as well as the extraction of water using water well. The amount of water an aquifer can hold depends upon the volume of voids

present in the aquifer and its ability to transmit the water depends on permeability. Most aquifers are layers of sand, gravels or stones. The aquifers are generally aerially extensive and may be overlain or underlain by confining beds.

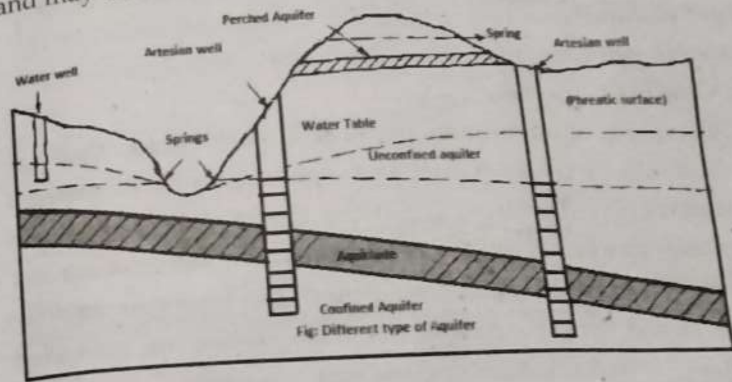


Fig: Different type of Aquifer

Confining beds:

A confining bed is a layer of geological material that hampers the movement of water into and out of aaquifer. Example: unfractured igneous rocks, metamorphic rock, sand, shale etc.

It is of following types:

i) **Aquicludes:**

The geological formation that permits the storage of water but by virtue of its properties, is not capable of transmitting water in sufficient quantity is called an aquiclude. It is o be treated as practically impermeable layer. Exampe :Clay

ii) **Aquifuge:**

The geological formation that neither permits the storage of water nor is capable of transmitting water is called aquifuge. It is made up of relatively impermeable material. It is free from pores. Example; Solid granite

iii) Aquitard:

When the aquifuge or aquiclude becomes locally leaky due to the development of partial perviousness caused as result of jointing or cracks then they are called aquitards.

Types of Aquifers:

There are two types of aquifers. They are;

- **Confined Aquifers**

Confined aquifers are permeable rock units that are bounded by layers of finer and more impermeable materials such as clay. The ground water is confined under pressure greater than atmospheric pressure by overlaying strata and hence it is called pressure aquifer. The confined aquifers are sealed in impermeable rock and hence are protected from contamination. Confined aquifers may be replenished. Replenishment can take a long time as its source of water is underground systems that have to travel long distance. Groundwater in these aquifers can sometimes be thousands of years old. It has low flow yield and has medium to low conductivity. It occurs at significant depth below the ground surface.

- **Unconfined Aquifers**

The aquifer in which the groundwater is in direct contact with the atmosphere through the open pore spaces of the overlying soil or rock is said to be unconfined aquifer. It lies between the zone of aeration and impermeable layer.It is bounded by porous rocks like limestones or sand and gravels. The upper groundwater surface in an unconfined aquifer is called the water table.

It is at a higher risk of contamination from bacteria and other organic matters as it is exposed to many external

sources like rain, streams etc. The rate of replenishment depends on its proximity to external water source and time it takes for water to recharge it, which in turn depends on soil and sand consistency or porosity of rock. It has high flow yield and medium hydraulic conductivity. It is found near the ground surface. It is also called water table aquifer.

They are usually recharged by rain or stream water infiltrating directly through the overlying soil. Typical examples of unconfined aquifers include many areas of coastal sands and alluvial deposits in river valleys.

3.4 Different types of Aquifer systems of Nepal

3.4.1 General hydrogeology of Nepal

a) **No groundwater potential zone**

Except the unfractured granite, gneiss of higher metamorphic grade in midland and higher Himalaya, the rest of the geology has potential for groundwater.

b) **Highly productive aquifer**

It consists of loose sediments of terai and inner terai.

c) **Moderately productive aquifer**

It consists of unconsolidated deposits of Kathmandu and surkhet valleys,siwalik rocks, non-krastic but fractured carbonate rocks in lesser Himalaya.

3.4.2 Different types of Aquifer system in Nepal

Mountain aquifer zone: The aquifers that are formed due to primary and secondary porosity are called mountain aquifer systems. Examples: caves, caverns and solution channels in limestones

Bhabar Zone: The aquifers that mostly consists of alluvi sediments deposits as outwash fan.It is considered as recharg zone of Terai region

Terai aquifer zone:

It consists of unconsolidated materials deposited by fluvi processes.

The major aquifers are:

- Unconsolidated:They are shallow aquifers consisting o 20-50% aquifer materials.
- Confined aquifers: They are deep aquifers.

EXERCISES

1. Define Aquifer. Write a short note on a Ground water movemen [2068 Magh]
   Ans: For first part see 3.3
   For second part see 3.4.1
2. What are the different Geological factors for Mature of differen Hydrological conditions?[2069 Poush]
   Ans: see 3.3
3. What are different Aquifer System in Terai, Hills and Mountains of Nepal? [2069 Bhadra]
   Ans: see 3.4.2
4. Describe the Importance of Darcy's law in Groundwater Movement.[2070 Magh]
   Ans: The importance of Darcy's law are as follows:
   - It gives the relationship between the rate of flow of water through a porous medium to other parameters.
   - It is the basic law that governs the fluidflow through porous medium.
5. Describe Types of Aquifer with Suitable Diagram. [2070 bhadra]
   Ans: see 3.3

6. How Darcy's Law describes ground water movement? Describe characteristics of confining beds? [2071 Bhadra]
   Ans: See Q.No.4 for first part

Characteristics of confining beds:

- Very low hydraulic conductivity.
- It retards the movement of water into &out of an aquifer.

7. Describe the different types of Aquifer System of Nepal.[2072 Magh]
   Ans: see 3.4.2
8. Differentiate Aquifer and Confining bed. Mention Geological Factors for formation of Hydrogeological conditions [2073 Bhadra]Ans:

S.N	AQUIFER	S.N	CONFINING BED
1.	An aquifer is a geological formation that contains layer of water bearing permeable rock which allows the storage as well as the extraction of water using water well	1.	A confining bed is a layer of geological material that hampers the movement of water into and out of a aquifer
2.	It is of two types: • Confined aquifer • Unconfined aquifer	2.	It is of three types: • Aquicludes • Aquifuge • Aquitard

For second part 3.3

9. Describe the process of the groundwater movement. [2073 Magh]
   Ans: see 3.2.5
10. What are the geological factors for formation of hydrogeological condition? How do you differentiate aquifer and confining bed? [2074 Bhadra]Ans: see question no 2
    For second part 3.3

CHAPTER-4

ENGINEERING GEOLOGY IN SITE SELECTION, INVESTIGATION & CONSTRUCTION/EXCAVATION

4.1 Introduction, Types and Method

Site investigation is one of the important parts of any project a the suitability of construction of any project is analyzed with the data obtained from the site investigation. Site investigation is defined as the overall evaluation of specific site condition which is selected for construction of any civil engineering infrastructure.

4.1.1 Phases of site investigation

There are three phase of site investigation. They are described below:

[A] Preliminary Study:

It is the first stage of site investigation which consist of study the geological factors that are important in determining the suitability of the construction of structure on proposed site. In this phase, generally direct and indirect investigation methods are carried out. The phase supports the feasibility of projects as the result obtained are used for the further investigation of site.

[B] Detail Investigation:

After the preliminary study show positive sign for the construction of the project it is necessary to carry out site exploration for determining prevailing condition for project, design, planning which are important for

construction of project. For this direct surface investigation, direct and indirect sub-surface investigations are carried out. In this phase geological data are obtained analyzed and evaluation is done for the suitability of project in term of economy, safety etc.

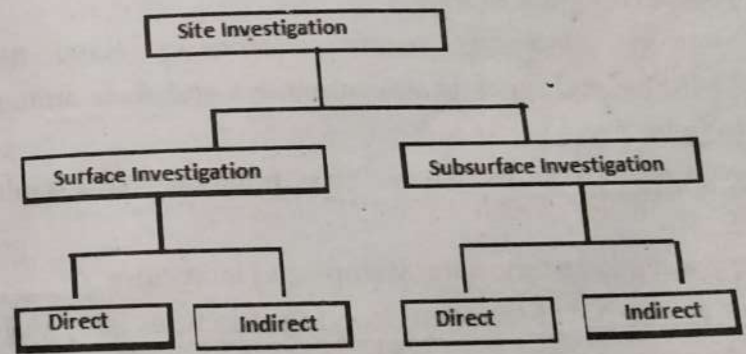
[C] Implementation Phase:

This phase starts after construction begins and taken as "learn as you go method". It is called so because the problem that we encounter is generally differ from what we were expected and we have to solve them by analyzing during the construction on real time.

4.1.2 Method of site investigation

Method of surface investigation #

There are mainly two type of surface investigation. They are



Surface Investigation:

Indirect surface investigation

Direct surface investigation

Indirect surface investigation #

In this investigation preliminary idea can be obtained about any specific site by not visiting directly the site.

- Review of previous literatures including geological maps if available.

- Topographical map analysis; slope drainage netwo[rk] existing structures.
- Remote sensing: Study and interpretation of aer[ial] photograph and satellite image using Stereoscope

Direct Surface Investigation

It is investigation carried out by visiting the actual si[te]. Information is collected and documented by observation, measurement and interpretation.

Following major data are to be collected in direct surfac[e] investigation

- Type of rock or soil and major component.
- *Attitude of rock*
- *Thickness of soil and rock*
- *Weathering grade of rock*
- Numbers, conditions, nature, weathering, water flow conditions and types of discontinuities and their attitude
- Strength of rock
- Geological structures like bedding, foliation, joints, faults, fold etc.
- Slope stability factors, natural slope and landslides

Presence or absence of major engineering structures like canals, dams, tunnels, bridge etc. Topography, drainage system, catchments area, flood level etc.

Indirect subsurface Investigation

- Mainly geophysical methods are used for indirect subsurface investigations..
- Following geophysical exploration methods can be used for the subsurface investigation:
- Seismic methods, electrical resistivity methods, gravity and magnetic methods, electromagnetic methods

- Using the data from geophysical methods and their correct interpretation, following data can be obtained

Type of material, ground water level, contact between geological formations and their thickness. Presence of aquifers or other structures like fault, fold and other discontinuities and also economically valuable materials and buried ancient heritage or engineering structures.

Direct Subsurface investigation

- Exploratory excavations: digging pits or trenches, dozer cuts tunneling
- Borehole exploration: Drilling , Logging

Depending upon the importance of the project, ~~budget~~ cost available and the extent of detail information needed, the spacing of drilling or digging may vary Hence subsurface exploration may be project specific and ~~budget~~ cost specific.

Bore hole exploration-is the process to drilling a hole in the ground. The test would include hand auger, motorized hand boring(wash boring), deep boring (rotary drilling) and trial pits.

Drilling -

direct method of subsurface exploration to find the nature of soil, geological structure, engineering properties of rock, porosity, permeability and water table

- using cable tool method and rotary

- Cable tool method-
  8 to 60 cm in diameter and depth of 600m in consolidated rock materials, is not effective in unconsolidated materials
- Rotary method- rapid method for drilling in unconsolidated bed Other common method are air rotary method, rotary-percussion method, reverse circulation rotary method etc.

- **Test method**
  - test pit- nature of ground, bedrock contact
  - trench-visual inspection and sampling wh… provide continuous profile of soil overburd… bedrock contact and structural features

- **Boring -**

  auger boring-

  commonly and less costly method to obtain soil sample, … not suitable for granular materials

- **wash boring -**

  in this method a steel chopping bit is churned inside a casi… 5 to 15 cm to break the rock and the cutting are floated … through the casing by wash water. The cutting then a… discharged into slump for nature and thickness … materials(disintegrated rock only)

- Core samples- cylindrical sample of rock to determine th… subsurface geology and ground condition and also used … bearing capacity of rock , attitude thickness structur… deformation and permeability Exploratory adits and shafts

  - adit- horizontal drill to observe joint, faults etc.
  - Shaft- vertical drill

4.1.3 Geophysical method:

Is a tool to detect the physical properties of the subsurfac… materials

i) Main methods used are
- Electrical method
- magnetic method
- Electromagnetic method
- Seismic method
- Gravity method

The sensing devices used are called geophones (microphoine) converts seismic vibration or motions of the earth to electrical impulses.

Limits of detection

- Detection of the target requires a strong contrast in Physical properties and suitable factors of scale and shape on the part of the target
- For each geophysical technique operating in a particular environment, detection requires that there is a minimum target volume whose dimension will depend on depth below surface and the average geophysical properties contrast of the proposed

Used to Detect

1. Depth of bedrock
2. Shape of bedrock surface
3. Depth of water table
4. Fault location
5. Rip ability assessment
6. Blasting assessment
7. Sand and gravel assessment
8. Cavity detection
9. Determination of dynamic elastic constant.

General Rules

Velocity is roughly proportional to the degree of consolidation Of rock or soil.

2. In consolidated materials, velocity increases with water content.
3. Weathering of rock will greatly reduce its velocity.

4. A particular rock type will include a range of velocities, these ranges may overlap for different rock types.
5. Correlation of velocity with the type of earth materials, great extent will depend upon the overall geology characteristics of the area under study.

Electric resistivity method: –

Give a physical property that characterizes a material almost definitely as its density.

Resistivity depends upon the quality and the quantity of water filling the open spaces in the rock.

The flow of current through soil and rock is by ion conduction which is dependent on a combination of the conductively of fluid present, porosity and percentage of saturation.

Dissolved salt

provide ion conductance of the electrical current -

Rock forming mineral-high resistive to current flow.

The resistivity method is a valuable one for identifying layer subsurface materials that have different electrical properties.

Gravity Method

- It measure density variation in the surface
- A Gravity survey provides a cumulative or integrated response of subsurface density variations -Typical applications of gravity surveys in site investigations are
- delineation of buried valleys and overburden troughs glaciated terrain
- the location of cavities in karsts environments and buried voids such as tunnels, mine adits etc.
- A gravity survey can be undertaken in areas where cultural noise precludes EM *electrical and even seismic surveying

- Changes in gravity values arise from vertical and lateral density contrasts in the subsurface Electrical Resistivity
- It methods requires the injection of electrical current through electrodes
- This method provides moderately detailed information about the subsurface in area of high resistivity. When current is injected into the ground through a pair of electrodes the patterns of subsurface flow of currents reflects the resistivity of the surface
- Main advantages of resistivity methods are low-cost and simple equipment requirements
- There is an analogy between the flow of fluid through a permeable medium and the flow of electricity through a conductive medium. For example the fluid potential and specific discharge are analogous to votage and current density respectively.

4.2 Geology in selection of The road alignments

Road:

Geological investigations play important role in the design, stability and economical construction and maintains of the roads .The most important step of the preliminary investigation is to locate the line of alignment with regard to geological setting of the area. Following geological condition is to be investigated for road

- Topography

- **Attitude of rock:** Horizontal or slightly dipping rocks with the strike parallel to the alignment of the road is favorable. Strength of rock: High strength of rock is favorable - Effect of water on rock: whether it dissolves the rock, weaken it .

1

- **Numbers of joints** : Minimum numbers of joints, ... spacing , rough joint plane or stepped, no or ... weathering along joints is favorable
- **Geologic structures** : absences of any structure like fau... fold, and unconformity is favorable , discontinuities
- If faulted, first to consider if it is active, if a road interse... an active fault nothing can be done to protect structure, ... alignment has to be shifted.
- Water table condition: seepage and spring can encoun... these are always be taken as weak and hazardous zones ... the road.

→ weathering

4.3 Geology in Site Investigation of Building, Bridge, Dams and Reservoirs

4.3.1 Building

1. **Soil characteristics and condition criteria**
   - The site have a stable soil and mostly consists of Non Cohesive soil(hard clay gravel and sand)
   - The site have a stable soil and mostly consists of rock.
2. **Groundwater condition**
   - The ground water table at the site should not be ver... high. High water pressure will also adversely affect th... stability of sloping ground and increase the loading o... a wall retaining the sloping ground
3. **Topography criteria**
   - The site is relatively flat. The levelled ground must b... selected.
4. **Geological structure**
   - The site should be free from the presence o... discontinuities. Such as fault fold joint

6 - 9 - 1

5. **Natural hazard criteria**
   Site must be free from any potential damage of injury from natural hazards. Effects of geological Hazards such as flood, mass movement etc. should be analyzed.

4.3.2 Bridge

discontinuity

Geological structure: like fold/fault and unconformity should be avoided

- Rock mass strength: should be high (competent bed), less fracture, joints in rock is favorable. - Attitude of rock: rock dip opposite to the water is favorable.
- Weathering : less weathered rock is favorable
- Expansive soil to be avoided.
- Lateral erosion (bank scouring) : The intensity of bank scouring in the site should be less
- Span of river: Narrow Span of river is desirable
- Drainage and catchments area: should be studied with available data on flood level. Particular attention needed to the origin, discharge and periods of high water.
- Environment Impact: the effect of structure to the surrounding region and that of surrounding region to the structure to be studied.

4.3.3 Reservoirs (X)

Permeability investigation:A reservoir is meant to hold water; hence the rocks and soils around as well as below it should form an impervious basin without need of excessive and expensive grouting.

- Limestone and to some extent sandstone with calcareous cement may present serious hazard
- Coarse sandstone, gravels, sand and glacial deposits are highly permeable whereas unjointed igneous rocks and massive limestone are impermeable

- Geological structure to be avoided. The syncline fo[r] plunging upstream can be favorable but anticline unfavorable

Groundwater conditions: high water table conditions a[re] favorable since there will be flow ofwater from reservoir ban[k] to the reservoir in low water table case, there is possibility o[f] flow of water from reservoir to the rock.

Siltation problems:

- Sedimentation of the reservoir with passage of time
- Siltation will make the project failure by reducing th[e] storage capacity
- Stream velocities along with the nature of tributaries and rock type through which it flows dictate the siltation problems
- Topography, climate, vegetation are to be studied since they can affect it.

Check dams, installation of outlets, silt basin and watershed improvements are methods of checking siltation

4.3.4 Dam

It is a solid barrier constructed across a river valley with a view of impounding water. Following parameters are to be studied during dam site selection

- Technically strong, impermeable and stable site
- Construction material: should not be far from the construction site

- Lithology should not vary at the site, Hard massive igneous rocks are best. Massive sedimentary rocks with siliceous cementing materials are also good.
- Stress condition: if acted, normal to bedding plane is favorable.
- Attitude of rock: Horizontal beds or beds gently dipping towards upstream are favorable. Strike parallel to the resultant stress is most unfavorable
- Geological structure: should be avoided,but small scales fractures and faults can be grouted. In syncline fold, water leakage from beneath the dam may occur
- Environment impact :effect of structure on surrounding and of surrounding to the structure to be studied
- Catchments area, flood levels etc. are to be studied and necessary countermeasure for them to be performed in case necessity.

4.4 Geological Considerations in site Investigations of Tunnel

Tunnels are underground routes or passages driven through the rocks or soft ground without disturbing the overlying soil rock cover.

Following geological condition is to be investigated for tunneling

- Attitude of rock: Horizontal or slightly dipping rocks with the strike parallel to the axis of the tunnel is favorable. Steeply dipping formations with the strike perpendicular to the axis of the tunnel are favorable too.
- Strength of rock: High strength of rock is favorable
- Effect of water on rock: whether it dissolves the rock, deteriorate it or produced no effect.

- Numbers of joints : Minimum numbers of joints, high spacing, rough joint plane or stepped, no or little weathering along joints is favorable
- Geologic structures : absences of any structure like faults, fold, and unconformity
- If folded, anticline is favorable since the vertical pressure relieved and do arch action by the up arch
- If faulted, first to consider if it is active, if a tunnel intersects an active fault nothing can be done to protect structure, so alignment has to be shifted. Even if it is not active , better is looking for other
- Water table condition: Water table below the tunnel is favorable. If tunnel is located below water table, a sand like suspension may rush into the tunnel.
- Cost: Project with minimum cost is desirable. If blasting has to be done or not, Tunnel boring machine is needed or excavations are enough. If yes which part, for what length and what cost. Which part needs support and what type, if water is likely to be encountered in what part and what amount

4.5 Engineering Geological, Documentation During Tunneling and Excavation Works

1. Preliminary survey
2. Feasibility Study
3. Analysis Study
4. Geological Condition
5. Rock Mass Rating
6. Q- system
7. Tunnel portal mapping
8. Support system Design

EXERCISE

1. Write the Geological consideration that should be taken into account in selection of Road Alignment. [2068 Magh]

Ans: See Theory portion 4.2

2. What are the types of site investigations? Describe about the role of Geology in selection of Tunnel Alignment. [2068 Magh]

Ans: See 4.1

3. Define over break. Describe direct methods of surface Investigation with reference to selection of Road Alignment in Rock slopes.[2068 Bhadra]

Ans: SeeQ.No 18 and see 4.2

4. Write the Geological consideration that should be taken in selection of Dam site and Bridge site. [2069 Poush]

Ans:See 4.3.4 and 4.3.2

5. Describe Geological Site Invention methods in brief. [2069 Poush] Ans:See 4.1
6. What are the Engineering Geological factors to be assessed for tunnel site selection? [2069 Bhadra]

Ans:See 4.4

7. Write down the Documentation process for this task.[2069 Bhadra]

Ans:See 4.5

8. Describe the different types and methods of Site Investigation and write down the different Geological Parameters for the Bridge site selection.[2070 Magh]

Ans:See 4.1 and See 4.3.2

9. Discuss the different type and methods of Site Investigation for the Road in Nepal Himalaya. [2070 Bhadra]

Ans:See 4.2

10. Define overbreak. Describe Geological Parameters for Evaluation of Bridge site selection?[2071 Bhadra]

Ans: See Q.No 18 and 4.3.2

CHAPTER-5

Geological Hazards

5.1 Introduction

A hazard is a phenomenon that might have negative effects on human or the environment. In the past history the hazards were taken as the sole act of nature and termed as act of god. But with the advancement in study it is found that human also contribute to geological hazard.

A hazard is defined by the United Nation as agent of threats that is "A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruptions or environmental degradation."

Disaster is an event that completely disturbs the normal ways of a community. It brings human, economic and environmental losses to the community which the community cannot bear on its own. The hazards are termed as disaster when they cause widespread destruction of property and human lives. For example: If forest fire broke out there where no loss of life and property then it is hazard but not disaster. If same forest fire broke out near to community and there were loss of life of people and property, then the process can called hazard as well as disaster.

Danger is something that may cause harm, loss or damage unless dealt with carefully. Risk is the probability of harmful

consequences or expected loss resulting from the interaction between hazards and vulnerable conditions.

Risk = Hazard× Potential worth of loss

Vulnerability means the degree of loss to a given elements or set of elements at risk, resulting from the occurrence of a natural phenomenon of a given magnitude. Hazards are of two types based on the factor resulting it. They are:

1) **Natural Hazards:** It includes all hazards caused naturally such as earthquakes, landslide, tsunami, pest attack, forest fire, flood, drought, cyclones etc.
2) **Man made Hazard:** It include all hazards induced due to human beings such as war, fire, technologic failure, armed conflict etc.

5.2 Major geological Hazards: Flood, GLOF, Erosion, Mass movement and their causes

5.2.1 Factor causing Hazards in Nepal

A geological hazard is one of adverse geological conditions capable of causing damage or loss of property and life. The most important geological hazards are landslide hazards, volcanic eruption, Earthquakes hazard, mass movement hazards etc. There are various factors that directly or indirectly cause hazards. Factor causing hazard are categorized as:

i. **Primary Factor:** It involves factor which are more or less long lasting and are inherent constituents of rock and soil such as strength of rock and soil masses, geological structures, vulnerable slopes, rock and soil type, rock discontinuities, porosity, permeability.

ii. **Secondary Factor:** The external factor other than soil and rock which contributes to the hazard falls in this category.

Such as seismicity, intensity of precipitation, land use pattern, weathering condition and groundwater condition. Some of the major factor causing hazard in Nepal are described below:

a. **Geological Structures:**

The several roughly east -west running faults and folds which are weak in strength are cause of natural hazards in Nepal. The MFT, MBT and MCT along with other local active faults are responsible for landslide hazards. Beside this bedding planes, foliation and joints in the rock also contribute to landslide hazards..

b. **High Relief and Vulnerable Slope:**

Slope failure related hazards are common hill in steeper than 60°. Mass movement hazards such as landslides, debris flow, rock fall and mud flow are result of change in slope gradient. About 83% of landmass of Nepal lies on Hilly region. In Nepal Himalayas, slope gradient between 30° and 40° are more critical for failure.

c. **Lithological Characteristics:**

Lithological characteristics of rock unit include its physical characteristics such as color, texture, grain size or composition. The lithological characteristic of fragile geology of Himalaya is main factor for causing hazard. Abundances of weak rocks in Himalaya and presence of calcareous rocks leads to high porosity and void formation due to leaching and dissolution resulting slope failure and landslide hazards.

d. **Depth and Degree of Weathering:**

Weathering reduces the strength of soil and rock contributing to mass movement hazard which is further

accelerated by chemical weathering such as ion exchange, hydration etc. The depth of weathering of rock affects the mass movement hazard. Himalayan rocks are in the warm temperature and sub- tropical climate zone which are usually deeply weathered and accelerates the landslide and mass movement hazards.

e. **Groundwater:**

Groundwater washout the fine particle which leads to formation of cavities and usually these cavities are occupied by water which causes liquefaction in sandy soil. Beside this, groundwater washout soluble cementing material and weakened the intergranular bond resulting reduction in mechanical strength leads to erosion hazards.

f. **Earthquakes:**

Nepal lies in seismic zone as the Indian Plate and Tibetan Plate boundary lies along the Himalayan zone due to which Nepal experience earthquakes and earthquakes leads to mass movement hazards.

g. **Glacier Lake Outburst Flood:**

Erosion or transportation of sediment from the boundary of Glacier Lake leads to instability of slope which finally results flood hazard.

h. **Geotechnical properties of soil:**

The properties of soil such as composition, depth, porosity, permeability, packing and grading of particles are the factor which affect soil slope failures. In Nepal, colluvium and residual soils are found in Himalayas while alluvium soil is found in river and terrace. Mostly these soils contains silty gravel which are prone to debris slide if present in steeper slope and occasionally contains clayey flood is overflow of

silt which are prone to rotational slide if present in gen
slope.

5.2.2 Flood

Floods are natural phenomena which cannot be prevent
Flood is a temporary covering by water of land which norma
not remains covered by water. In another word, a flood is
overflow of water that submerges land which is usua
remains dry.

Topography of Nepal is mainly responsible for flood. Most
Flash flood and downstream flood occurs in Nepal. Flash floo
are very common in hilly region of Nepal while downstrea
floods are common in Terai region. Flash flood is due to hea
rainfall over a relatively short period of time. Rainfall intensi
rainfall duration, surface condition and topography are ke
factor for flash flood. Downstream flood occurs during
following heavy or prolonged rainfall when water delivered
the river channel exceeds the channel carrying capacity. Exce
water escapes as overbank flow onto the flood plain of th
river. Rapid melting of snow also contributes to th
downstream flood.

Causes of Flood

Following are the cause of flood occurring in Nepal:

- Intensive Rainfall
- Heavy snowmelt
- Landslide
- Glacial Lake Outburst flood
- Collapse of protective structures
- Debris flow
- Deforestation

Intensive Ra
heavy snowme
landslide
Glacial lake
burst flood
Debris flo
Deforestat

5.2.3 Glacier Lake Outburst Flood:

A glacial lake outburst flood is a type of outburst flood occurring when water dammed by glacier or moraine is released. A glacier lake outburst flood is a type of outburst flood that occurs when the dam containing a glacial lake fails.

There are two types of GLOFs:

- One type occurs when the moraine banks, deposited rock and mud that dam glacial lakes burst when the earth is disturbed such as earthquake.
- Another type can occur when glacial lake rise in volume due to increased glacial melting caused by climate.

Nepal is nested along the Himalayan range known as the 'Third pole of the world' due to its concentration of glacier. Glacier lakes in Nepal are moraine-dammed lakes, glacier ice dammed lakes and ice core moraine dammed lakes. The transportation of sediments from the boundary of glacial lake leads to GLOF. In the recent past, Nepal had experienced 24 GLOF incidents.

The TshoRolpa situated at an altitude of 4,580m is one of the biggest glacial lakes in Nepal. The frequency and extent of GLOFs in the Himalayas are not yet adequately documented. Most of the known cases have occurred in the major rivers of the Koshi basin. Some of the well recorded events are along the BhoteKoshi-Sunkoshi in 1964 and 1981; in Arun river (1964), Tamur river (1995). The earthquake in 2072 Baishak 12 had had activated many glacial lake.

Causes of GLOF

The causes of the GLOF are following below:

- Buildup of water pressure

- Earthquake
- Climatic change (increase in temperature)
- An avalanche of rock or heavy snow
- Erosion

Process of eroding or being eroded by wind & water

5.2.4 Erosion

Erosion is a process that describes continuous physical and chemical events which causes soil and rock on the earth's surface to loosen and move to a new location. Soil erosion is naturally occurring process on all land. The agents of soil erosion are water and wind each contributing a significant amount of soil erosion either slow process or occurring rapidly. The erosion process of soil involves three steps. They are detachment, movement and deposition.

other natural agents

Causes

Soil erosion can be caused by both natural and unnatural process. Soil erosion either related to naturally occurring events or influenced by the presence of the human activity. The causes of erosion are:

- ❖ **Rain and Rain water Runoff:** Heavy rain water first break down the soil structure, disperse the soil particles and finally washed away by the runoff water.
- ❖ **High Winds:** High wind picks up the loose soil particle with its natural force and transports it to the new location.
- ❖ **Traditional Farming:** Due to tilling of land, there is always break up and softening of soil structure takes place which make it susceptible to rain for erosion.
- ❖ **Deforestation:** Plants and tree holds the soil particles and prevent it from getting disturbed due to rainwater and other

agent of erosion which reduces the amount of soil erosion. Deforestation makes the land more exposed to rainwater which can easily destroy the structure of soil and leads to erosion.

- ❖ **Overgrazing by cattle:** Overgrazing by cattle reduces the cover of ground and also breaks down the soil structure giving exposure for erosion agent.
- ❖ **Rivers and Stream:** The flowing water in the stream and rivers erodes its bank due to its flow velocity.

5.2.5 Mass Movement

Q. M.I

Mass movement is the downslope movement of soil, rock and other earth material by gravity without the direct help of transferring medium such as ice, water or wind. Mass movements occur at various rates. Faster mass movement is more hazardous while slow mass movement is also harmful.

Mass movement is serious concern for engineering to run project in hill sides. Mass movement can be very fast or very slow. Gravity is the force behind the mass movement however several factors make slopes more susceptible. Some of the factors are:

(i) **Saturation of surface material with water:** Due to filled pore water rock particle slides past one another resulting mudflow.

(ii) **Over steeping of slope:**

(iii) **Removal of vegetation:** Plants makes slopes more stable. Their roots bind the soil together. When plants are moved by human activity mass movement occur.

(iv) **Earthquake:**

Mechanism of Mass Movement

g.m.p

The material weathered due to various agents such as water wind etc. The mass movement of weathered materials depends on the ratio of two factors as shown below:

$$\text{Fos} = \frac{\text{Shearing resistance of materials}}{\text{Magnitude of shearing force}} = \frac{m_R}{m}$$

When the shearing resistance of material is greater than the magnitude of the shearing force i.e Fos>1, no mass movement occur. When the shearing resistance of material is lesser than the magnitude of shearing force i.eFos<1. Then, the materials begin to move downslope and mass movement occur. The mass movement may result either due to decrease in shearing resistance of material or increase in magnitude of shearing force or both. Shearing resistance of material may decreased due to alternating cycle of wetting and drying and magnitude of shearing force may be increase due to increase in load.

5.3. Types of Mass Movement

There are three types of mass movement based on particle movement. They are described below:

i. **Landslide:** Sliding of a large solid mass occurs in a gentle slope

Landslide is the defined as the down slope transport of mass of soil and rock material along a slip surface under the influence of gravitational force. It has clear sliding surface with large dimension. It generally occurs in the gentle slope and the movement is slow and continuously.

ii. **Debris Flow:**

Debris flow is movement of deposited or eroded sediments along the stream. It involves downslope movement of enormous amount of viscous soil and boulders either

The process of falling down of ~~water~~ mass of soil with water is

separately or mixed together. It generally occurs along the river valley sides. Slope failure is the movement of weathered surface soil in steep slop,

iii. **Slope Failure:**

The Slope failure is the movement of weathered surface soil layer/ rock of steep slope in small dimension. There is absence of slip surface. The movement of slope failure is rapid .It mainly occur in steep slopes with loose soil and excavation of rock or soil on downhill slope.

Varne's Classification of Landslides

The landslide classification based on varne's system has two terms:

- The first term describe the material type
- The second term describes the type of movement.

The Varne's classification is presented in table.

Type of Movement			Type of Material		
			BED ROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly Fine
Falls			Rock Fall	Debris Fall	Earth Fall
Topples			Rock Topple	Debris Topple	Earth Topple
Slides	Rotational	Few units	Rock Slump	Debris slump	Earth Slump
	Translational	Many units	Rock block slide	Debris block slide	Earth block slide
			Rock Slides	Debris Slide	Earth Slide
Lateral spreads			Rock Spread	Debris spread	Earth Spread
Flows			Rock Flow (deep creep)	Debris flow	Earth flow
Complex			Combination of two or more principal types of movement		

Rock: It is a hard or firm mass that was intact and in its natural place before its initiation of movement.

Soil: It is an aggregate of solid particles of minerals and rocks which may either transported from the other place or formed by weathering of rock in that place.

Earth: It is the material in which 80% or more of particles are smaller than 2mm.

Mud: It is the material in which 80% or more of the particles are smaller than 0.06mm.

Debris: It contains a significant proportion of coarse materials; 20 to 80% of the particles are larger than 2mm, and the remainders are less than 2 mm.

Classification of Landslide

❖ Slumps:

The sliding slope failure in which there is downward and outward rotational movement of rock or regolith occurs along a concave upslip surface is called slumps. Slump produces either a singular or a series of rotated blocks, each with the original ground surface tilted in the same direction. They are common after earthquake and commonly occurred along road sides and other slopes that have been artificially steepened to make room for the other structure.

❖ Topples:

A toppling is a block or rock that tilts or rotates forward on a pivot or hinge point and gets separated from the main mass by falling to the slope below and subsequently bouncing or rolling down the slope.

❖ Falls:

Falls are the abrupt movements of masses of geologic materials that become detached from the steep slopes or cliffs. The mass movement may result by free-fall,

bouncing and rolling. Falls are influenced by gravity, mechanical weathering and presence of moisture. The rate of this type of mass movement is fast and is accelerated by undercutting, weathering, excavation, frost action etc. Depending upon the materials which get involved in the process the fall are termed as rock fall, soil fall, debris fall, earth fall etc.

- **Rock fall:**

  When the detached bodies of bedrock fall freely from a cliff or steep slope Rock fall occur. They are commonly occur in steep slopes are and the material of rock fall gets deposited at the base of the cliff. Rock fall is responsible for the destruction of parts of many villages in the steep mountain ranges and also dammed many rivers which result in formation of new lake.

- **Creep:** Creep is the slowest type of mass movement resulted due to alternate freezing/ thawing or wetting/ drying of soil particles. It travels only a few centimeters per year. The creep occurs throughout the upper parts of regolith and there is no single surface along which slip has occurred. Creep causes the leaning of telephone poles, fences and many of the cracks in sidewalks and roads.

❖ Flows:

When the material, soil and/or rock behave like a liquid or fluid then flow occurs. The flow occurs due to a large amount of water or ice present in the soil or material. The flows are most often fastest travelling and the speed is mostly affected by the location and the steepness of the slope. The flows are further divided based on the material involved such as mud flow, debris flow etc.

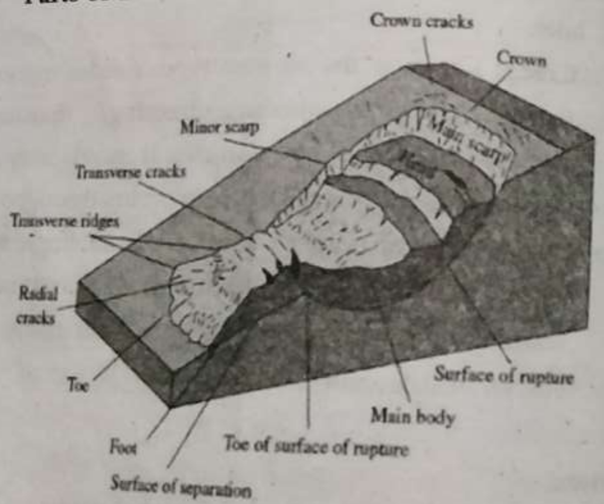
❖ **Spreads:**

Spread is caused by liquefaction in which saturated, loose, cohesion less sediment are transformed into liquid state. They are usually occurs on very gentle slopes or flat terrain. Spread is accelerated by ground movement such as earthquake and other artificial process causing movement. It is starts suddenly in a small area and spreads rapidly.

❖ **Complex Failure:**

These are the slides in which the failure occurs due to a combination of the above types of movements i.e combination of fall, low, slide, spread etc. with multiple slip surface.

Parts of Landslide



1. **Crown:** The practically undisplaced material still in place and adjacent to the highest parts of the main scrap.
2. **Main Scarp:** A steep surface on the undisturbed ground at the upper edge of the landslide, caused by movement of the displaced material away from the undisturbed ground. It is visible part in the surface of rupture.

3. **Top:** The highest point of contact between the displaced material and the main scrap.
4. **Head:** The upper parts of the landslide along the contact between the displaced material and the main scarp.
5. **Minor Scarp:** A steep surface on the displaced material of the landslide produced by differential movements within the displaced material.
6. **Main Body:** The part of the displaced material of the landslide that overlies the surface of rupture between the main scarp and the toe of the surface of rupture.
7. **Foot:** The portion of the landslide that has moved beyond the toe of the surface of rupture and overlies the original ground surface.
8. **Tip:** The point of the toe farthest from the top of the landslide.
9. **Toe:** The lower, usually curved margin of the displaced material of a landslide, it is the most distant from the main scarp.
10. **Surface of Rupture:** The surface which forms (or which has formed) the lower boundary of the displaced material below the original ground surface.
11. **Toe of the Surface of Rupture:** The intersection (usually buried) between the lower part of the surface of rupture of a landslide and the original ground surface.
12. **Surface of Separation:** The part of the original ground surface overlain by the foot of the landslide.
13. **Displaced Material:** Material displaced from its original position on the slope by movement in the landslide. It forms both the depleted mass and the accumulation.

14. **Zone of Depletion:** The area of the landslide within which the displaced material lies below the original ground surface.
15. **Zone of Accumulation:** The area of the landslide within which the displaced material lies above the original ground surface.
16. **Depletion:** The volume bounded by the main scarp, the depleted mass and the original ground surface.
17. **Depleted Mass:** The volume of the displaced material, which overlies the rupture surface but underlies the original ground surface.
18. **Accumulation:** The volume of the displaced material, which lies above the original ground surface.
19. **Flank:** The undisplaced material adjacent to the sides of the rupture surface. Compass directions are preferable in describing the flanks but if left and right are used, they refer to the flanks as viewed from the crown.
20. **Original Ground Surface:** The surface of the slope that existed before the landside took place.

Landslide dimensions

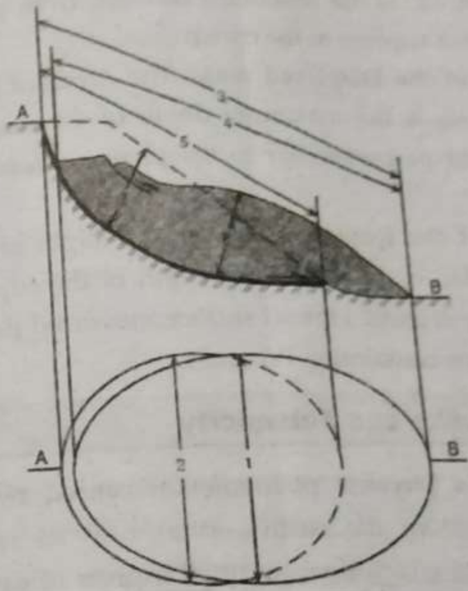


Fig:Dimension of Landslide

1. **Width of the Displaced Mass:** The width of displaced mass, Wd, is the maximum breadth of the displaced mass perpendicular to the length of the displaced mass, Ld.
2. **Width of the Rupture Surface:** The width of the rupture surface, Wr , is the maximum width between the flanks of the landslide, perpendicular to the length of the rupture surface, Lr.
3. **Total length:** The total length, L, is the minimum from the tip of the landslide to the crown.
4. **Length of the Displaced Mass:** The length of displaced mass, Ld is the minimum distance from the tip to the top.

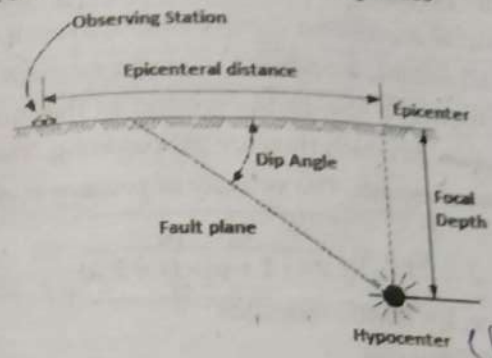
5. **Length of the Rupture Surface:** The length of the rupture surface, Lr, is the minimum distance from the toe of the surface of rupture to the crown.
6. **Depth of the Displaced mass:** The depth of the displaced mass, Dd, is the maximum depth of the displaced mass measured perpendicular to the plane containing Wd and Ld.
7. **Depth of the Rupture Surface:** The depth of the rupture surface, Dr, is the maximum depth of the rupture surface below the original ground surface measured perpendicular to the plane containing Wr and Lr.

5.4 Earthquake and Seismicity

Earthquake is a physical phenomenon caused by release of seismic waves from the earth's interior to its surface. The branch of science which deals with all aspects of earthquake is called seismology. The instrument used for the detecting and recording earthquakes is called seismographs. The record produced by seismograph is called seismograms.

Sudden vibration of land by releasing of energy is called

5.4.1 Terminologies used in Earthquakes



(Focus)

❖ **Focus:**

It is the zone in the interior of earth from where the earthquake originates. Sometimes it is also called Hypocenter. It may lie from few hundred meters to hundreds of kilometers below the earth surface. Shock wave originated from the focus travels in all direction causing disturbance.

❖ **Epicenter:**

Epicenter is a place directly above the focus on the ground surface. It is the place on the earth surface where vibration of earthquake is first experienced.

❖ **Seismic waves:**

The elastic wave generated at the focus during the earthquake is called Seismic waves. These wave travel in all directions with their characteristics velocity. There are two types of seismic waves generated during earthquakes. They are:

1. **Body waves:**

   The seismic wave which passes through the interior of the earth is called Body waves. There are two types of body waves:

a. P or Primary waves: P- waves are also called longitudinal waves and compression waves. It is fastest among all seismic waves. It can travel through all three state of matter. It shakes the ground in the direction in ~~the direction~~ in which they are propagating. They arrive first on seismogram. The velocity of p-wave is given by

$$V_P = \sqrt{\frac{E(1-\mu)}{P\times(1+\mu)-(1-2\mu)}}$$

Where, E= Elastic modulus

μ= Poisson ratio

ρ= density

Compression

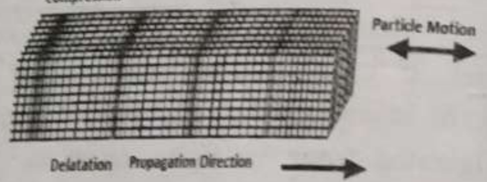


Fig: P-Wave

The P- wave change the shape of the bodies through which it passes.

b) S or Secondary waves:

S- Wave is also called shear waves, transverse waves. It is slower than P- wave. It is slower than p-wave. It can travel through solid only. It shakes the ground in the direction perpendicular to the direction of propagation of wave. It arrives after the arrival of the P- wave on seismogram. It causes the most serve shaking when passes through body and damage the structures. The velocity of s- wave is given by:

$$v = \sqrt{\frac{\mu}{p}}$$

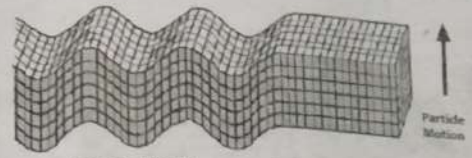
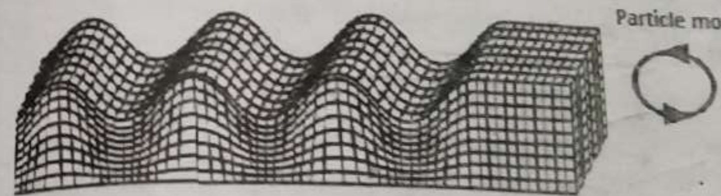


Fig: S-Wave

2. Surface waves:

The waves which appear at the surface of the earth during a quake are called surface waves. There are two types of surface waves.

a) Rayleigh wave:-



Propagation Direction

Fig: Rayleigh Wave

Rayleigh wave rolls on the ground surface in the same way rolls in lake or in an ocean. The Rayleigh wave travels at a speed slower than the direction s-wave. It causes vertical together will back-and-forth horizontal motion. The Rayleigh wave usually arrives last on a seismogram. It is more damaging because it makes structure to move in two directions at once.

b) Love wave:-

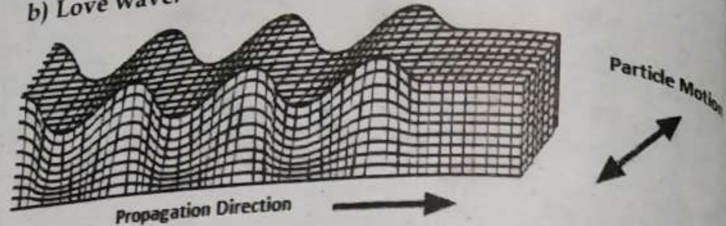


Fig: Love Wave

Love wave is the fastest surface wave and shakes th ground from side to side. They arrive after S- wave and befo the Rayleigh wave.

5.4.2 Causes of Earthquakes

The causes of earthquakes are as follow:

- Collision of Tectonic plates
- Volcanic eruption
- Nuclear explosion
- Collapse of huge man-made structures leadin to shaking of ground
- Subsidence of ground underneath due t improper filling.

5.4.3. Elastic Rebound Theory

Elastic rebound theory was developed by H.F. Reid fo explaining the mechanism of earthquake. Elastic rebound theory states that as tectonic plates move relative to each other elastic strain energy builds up along their edges in the rocks along fault planes. As the plates are moving against each other stress is gradually built up along the plate's edge. Since the plates are huge and their edges can span thousands of kilometers, great amount of energy can be stored. When there is a sudden release of large amount of stored energies an earthquake occurs.

5.4.4. Classification of Earthquakes

[A] Based on the depth of focus:

Earthquakes are divided into three group based on the depth of focus. They are:

i) Shallow earthquake

The earthquake in which depth of focus lies anywhere upto 60 K.M. below the earth surface is called Shallow earthquake.

ii) Intermediate earthquake

The earthquake in which depth of focus lies between 60 km and 300 km below the surface of the earth is called Intermediate earthquake.

iii) Deep seated earthquake

The earthquake in which depth of focus lies between 300 km and 700 km below the surface of the earth is called deep seated earthquake.

[B] Based on the origin

Earthquakes are divided into two groups on the origin. They are:

i) Tectonic earthquake:-

The earthquakes which are formed due to tectonic activities are called Tectonic earthquake.

ii) Non-tectonic earthquake:-

The earthquakes which are formed due to other causes than tectonic activities are called Non- tectonic earthquake.

5.4.5. Strength of Earthquake

Earthquake strength is measured by two different ways. One method determines the how much and what kind of damage the earthquake has caused and other method measured the amount of energy released at the earthquake. The first one represent intensity and latter one represent magnitude. The brief descriptions of above methods are given below:

1. **Intensity:**

   Intensity measures the strength of shaking produced by the earthquake at a certain location. Intensity is determined from effects on people, human structures and natural environment. Two scale Rossi Forrel Scale and Mercalli scale are present for Seismic intensity measurement. In the past Rossi Forrel scale was used. The modification in Mercalli scale has made and is commonly used for intensity measurement in present days.

   Mercalli scale ranges From I to XII in ascending order. The intensity assigned to any earthquake is based on observations of witness and assessment of damages in the area around the epicenter and for tens to hundreds of kilometers away. Intensity of earthquake depends on distance from epicenter, type of construction, magnitude of earthquake, duration of earthquake and depth of focus.

2. **Magnitude:**

   Magnitude measures the energy released at the source of the earthquake. It is determined from measurement on seismographs. The Richter scale is used to measure the amount of seismic energy released during an earthquake. Richter scale is a logarithmic scale. A difference of 1 magnitude unit is equivalent to 10 fold difference in the amplitude of the waves on a seismograph.

The amount of energy released due to specific magnitude of earthquake is calculated by following relation:

$$\text{Log } 10^{E} - 4.4 + 2.14m - 0.05m^2$$

Where M is magnitude of the earthquake and E is corresponding energy released.

S.N	Magnitude	S.N	Intensity
1.	Magnitude is a quantitative measure of actual size of the earthquake.	1.	Intensity is an indicator of the severity of shaking generated at a given location.
2.	It is measured by Richter Scale.	2.	It is measured by Mercalli Scale.
3.	It is amount of energy released during earthquake.	3.	It is the level of damage in terms of property and human life caused by an earthquake.
4.	Magnitude is determined from measurement on seismographs	4.	Intensity is determined from effects on people, human structures and the natural environment.
5.	It depends on the size of fault that breaks.	5.	It depends on the distance to earthquake and strength of earthquake.

5.4.6 Location of epicenter of an earthquake

The location of epicenter of earthquake is determined with the help of arrival time difference between p- wave and s-wave. The distance can be obtained from the time arrival interval but not direction. So, we need to determine the direction. For determining the direction we need seismographs data of three stations. The procedure is shown below:-

1. Initially, the seismographic stations are located on the map.

2. Then distance corresponding to arrival time interval is determined from standard tables for distance.
3. Now, circles are made from each seismographic station with corresponding distance obtained above.
4. The point of intersection of three circles is the epicenter of the earthquake.

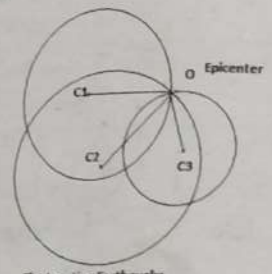


Fig: Locating Earthquake epicenter

5.4.7 Earthquake Effects:

The shock of largest magnitude during the earthquake is termed as main shock. The earthquakes that occur before the main shock are called foreshocks. Earthquake that occur after the main shock are called after shocks. This shock is destructive and has negative effect on human and environment. The effects of earthquakes are enlisted below:

- It causes destruction of various civil engineering structures.
- Loss of life
- It can cause uplift or subsidence of large areas.
- Soil liquefaction
- It causes the landslide along hill slope.
- It may change the course of rivers and streams.
- It may lead to formation of new springs and disappearance of old spring.
- Submarine earthquake leads to Tsunamis.

- Sometimes earthquake cause fire due to broken gas lines, contributing to the loss of life and economy.
- The vibration of ground damages the infrastructures like roads, water pipeline, transmission line etc.

Civil Engineering consideration in seismic area

- ❖ Earthquake resistant structure should be constructed.
- ❖ Building code should be strictly followed and seismic load should be considered during designing phase.
- ❖ The quality of construction material should be maintained.
- ❖ The openings in the building are weakest point during earthquake. So, the opening should not be very large and must be properly placed.
- ❖ Cantilever portion, parapet etc. are weakest part of the building and need to be properly treated.
- ❖ Retrofitting should be done for old structure.

5.5 Structural Control on Geo-Hazards

The geo-hazards can be controlled to some extent by using structure. The structures to be used for controlling different geo-hazards are enlisted below:

[A] For Flood Hazard

The structural controls for flood hazards are:

i. **Storage Reservoir:**

ii. **Levees:**

iii. **Flood wall:** Flood wall is a sort of gravity dam constructed along the river. They are designed to withstand the hydrostatic pressure like gravity dam.

iv. **Channel Improvement Works:** It is done to reduce the river stage at a specific point in the reach. It can be done by increasing the channel section, realignment of river, increasing water way at crossing etc.

v. **Diversion System:**

[B] For GLOF

Glacial Lake Outburst flood is caused due to erosion of glacial lake boundary or due to rise in volume. Thus following method can useful to control the GLOF.

- Build artificial reinforced channel that lowers a lake's volume so that it does not overflow.
- Water storage and appropriate use of hydroelectric power could limit the danger from GLOF.
- Uses of retaining structure and soil improvement technique to prevent the boundary material of GLOF from erosion.

[C] For Erosion Control

- Geo netting
- Construction of Retaining structure

[D] For Mass Movement Control

- Retaining structure
- Drainage structure
- Rock bolting
- Bio-engineering Technique

5.6 Geological Hazard in Soil Mass and Rock Mass

The geological hazards in soil mass are:

- Sheet Erosion
- Slump
- Soil erosion
- Mud flow
- Lateral spread
- Landslide

The geological hazards in rock mass are:

- Rock fall
- Landslide
- Rock toppling
- Rock avalanches

- Ex-foliation

EXERCISE

1. Define Hazard and Risk. Describe the types of Erosion.

Ans: See 5.1

Splash erosion:

Splash erosion is the first stage of the erosion process. It occurs when raindrops hit bare soil. The explosive impact breaks up soil aggregates so that individual soil particles are 'splashed' onto the soil surface. The splashed particles can rise as high 60cm above the ground and move up to 1.5 metres from the point of impact. The particles block the spaces between soil aggregates, so that the soil forms a crust that reduces infiltration and increases runoff.

Sheet erosion: Sheet erosion is the removal of soil particles by water drops and surface flow. Sheet erosion can be hard to detect but can be extremely damaging. Uncovered soil with little to no vegetation is the most susceptible. Sheet erosion can be reduced by increasing vegetation to slow water flow and help increase infiltration.

Rill erosion:

Rill erosion is the next step in the progression it consists of channels smaller than 30cm deep. Once again it can be combated with methods that reduce the amount and speed of water flow and increase infiltration such as cultivating grasses or adding contoured drains.

Gully erosion: Gully erosion consists of channels greater than 30cm. Conservation practices outlined above can become very difficult to implement because of the upslope cutting of rills and more pronounced slopes can make it much harder to establish vegetative cover. A headcut might be an option to help mitigate erosion damage in this stage as it helps prevent further upstream damage.

2. What is meant by GLOF? Explain the types of Mass Movement. [2068 Magh] Ans: See 5.5[B] and See 5.3
3. Write down the Mechanisms of Mass Movement. Discuss the Control Measures Against landslide. [2068 Bhadra] Ans:See 5.2.5 and 5.5[D]
4. What is Mass Movement? Mention the classification of Mass movement as per Varnes (1978).[2069 Poush] Ans: See 5.2 for first part. See 5.3 for second part
5. What are the Engineering Geological Factors that cause Hazards in the Nepal Himalaya? [2069 Poush] Ans: See 5.2.1
6. How do you differentiate P-wave and S- Wave? Describe strength of Earthquake. [2069 Poush] Ans: See 5.4.1 For second part see 5.4.5
7. Define Mass Movement. Describe causes of Landslide. [2069Bhadra] Ans: See 5.2 For second part see 5.3
8. Define Mass Movement. Differentiate between landslide and debris flow. [2070 Magh] Ans: See5.3
9. Describe the Mechanism of an Earthquake. What are the differences between magnitude and Intensity of an Earthquake? [2070 Magh] Ans: See 5.4.3 for first part See 5.4.4 for second part
10. How Mass movements Occur? Classify the Landslide according to Varnes. [2070 Bhadra]Ans: See 5.2 for first part See 5.3 for second part
11. Explain the different effects of Earthquake and GLOF in the Nepalese context. [2070 Bhadra] Ans: See 5.5[B] for first part See 5.4.7 for second part

12. Define Intensity and Magnitude of the Earthquake. Explain the different types of Waves Generated during Earthquake. [2071 Bhadra] Ans: See 5.4.5
13. Differentiate between Hazard & Risk. Describe how Strength of Earthquake Measured? [2071 Magh] Ans: See 5.4.5

S. N	Hazard	S. N	Risk
1.	A hazard is defined by the United Nation as agent or threats that is "A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruptions or environmental degradation.	1.	Risk is the probability of harmful consequences or expected loss resulting from the interaction between hazards and vulnerable conditions.
2.	It is a source of risk.	2.	It is a potential loss of life and property.
3.	Hazard is an unavoidable danger.	3.	Risk is caused only by chance.

14. How Mass Movement Occurred? Describe Varne's Classification of Landslide. [2071 Magh] Ans: See 5.3
15. What is the Magnitude of Earthquake Hazard in Nepal? Differentiate between Intensity and Magnitude. [2072 Magh] Ans:See 5.4.5
16. Describe the Geological Hazard in Nepal due to GLOF. [2072 Magh] Ans:See5.5[B]

17. What is factor of safety? Describe Strength of Earthquake. [2072 Ashwin] Ans:See 5.2.5 for first part
See 5.4.5 for second part

18. How Varnes classified Landslide? Explain. [2072 Ashwin]
Ans: See 5.3

19. Differentiate Hazard and Risk. [2072 Ashwin]
Ans: See 5.4.5

20. Define Hazard and Risk. Describe Mechanism of Mass Movement. [2073 Bhadra]
Ans: See Q.No 15 and Portion 5.2

21. Describe parts of Landslide with Labelled Diagram. Mention types of movement with reference to Varne's classification. [2073 Bhadra]
Ans:SeeQ.No 5.3

22. How Earthquake Occurs? Differentiate between Magnitude and intensity. [2073 Magh]
Ans: See 5.4.3 for first part.
See 5.4.5 for second part.

23. What is GLOF? Discuss the Cause and effect of GLOF. [2073 Magh]
Ans:See 5.2.3

24. How GLOF occurred? What are the types of Movement According to Varne? Describe in Brief. [2074 Bhadra]
Ans:See 5.2.3 for first part, See 5.3 for second part

G

CHAPTER-6

Measurement, Analysis and Interpretation of Structural Geological Data

6.1 Rock Mass: Introduction, Properties, Classification systems

6.1.1 Introduction

The large volume of rock intersected by discontinuities is known as rock mass. The rock mass is heterogeneous in nature due to variation in rock type, discontinuities and degree of weathering. The strength of rock mass depends on the discontinuities more than the intact rock strength. The rock mass is simply described by relation:

Rock mass = Intact Rock + Discontinuities

Intact Rock:

The intact rock is the rock in which there is absence of discontinuities. Intact rocks are described by its rock name, mineralogy, texture, degree and kind of cementation and weathering.

Discontinuities: Discontinuities are the structural features of the rock which are developed due to existence of different stress on the periphery of the earth. Discontinuities includes bedding plane, joints etc.

6.1.2 Properties

Properties of rock mass depend on the properties of intact rock and discontinuities. The properties of intact rock and discontinuities are described below:

6.1.2.1. Properties of Intact rock

The properties of intact rock are described below:

i) Rock strength:

Strength is the fundamental quantitative engineering property of rock specimen. Rock experience different type of stress such as tensile, shear and compressive stress giving rise to corresponding strength Compressive strength is widely used in engineering application. Strength of rock mass depends on grain size, texture, mineralogy and degree of foliation etc.

No	Description	USCS (MPa)	Example
R1	**VERY WEAK ROCK** - crumble under sharp blows with geological pick point and can be cut with pocket knife.	1-25	Chalk, rock salt
R2	**MODERATELY WEAK ROCK**- shallow cuts or scarping with pocket knife with difficulty, pick point indents deeply with firm blow.	25-50	Coal, schist, siltstone
R3	**MODERATELY STRONG ROCK**- knife cannot/can be used to scratch or peel surface, shallow indentation under firm blow from pick point.	50-100	Marble, gneiss
R4	**STRONG ROCK** - hand sample breaks with one firm blow from hammer end of geological pick	100-200	Gabbro, basalt
R5	**VERY STRONG ROCK** - requires many blows from geological pick to break intact sample	>200	Quartzite, granite

ii) Weathering Grade:

The engineering properties of rock are significantly influenced by the weathering condition of rock. The degree of weathering of rock depends upon various factors such as size, orientation of discontinuities and groundwater movement

Grade	Degree of weathering	Description
VI	Residual soil	Rock is discolored, lost original fabric and completely changed into soil. Hazards depend on water-content and natural slope.
V	Completely weathered	Rock is discolored, converted to soil but do not lost original fabric. It is severely hazardous.
IV	Highly weathered	Rock is discolored and original rock fabric may be altered. Discontinuities may be open, discolored surface with deep penetration inwards. Highly hazardous.
III	Moderately weathered	Rock is discolored. Discontinuities may be open and show discolored with little inward penetration. Moderately hazardous.
II	Slightly weathered	Rock is slightly discolored. Discontinuities may be open with slightly discolored surfaces. It is considerably less hazardous.
I	Fresh	No weathering. Free from hazards.

6.1.2.2. Properties of Discontinuities

The properties of Discontinuities are

i) **Orientation**

Orientations of discontinuities are obtained by measuring the altitude of planes. Discontinuities having same altitude are termed as a set of joint and the altitude is defined in terms of dip direction (angle with respect to north) and dip amount (angle with horizontal). If the direction of discontinuity is in same direction to rock mass, then it will leads to rock instability which may cause plane, wedge or toppling failure in the rock mass based on relationship between joint sets and hill slope.

ii) Spacing

The perpendicular distance between the two adjacent parallel discontinuity planes is called spacing of discontinuities. Greater spacing of discontinuities will provide the greater strength to rock mass. The spacing of discontinuities may be affected by lithology, tectonic stress, depth etc.

iii) Continuity (persistence)

Persistence or length is measure of extent of development of discontinuities and is measured in an exposed rock surface. Due to limited surface exposures, the measured continuity in a given set may not be representative.

iv) **Aperture (width) and Infilling materials**

The aperture is the perpendicular distance separating the adjacent rocks walls on an open discontinuity, in which the intervening space is air or water filled. In another word, it is widening distance between two discontinuities. The aperture may be tight or open. The opening of

discontinuities may be empty, partially filled or completely filled. If the discontinuities contain clay infilling then there will be high chance of sliding due to seepage water. Thus, the strength of rock mass becomes low. If discontinuities contain sand filling the strength of rock mass will be high.

v) **Surface Characteristics (Roughness)**

The surface discontinuity may be rough or smooth. Rough surface is considered good as smooth surface leads to sliding.

vi) **Groundwater condition**

The increase in water pressure reduces the resisting force and causes instability of slopes. Discontinuity under dry condition has good strength than the discontinuity under wet condition. Based on intensity of water flow, for seepage may be categorized as follows:

Dry - - Damp - - Wet - -Dripping - - Flowing

increasing in the intensity of water flow →

6.1.3 Rock mass Classification system

Different rock mass classification system has been established till today by different scientist. The rock mass classification helps to improve the quality of site investigation by providing quantitative information for design purpose. It is also used to determine the strength of rock and help to determine the support condition required for rock to provide desired strength and leads to successful completion of project.

The different types of rock mass classification are:

1. Terzaghi rock mass classification
2. Rock quality Designation Index (RQD)
3. Bieniawski's Geomechanics classification RMR
4. Rock Tunneling Quality Index (Q- value)

6.1.3.1. Terzaghi rock mass classification

This is the first truly organized system proposed by Dr. Karl Terzaghi. The system was mainly qualitative and used for rock tunnel design and construction projects.

Type	Rock characteristics
Intact rock	Rock with no joints
Stratified rock	Rock with little strength along bedding surface
Moderately jointed rock	Rock mass jointed but cemented
Blocky and seamy rock	Jointed rock mass without any cementing of joints
Crushed rock	Rock that has been reduced to sand size particles without any chemical weathering
Squeezing rock	Rock containing considerable amount of clay
Swelling rock	Rock that squeezes primarily from mineral swelling

6.1.3.2. Rock Quality Designation Index (RQD)

The RQD index was introduced by Deere to provide a quantitative estimate of rock mass quality from drill core log. RQD is the sum of the length of rock core bits longer than 10 cm expressed as a percentage of the total length.

$$RQD = \frac{\text{Length of core pieces} > 10 \text{ cm length}}{\text{Total length of core run}} \times 100\%$$

Sometime the drilling may inaccessible in such case the RQD can be determined by the relation suggested by Plamstrom as shown below:

$$RQD = 115 - 3.3J_v$$

Where

J_v = sum of the number of joints per unit length for all joint (discontinuity) sets known as the volumetric joint count.

From the value of RQD obtained the Rock mass is classified according to the table shown below:

RQD%	Rock mass quality
<25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

6.1.3.3. Bieniawski'sGeomechanics Classification

Rock Mass Rating (RMR) system is a geomechanical classification system for rock developed by Z.T. Bieniawski. He has given different rating to different parameter. The sum of the rating of individual parameter gives the final rating value. The RQD is used to classify a rock mass using RMR system are:

1) Uniaxial compressive strength of rock material
2) Spacing of discontinuities
3) Condition of discontinuities
4) Rock Quality Designation RQD
5) Groundwater Condition
6) Orientation of discontinuities

Class No.	Rating value	Rock quality
I	100 - 81	Very good rock
II	80 - 61	Good rock
III	60 - 41	Fair rock
IV	40 - 21	Poor rock
V	< 21	Very poor rock

Guidelines for excavation and support of 10mspan rock tunnels in accordance with the RMR system (After Bieniawski 1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATIONS

Parameters			Range of value						
1.	Strength of intact rock	Point load index	>10MPa	4 - 10 MPa	2 - 4 MPa	1 - 2MPa	For the low range uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250MPa	100 - 250MPa	50 - 100MPa	25 -50MPa	5 - 25MPa	1 - 2MPa	<1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality RCD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	25%		
	Rating		20	17	13	8	5		
3	Spacing of		<2m	0.5 - 2m	200 - 600mm	80 - 200mm	<80mm		
	Rating		20	15	10	5	5		
4	Condition of the discontinuities (See E) Very rough surfaces Not continuities NO separation Unthreaded well rock			slightly rough surface separatio n <1mm Slightly threaded wall	slightly rough surface Separatio n < 1mm Highly well threaded	Sicken sided surface Or Gauge < 5mm thick Continuities	Soft gouge >5mm rock Or separation >5mm Continuities		
	Ratting		30	25	20	10	0		
5	Groundsel	Inflow per 10m tunnel length thin	None	<10	10 - 25	29 - 125	>125		
		(Joint water prissily (Major principal or)	0	<0.1	0.1 - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	flowing		
		Rating	15	10	7	5	0		

B. RATING ADJUSTMENT FOR DISCONTINUTY ORIENTATIONS (See F)

Strike and dip orientation		Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
Ratings	Tunnels and miners	0	-1	-5	-10	- 12
	Foundations	0	-2	-7	- 15	- 25
	Steps	0	-5	-25	- 50	

C. ROCK MASS LLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 - 81	80 - 61	60 - 42	40 - 21	<21
Class number	I	ii	iii	iv	v
Description	Very good rock	Good rock	Fat rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	i	ii	iii	iv	v
Average stand - up time	20 yrs 15m span	1 yrs for 10 m span	1 weak for 5 m span	10 hrs 2.5 m span	30 min for 1m span
Cohesion of rock mass (MPa)	>100	300 - 400	200 -300	100 - 200	<100

Friction angle of rock mass (deg)	>45	35 - 45	25- 35	15 - 25	<15

E. GUIDELINES FOR CLASSFICATION OF DISCONTINUTIY CONDITION

Discontinuity length (persistence)	<1mm	1 - 3m	3 - 10m	10 - 20m	>20m
Rating			2	1	0
Separation (aperture)	None	<0.1mm	0.1 - 10mm	1- 5mm	> 5mm
Rating	5	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Sicken sided
Rating	6	5	3	1	0
Infilling (gauge)	None	Hard filling < 5mm	Hard filling > 5 mm	Soft filling , 5mm	Soft filling < 5 mm
Rating	5	4	2	2	0
Weathering	Un weathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP DRIENTATION IN TUNNELLING

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip. Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Drive with dip - Dip 20 - 45°	Dip 20 - 45°
Very favorable	Favorable	Very Favorable	Fair
Drive against dip - Dip 45 - 90°	Drive against dip - Dip 20 - 45°	Dip 0 - 20 Irrespective of strike	
Fair	Unfavorable	Fair	

Some conditions are mutually exclusive . For example , infilling is present the roughness of the surface will be overshadowed by the influence of the gouge , in such cause A. A directly .

Modified after Wickham et at (1972).

Rock mass class	Excavation	Rock bolts (20mm diameter, fully grouted)	Shotcrete	Steel sets
I- Very good rock RMR: 81-100	Full face, 3m advance.	Generally no support required except spot bolting.		
II- Good rock RMR: 61-80	Full face, 1-1.5m advance. Complete support 20 m from face	Locally, bolts in crown and walls with wire mesh in crown	50 mm in crown where required.	None.
III- fair rock RMR: 41-60	Top heading and bench 1.5-3m advance in top heading. Commence support 10 m from face.	Systematic bolts 4m long, spaced 1.5-2m in crown and walls with mesh in crown	50-100mm in crown and 30 mm in sides.	None.

IV- Poor rock RMR: 21-40	Top heading and bench 1.0-1.5m advance in top heading. Install support concurrently with excavation, 10m from face	Systematic bolts 4-5m long, spaced 1-1.5m in crown and walls with wire mesh.	100-150 mm in crown and 100mm in sides.	Light to medium ribs spaced 1.5m where required
V- Very poor rock RMR: <20	Multiple drifts 0.5-1.5m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6m long, spaced 1-1.5m in crown and walls with wire mesh. Bolt invert.	150-200mm in crown, 150mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75m with steel lagging and forepoling if required. Close invert.

6.1.3.4. Rock Tunneling Quality Index (Q- value)

Q-system was originally proposed by Barton, Lien and Lunde on the basis of about 200 case histories of tunnel and carvens. The Rock mass Quality Q has been defined as:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Where

RQD= Rock Quality Designation

J_n= joint set number

J_r= joint roughness number for critically oriented joint set

J_a= joint alteration number for critically oriented joint set

J_w= joint water reduction factor

SRF= Stress Reduction factor

In the equation the Q-value can be considered a function only three parameters which are approximate measures of:

a) Block size (RQD/ J_n) : It represent rock mass structure and a block size or the size of the wedge formed by the presence of different joints sets.

b) Inter block shear strength (J_r/ J_a) : It represent the roughness and frictional characteristics of joint walls or filling materials. The (J_r/ J_a) is collected for the critical joint set.

c) Active Stress (J_w/SRF):It is an empirical factor for describing "active stress condition". The stress reduction factor is measure of:

i) loosening pressure in the case of an excavation through shear zone and clay bearing rocks,

ii) rock stress in competent rocks,

iii) squeezing pressure in plastic incompetent rocks, $J_w$is a measure of water pressure, which has an adverse effect of the shear strength of joints due to reduction in effective normal stress.

The rock mass classification based on the Q-value is shown below:

Q-value range	Rock Quality
0.001-0.01	Exceptionally poor
0.01-0.1	Extremely poor
0.1-1.0	Very poor
1.0-4.0	Poor
4.0-10	Fair
10-40	Good
40-100	Very good
100-400	Extremely good
400-1,000	Exceptionally good

6.2. Measurement of the Structural Geological data from Rock mass

The data we get from the rock mass include attitude of rock mass which includes strike, dip, etc. The term used are described below:

Strike:

Strike is a geological direction given by the line of intersection of the horizontal plane with bedding plane of the layer of rock. It is measured in the field with the help of compass.

Dip:

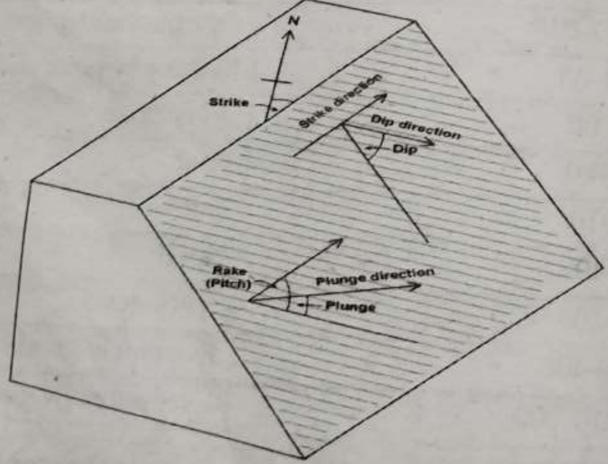
It is defined as the maximum angle of slope of bed or layer of rock with the horizontal. It is expressed both in terms of degree of inclination and direction of inclination.

(i)Dip amount:

Dip amount is the inclination with respect to horizontal plane. The value of dip amount ranges from 0° to 90°.

(ii) Dip direction:

Dip direction is the direction in which the beds inclined. It is measured by Brunton compass, holding its northe towards the direction of inclined beds or foliation.



True dip:

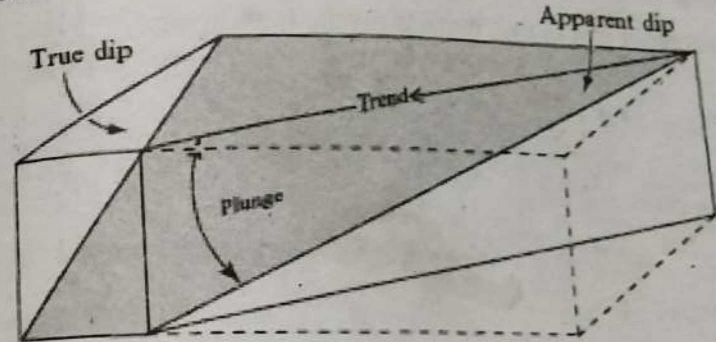
When the dip of the layer is measured in a direction that is essentially at right angles to the strike of the particular layer, then it is called true dip. It shows direction of maximum

inclination. In other word, it is the inclination in which water would flow, if poured on the surface of the bed.

Apparent dip:

When the dip of the layer is measured in any other direction which is not a right angled to the strikes direction is called apparent dip. It becomes lesser and lesser when it is deflected from true dip towards strike direction. When the cross section line is parallel to strike, apparent dip becomes zero.

Relation between true and apparent dip



$\tan\theta = \tan\alpha \cdot \sin\delta$

Where, θ = apparent dip

α = true dip

δ = angle between strike line and cross section line

Plunge:

It is the vertical angle between the inclined linear features and an imaginary horizontal plane is called plunge.

Trend:

compass bearing in the direction of the plunge of the linear geological feature is called trend.

Measurement of orientation of geological strata :

We will begin by taking the strike of a bedding plane. For these measurements we will use a Brunton compass like the one you see in the pictures above. In order to measure the strike, place the side or edge of the compass against the plane of the outcrop. Sometimes it is easier to put your field book against the outcrop and then the compass against the book to get a smoother and/or a larger surface. Now, rotate the compass keeping the lower side edge of the compass fixed, until the bulls-eye level bubble is centered (the round tube; not the long narrow one). When the bubble is centered, the compass is horizontal against the plane and parallel to the line of strike. Now, with the bulls-eye bubble centered, record the number that either end of the compass needle is showing.

Fig: Brunton Compass

In other words:

1. Place the bottom EDGE of the compass flat against the plane of interest.
2. Adjust the compass orientation, making sure the bottom edge is always flat against the plane, until the air bubble in the "Bull's eye level" is centered.
3. Read either end of the compass needle to obtain the value of strike.

Measuring Dip:

To measure the dip of the bedding plane, take your compass and put its side against the rock so that it points in the same direction as the line of dip (The dip line is perpendicular to the

strike line). Move the clinometer until the clinometer level bubble is centered. As we did when we found the strike, record where the white tipped end of the clinometer needle is pointing. Note the degrees and the direction. Recall that the dip direction must always be perpendicular to the strike direction (e.g., a strike of 40° could only dip to the SE or NW, never NE or SW)

In other words:

1. After you determine strike, rotate the compass 90°.
2. Place the side of the compass flat against the plane.
3. Adjust the lever on the back of the compass until the air bubble in the "Clinometer level is centered.
4. Read the dip directly from the scale in the compass.

6.3 Stereographic projection: Plotting a line and plane

6.3.1 Stereographic projection

Stereographic projection is easy, simple, useful and scientific tools for solving structural and engineering geological problem. The stereographic projection allows the three dimensional orientation data to be represented and analyzed in two dimensions. Stereographic projection removes one dimension from consideration so that lines can represent the plane and point can represent the line. The sphere is known as projection sphere and graph of nets use for projection is called stereo net.

Uses of Stereographic projection

- It provides a quick and reliable status of discontinuities plane and their intersection.
- It helps to estimate cut slope angle for prevention of slope failure and safety factor.
- It helps to prepare hazard map.

- It helps to determine orientation of intersection of two planes, angle between lines plane and angle between two planes.

Limitation:

It only considered angular relationships of the lines and plane and do not represent the position or size of the feature.

6.3.2 Plotting a line

The line in three dimension become point in two dimensions. The following procedures are followed for plotting a line:

i. Place the tracing paper over the stereo net and draw the primitive circle.

ii. Mark the E, W, N, S on the tracing paper.

iii. Find the trend and positioned it on the primitive circle.

iv. Then rotate the tracing paper to coincide the point to E-W axis.

   - *If the trend is <180⁰ then coincide with East.*
   - *If the trend is > 180⁰ then coincide with West.*

v. Count the plunge on the E-W diameter of the stereo net away from the primitive circle and mark it with the point.

vi. Again rotate the paper to get original position.

6.3.3 Plotting of a plane

i. Mark the strike with a tick on the primitive circle.

ii. Bring the tick to the N or S, whichever is closest.

iii. Count the dip amount on the E-W axis of the stereo net on the dip direction side, away from the primitive circle and mark with dot.

iv. Trace the great circle on tracing paper passing through the dot obtained.

v. Rotate the paper to original position.

6.4 Structural Analysis; Principles, Phases of the Analysis, Analysis of the Structural Geological data using Stereo net, Rose diagrams, Block Diagrams and histogram

6.4.1 Steps for Checking Stability of Discontinuity by stereo net

Following step are required for checking stability of discontinuities.

i. Simply check the difference between the discontinuity and hill slope. The discontinuity having same direction to hill slope subjected to plane failure while discontinuity having opposite dip direction to hill slope subjected to Toppling failure. For wedge failure the intersection of two discontinuities must dip in same direction to hill slope.

ii. Now take discontinuity whose dip direction is in same direction to hill slope for plane failure analysis. Each of the following condition should satisfy for plane failure.

- Dip Direction of hill slope/ cut slope and direction of discontinuity planes must be in same direction.
- Dip amount of cut/ Hill slope must be greater than that of dip amount of discontinuity.
- Dip amount of discontinuity plane must be greater than frictional angle.
- Additional condition strike difference must be within 20⁰.

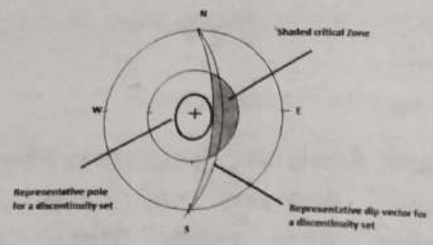


Fig: 6.4.1 Plane failure

iii. Now take discontinuity whose dip direction is in opposite to the hill slope for toppling failure. All of the below condition must satisfy for toppling failure.

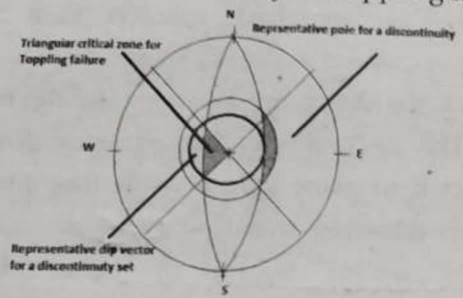


Fig: 6.4.2 Toppling Failure

- Dip Direction of hill slope/ cut slope and direction of discontinuity planes must be in opposite direction.
- Dip amount of hill slope should at least 55°.
- Dip amount of discontinuity should steeper than hill slope.(dip of h/s < dip of discontinuity)

  Additional condition strike difference must within 180°±30°.(150° to180°)

iv. Now, analysis of the intersection of discontinuity for wedge failure. The following condition must meet.

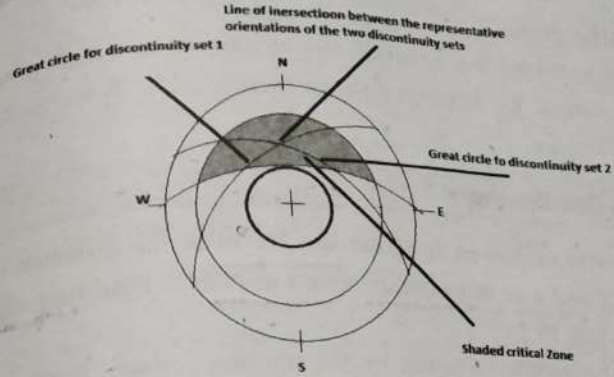


Fig: 6.4.3 Wedge Failure

- Dip Direction of hill slope/ cut slope and intersection of discontinuities planes must be in same direction.
- Dip amount of cut/ Hill slope must be greater than that of dip amount of intersection of discontinuities.
- Dip amount of discontinuity plane must be greater than frictional angle.

If dip amount of intersection is not provided then we cannot analysis for wedge failure but condition (ii) and (iii) may simply satisfies if it lies between the critical region (region between frictional angle and dip amount of hill slope).

6.4.2 Rose Diagrams:

Rose diagram is combination of concentric circle and radial line. The radial lines give directional data and concentric circle displays the frequency of each class. They are used to explain frequency of lineation in a given orientation used in sedimentary geology to display plaeocurrent data on orientation of joints and dykes.

6.4.3 Block Diagrams:

Block Diagram is a 3-Ddrawing representing a block of the earth's crust, showing geological structure.

6.4.4 Histogram:

A histogram is a visual display of information. It uses bars to show the frequency of an item of data in successive intervals.

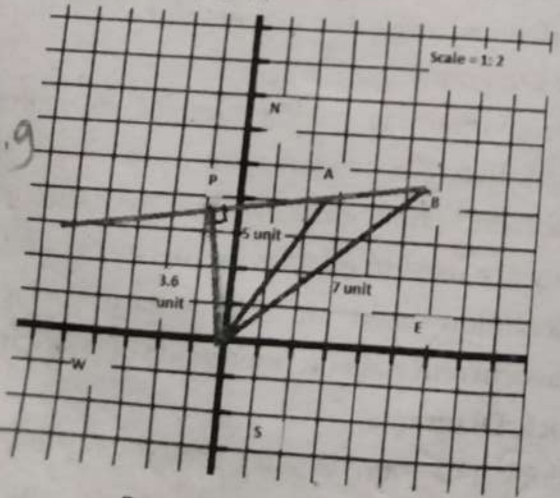
Work Out Example

1. **A coal seam has an apparent dip 1in 14 in the direction of N50°E and 1 in 10 in the direction of N35°E. Find true dip. [2012 fall, PU]**

Sol: The steps to be follow for the solution is stated below:

- Draw the line with given angle passing through the origin.
- Now choosing scale 1 unit: 2, mark the point on corresponding line named the point A and B respectively. Join the point A and B by straight line.
- Then, draw a line perpendicular to the line AB and passes through origin.
- Measure the angle of perpendicular line passing through origin and its length. The express the angle in form of dip direction and dip amount in ratio.
- True Dip amount=1 : (2*3.6)=1:7.2
- True Dip Direction=N9°W

$\tan\theta = 1/8.9$



Find the true Dip.

[*Note: The points above mentions are only for reference.]

2. **Determine the RQD value from the given data of drilled core and classify the rock. The length of core obtained are; 11cm, 12cm, 25cm, 6cm, 8cm, 20cm, 13cm.**

Sol: Here

Total sum of core length=11+12+25+6+8+20+13=95cm

Sum of length of pieces >10 cm=11+12+25+20+13=81cm

$$RQD = \frac{\text{Length of core pieces} > 10\text{cm length}}{\text{Total length of core run}} \times 100\%$$

$$RQD = \frac{81}{95} \times 100\%$$

$$RQD = 85.23\%$$

From Table, the rock mass Quality of rock is Good.

3. **In the featureless terrain three borehole A,B and C are sunk to ascertain the attitude of limestone bed. At point A limestone bed is reached at a depth of 600ft, C is at 1800ft due S10°E of A and limestone is reached at a depth of 400ft, B is 1500ft due S45°W of A and limestone reached here at a depth of 900ft. Determine the attitude of limestone bed. Also calculate thickness of limestone bed. [2014 fall, 2015 , 2017 Fall]**

Sol: Here

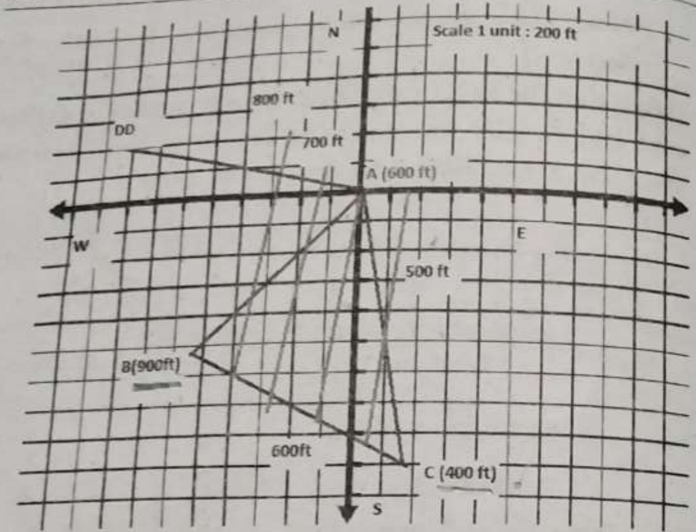
From the graph

A > 600ft

Strike= N9°E/ S9°W

Dip Direction= N81°W

1800ft



Dip Amount:

$$\text{Tan}(\theta) = \frac{\text{Strike Difference}}{\text{Hortizontal distance}}$$

$$= \frac{100}{1.4 - 200}$$

$$= \tan^{-1}\left(\frac{100}{1.4 \times 200}\right)$$

$$= \tan^{-1}(0.357)$$

$$\theta = 19.64^{0} \approx 20^{0}$$

True Thickness = Apparent thickness * cos(θ)

4. **Calculate the true dip from given, apparent dips. Given apparent dip 1:7 due to N45°W and 1:12 due N20°E. [2015 fall PU].**

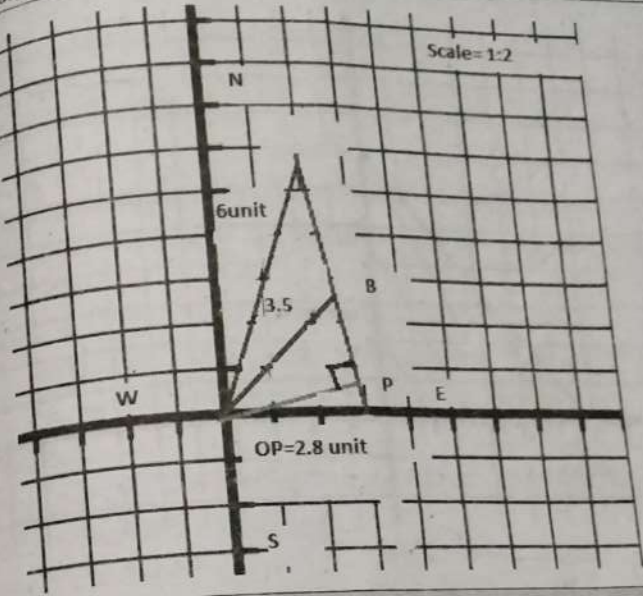
Sol: Here

Dip Direction = N81°E

Dip amount = 1:2*(2.8)

= 1:5.6

Abtibude → Strike & Dip Dir



Numerical problem

1. **Borehole A is 700m due north of bore hole B and bore hole C is 600m due west of bore hole B. The tops and bottoms of a rock layer are reached at the following altitudes relative to the sea level in three holes.**

Borehole A: -410m and -430m

Borehole B: -380m and -400m

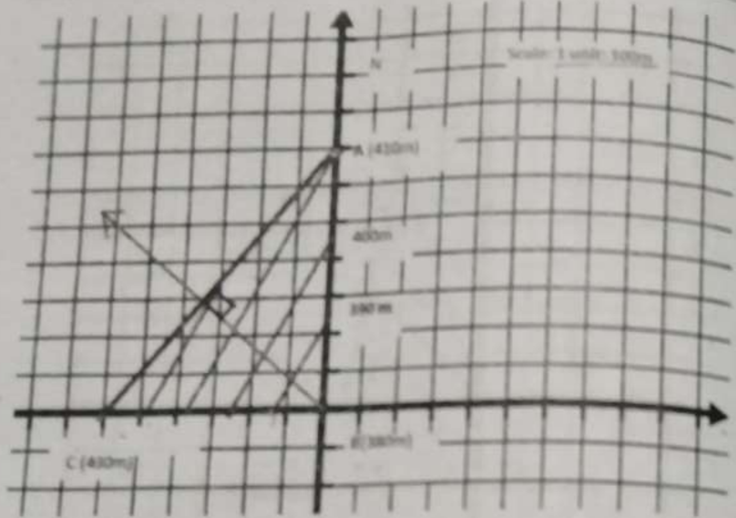
Borehole c: -430m and -450m

Find the altitude and thickness of the rock layer. [2068 Bhadra]

Ans: Here

Strike=N30°E/ S30°W

Dip direction= N60°W



Dip Amount:

$$\tan(\theta) = \frac{\text{Strike Difference}}{\text{Hortzontal distance}} = \frac{10}{1.1 \times 100} = \tan^{-1}\left(\frac{10}{1.1\times100}\right)$$

$= \tan^{-1}(0.091)$ $\theta = 5.2° = 5°$

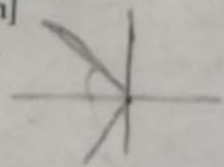
True Thickness= Apparent thickness * cos(θ)

= 20*cos(5°)

=19.92m

2. **A stream flows in a southerly direction across a limestone that strikes N30°W and dips 50°SW. Determine the true thickness of the limestone if the base of the limestone is exposed at an altitude of 2900m and the top is exposed at an altitude of 2000m. The breadth of the limestone along the stream is 2100m. [2069 Poush]**

Ans:



Here

Strike: N30°W

Dip amount(θ)= 50°

Apparent thickness of limestone=2900-2000=900m

True thickness= Apparent thickness cos(θ)

= 900* cos(50°)

=578.508m

N30° W 150

3. **Bore B in an oil field is 5000 feet due north of bore hole A and bore hole C is 10,000 feet due east of bore hole A. The tops and bottoms of a key sandstone bed are reached at the following altitude relative to sea leveling the three holes: A,-2500 and -2700 feet; B, -2800 and -3000 feet; and C, -3000 and -3200 feet. What is the altitude of the sandstone and how thick is it? [2069 Bhadra]**

Ans: Here

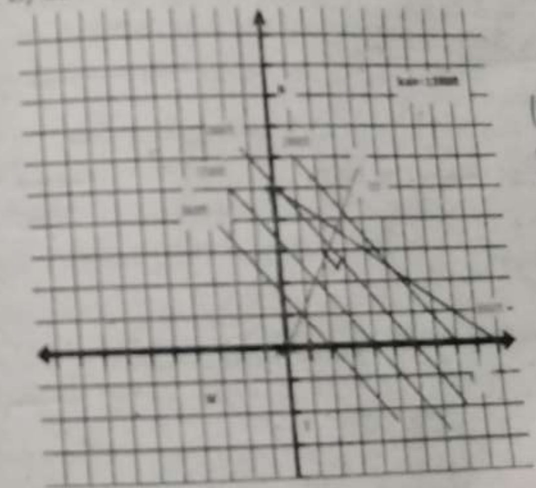
We Plot the borehole at scale 1 unit: 1000 ft with given data.

Altitude of Sandstone bed:

Dip direction=N40°E

Strike=N50°E/S50°W

5 → 3 900
10 → 200 N30° W / 50°



10 → 200
5 → 300

Dip Amount: $\tan(\theta) = \frac{\text{Strike Difference}}{\text{Hortozontal distance}}$ 10 - 2

$= \frac{100}{1.3\times1000}$

$= \tan^{-1}\left(\frac{100}{1.3\times1000}\right)$

$= \tan^{-1}(0.0769)$

$\frac{5}{3} = \frac{5}{3} = 1.67$

$\frac{10}{2} = 5$

$\theta = 4.397^0 \approx 4^0$

Thickness of limestone bed = Vertical Thickness *cos(θ)

= 200*cos(4°)

= 199.51 ft

4. Three boreholes A, B and C were drilled for limestone reserve calculation. Bore hole A lies at 600m distance due N28°E from borehole B. Borehole C lies at 400m distance due S10°W from borehole B. The top and bottom of limestone bed was encountered at the following depth of given borehole.

Borehole	Top(m)	Bottom (m)
A	200	260
B	220	280
C	240	300

Calculate the true thickness of the limestone bed. **[2070 Bhadra, 2073 Bhadra]**

Ans: Here

We Plot the borehole at scale with given data.

Attitude of limestone bed:

Dip direction=N30°W

Strike=N60°E/S60°W

Dip Amount: $\text{Tan}(\theta) = \frac{\text{Strike Difference}}{\text{Hortozontal distance}}$

$$\frac{10}{1.5\times100}$$

$$\tan^{-1}\left(\frac{10}{1.5\times100}\right)$$

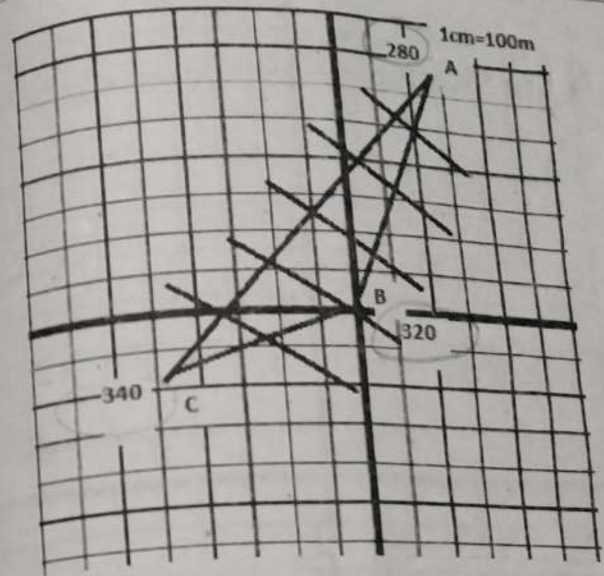
$$\tan^{-1}(0.0667)$$

$$\theta = 3.82^0 \approx 4^0$$

Thickness of limestone bed = Vertical Thickness *cos(θ)

= 60*cos(4°)

= 59.85m



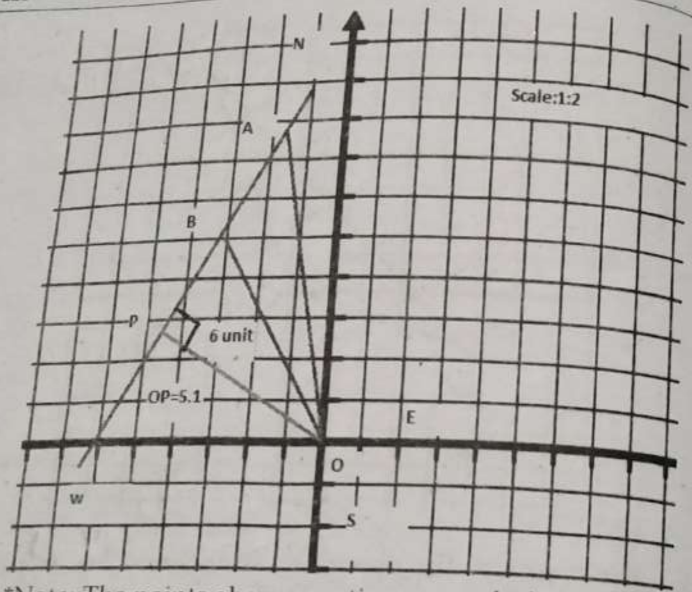
5. The apparent dip amount of an inclined bed is 1:12 and 1:16 along N30°W and N10°W respectively. Calculate the true dip amount and direction. [2070 Magh]

Ans:

- Let us plot a line in NW plane making angle (90°-30°) =60° with W and plot another line in same plane making angle (90°-10°)=80° with W.
- Now choosing scale 1unit : 2cm, mark the point on corresponding line named the point A and B respectively. Join the point A and B by straight line.
- Then, draw a line perpendicular to the line AB and passes through origin.
- Measure the angle of perpendicular line passing through origin and its length. The express the angle in form of dip direction and dip amount in ratio.

True Dip amount=1:(2*5.1)=1:10.2

True Dip Direction=N56°W



*Note: The points above mentions are only for reference.

6. **Three boreholes A, B and C were drilled at featureless terrain for a hydropower project. Borehole A lies at 700m distance due N23°E from borehole B and borehole C lies at500m due S71°W from borehole B. Top of bedrock was encountered at the following depths of three boreholes respectively. Find the altitude of bed rock and thickness of the bed.**

Borehole	Depth (Bottom) m	Depth (Top) m
A	-280	-240
B	-320	-280
C	-340	-300

[2071 Magh]

Ans:Here

We Plot the borehole at scale1cm:100m with given data.

Attitude of limestone bed:

Dip direction=N25°E

Strike=N65°W/S25°E

Dip Amount: $\tan(\theta) = \dfrac{\text{Strike Difference}}{\text{Horizontal distance}}$

$$= \frac{10}{1.6 \times 100}$$

$$= \tan^{-1}\left(\frac{10}{1.6 \times 100}\right)$$

$$= \tan^{-1}(0.0625)$$

$$\theta = 3.58^0 \approx 4^0$$

Thickness of limestone bed = Vertical Thickness *cos(θ)

$$= 40^*\cos(4^0)$$

$$= 39.903\text{m}$$

7. **Three borehole were drilled to find out stable place for dam foundation of hydroelectric project. The apparent thickness of quartzite was found as 210m. The attitude of Quartzite bed was 220°/36° NE. Calculate true thickness of bedrock. [2072 Ashwin]**

Ans: Here

Dip amount=36°

Apparent Thickness=210m

True Thickness=?

We know that,

True thickness = apparent thickness * cos (θ)

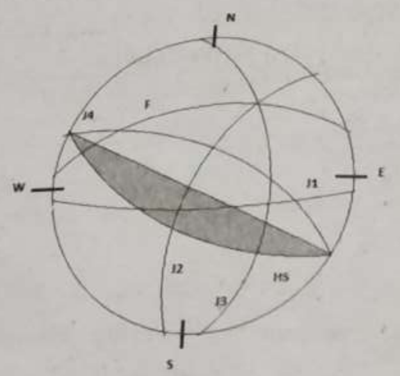
$$= 210^* \cos(36^0)$$

$$=169.89\text{m}$$

[**Problem related to slope failure**]

8. **Discuss the stability analysis based on the following data:**

HS=202°/65°, F=350°/27°, J_1=180°/81°, J_2=78°/69°, J_3=21°/73°, J_4=293°/52° [2070 Magh]



Ans: Here

Let us assume friction angle (ϕ)=30°

a) **For Analysis of Plane failure:**

Since the joint 1 and 4 are in same direction to hill slope thus they may suspect to plane failure. For stability we check the condition with Markland test.

Analysis of H.S and Joint 1:

Strike difference= 202°-180°=22°>20° (do not satisfy)

Since the condition do not satisfy so joint 1 is stable.

Analysis of H.S and Joint 4

Strike difference= 293°-202°=91°>20° (do not satisfy)

Since the condition do not satisfy so joint 4 is stable.

b) **For Analysis of Toppling failure:**

Since the joint 2 and 3 lies in opposite direction, they may susceptible to Toppling failure.

Analysis of H.S and joint 2

Strike difference= 202°-78°=124°(which do not lies between 180°±30°)

Since the condition do not satisfy so joint is stable.

Analysis of H.S and joint 3

Strike difference= 202°-21°=181°(which lies between 180°±30°) (satisfy)

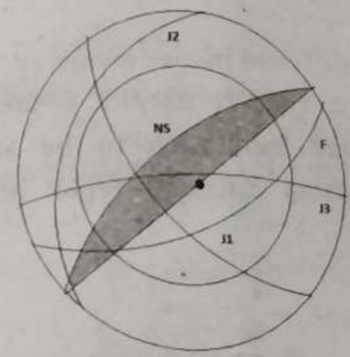
Dip of Hill slope is less than dip of joint 3. (Satisfy)

Thus, joint 3 have Toppling Failure.

c) **For Wedge Analysis:**

Since the data is insufficient so we cannot determine wedge failure.

9. **Discuss he stability analysis of the given planes. [2071 Bhadra]**
NS=320°/70°, F=155°/68°, J_1=240°/80°, J_2=310°/35°, J_3=10°/85°, ϕ=30°



Ans: Here

Friction angle (ϕ)=30°

a) **For Analysis of Plane failure:**

Since the joint 2 is in same direction to hill slope thus it may suspect to plane failure. For stability we check the condition with Markland test.

Analysis of H.S and Joint 2:

Strike difference= 320°-310°=10°<20° (satisfy)

Dip of NS > dip of joint 2 >ϕ (satisfy)

Since the conditions satisfy so joint 2 has plane failure.

For Analysis of Toppling failure:

Analysis of H.S and joint 1

Strike difference= 320°-240°=80°(which do not lies between 180°±30°)

Since the condition do not satisfy so joint is stable.

Analysis of H.S and joint 3

Strike difference= $320^\circ-10^\circ=310^\circ$ (which lies between $180^\circ\pm30^\circ$) (do not satisfy)

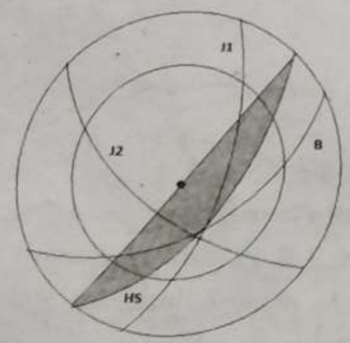
Thus, joint 3 have Toppling Failure.

For Wedge Analysis:

Intersection of Joint 1 and Joint 2

Since the data is insufficient so we cannot determine wedge failure.

10. The altitude of different planes are given below.
$HS=110^\circ/40^\circ$, $B=130^\circ/20^\circ$, $J_1=100^\circ/40^\circ$, $J_2=200^\circ/50^\circ$, $\phi=32^\circ$. Design cut slope inclination to be stable of given discontinuities from different types of failure. [2072 Magh]



Ans: Here

Friction angle $(\phi)=32^\circ$

a) **For Analysis of Plane failure:**

Since the joint 1 is in same direction to hill slope thus it may suspect to plane failure. For stability we check the condition with Markland test.

Analysis of H.S and Joint 1:

Strike difference= $110^\circ-100^\circ=10^\circ<20^\circ$ (satisfy)

Dip of HS > dip of joint 2 >ϕ (satisfy)

Since the conditions satisfy so joint 1 has plane failure.

For Analysis of Toppling failure:

Analysis of H.S and joint 1

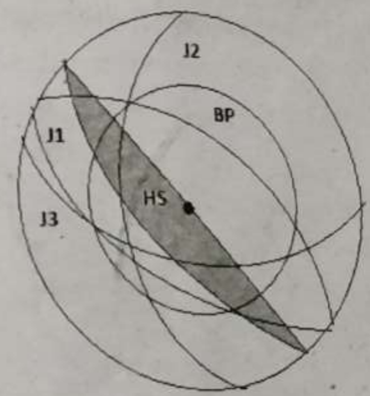
Strike difference= $200^\circ-110^\circ=90^\circ$(which do not lies between $180^\circ\pm30^\circ$)

Since the condition do not satisfy so joint is stable.

For Wedge Analysis:

Since the data is insufficient so we cannot determine wedge failure.

11. **Suggest the possible mode of failure from the following figure: [2073 Magh]**
Hill slope: $75^\circ/230^\circ$, Bedding plane: $68^\circ/045^\circ$, Joint 1: $49^\circ/215^\circ$, Joint 2: $55^\circ/265^\circ$, Joint 3: $65^\circ/199^\circ$, Internal friction angle $(\phi)= 32^\circ$



Ans: Here

Internal friction angle $(\phi)= 32^\circ$

a) **For Analysis of Plane failure:**

Since the joint 1, 2 and 3 are in same direction to hill slope thus they may suspect to plane failure. For stability we check the condition with Markland test.

Analysis of H.S and Joint 1:

Strike difference= $230^\circ-215^\circ=15^\circ<20^\circ$ (satisfy)

Dip of HS > dip of joint 2 >ϕ (satisfy)

Since the conditions satisfy so, joint 1 has plane failure.

Analysis of H.S and joint 2

Strike difference= 265°-230°=35>20°(do not satisfy)

Since the condition do not satisfy so joint 2 is stable.

Analysis of H.S and joint 3

Strike difference= 230°-199°=31°>20°(do not satisfy)

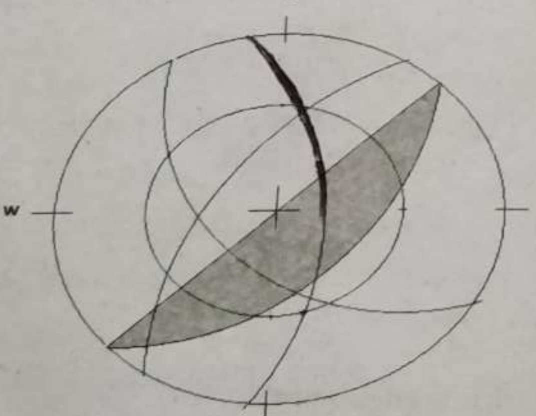
Since the condition do not satisfy so joint 3 is stable.

For Wedge Analysis:

Since the data is insufficient so we cannot determine wedge failure.

12. **Intrepretate the stability condition of rock slope where canal alignment have to be pass. The orientation discontinuities and hill slope and internal friction angle are as follow:[2074 Bhadra]**

HS=138°/45°, J_1=234°/38°, J_2=098°/58°, J_3=315°/60°, ϕ=25°



Ans: Here

Internal friction angle (ϕ)= 25°

a) **For Analysis of Plane failure:**

Since the joint 2 is in same direction to hill slope thus it may suspect to plane failure. For stability we check the condition with Markland test.

Analysis of H.S and Joint 2:

Strike difference= 138°-098°=40°>20° (do not satisfy)

Since the conditions do not satisfy so, joint 2 is stable.

For Analysis of Toppling failure:

Analysis of H.S and joint 1

Strike difference= 234°-138°=96°(which do not lies between 180°±30°)

Since the condition do not satisfy so joint is stable.

Analysis of H.S and joint 3

Strike difference= 315°-138°=177° (which lies between 180°±30°) (satisfy)

Dip of Joint 3> Dip of HS (satisfy)

Since the additional requirement that dip of HS should at least 55° is not satisfy. So the Joint is stable.

For Wedge Analysis:

Since the data is insufficient so we cannot determine wedge failure.

EXERCISE

1. a) What is Rock Mass? Classify the Rock Mass. [2068 magh]

Ans: The Large volume of Rock intersected by Discontinuities is known as Rock Mass.

For second part see 6.1.3

2. Define Discontinuity. Write down the widely Accepted properties for Rock Mass.

Ans: For first part see 6.1.1

For second part :

The widely accepted properties for rock mass are RQD,Q-value.

3. What is Stereographic Projection? What are kinematic Tests for Failures? [2068 magh]

Ans: For first part see 6.3.1
For second part see Q.N.4,16,17

4. Describe condition of Toppling Failure.[2068 Bhadra]

Ans: Toppling condition occurs when the following conditions meet.

- Dip of hill slope is opposite to dip of discontinuity.
- Dip of discontinuity is steeper than dip of Hill slope.

5. Define Rock Mass. Discuss Geo-mechanics classification of Rock Mass.
Ans: See 6.1.3.3

6. Define Rock Mass Rating (RMR). and Describe its importance in Rock Mass Classification. [2069 Poush]
Ans: SeeQ.n 20

7. Mention the different types of Rock Mass classification system. How do you measure RQD from given Drill Core sample.[2070 Magh]
Ans: See 6.3.1and Q.No 15

8. What is Rrock Mass? Describe the Rock classification based on Q-system and discuss its implication for its tunnel support design. [2070 Bhadra]
Ans: See 6.1.3.4

9. Discuss the different condition for plane failure in the Rock slope. [2070 Bhadra]
Ans:See Q.No.17

10. What are differences between Intact Rock and rock Mass? Explain about the importance of Rock quality designation (RQD) in Rock Mass Classification system based on Rock Mass Rating (RMR) in underground excavation. [2071 Bhadra]

Ans:

S.N	INTACT ROCK	S.N	ROCK MASS
1.	The intact rock is the rock in which there is absence of discontinuities. Intact rocks are described by its rock name, mineralogy, texture, degree and kind of cementation and weathering.	1.	The rock mass is heterogeneous in nature due to variation in rock type, discontinuities and degree of weathering.
2.	The strength of intact rock depends on the nature and composition of rock.	2.	The strength of rok is more a function of discontinuities within a rockmass than of intact rock strength.

11. How Rock tunneling Quality Index (Q) calculated? According to RMR- system, which Rock Mass classes require steel rib and thick shotcrete for support of underground excavation? [2071 Magh]Ans: See 6.1.3.4

12. Define Stereographic projection and mention the use of stereographic projection in the different field of engineering geology. [2072 Magh] Ans: See6.3.1

13. Describe the Role of RMR system in underground excavation and support design. [2072 Magh]

Ans: RMR system provide basic idea about the support design that must be used for the specific class of rock and also give the information regarding the excavation that can for particular class type. The table below show the excavation and support design according to RMR system.

Rock mass class	Excavation	Rock bolts (20mm diameter, fully grouted)	Shotcrete	Steel sets
I- Very good rock RMR: 81-100	Full face, 3m advance.	Generally no support required except spot bolting.		
II- Good rock RMR: 61-80	Full face, 1-1.5m advance. Complete support 20 m from face	Locally, bolts in crown and walls with wire mesh in crown	50 mm in crown where required.	None.
III- fair rock RMR: 41-60	Top heading and bench 1.5-3m advance in top heading. Commence support 10 m from face.	Systematic bolts 4m long, spaced 1.5-2m in crown and walls with mesh in crown	50-100mm in crown and 30 mm in sides.	None.
IV- Poor rock RMR: 21-40	Top heading and bench 1.0-1.5m advance in top heading. Install support concurrently with excavation, 10m from face	Systematic bolts 4-5m long, spaced 1-1.5m in crown and walls with wire mesh.	100-150 mm in crown and 100mm in sides.	Light to medium ribs spaced 1.5m where required.
V- Very poor rock RMR: <20	Multiple drifts 0.5-1.5m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6m long, spaced 1-1.5m in crown and walls with wire mesh. Bolt invert.	150-200mm in crown, 150mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75m with steel lagging and forepoling if required. Close invert.

14. What are the meanings of Rock Mass classification from RMR- System? [2072 Ashwin]

Ans: The meanings of rock mass classification from RMR system.

Class Number	Average stand up Time	Cohesion of Rock Mass(Kpa)	Friction angle of Rock Mass(deg)
I	20 Yrs for 15m span	>400	>45
II	1 year for 10m span	300-400	35-45
III	1 week for 5m span	200-300	25-35
IV	10 hrs for 2.5m span	100-200	15-25
V	30 min. for 1m span	<100	<15

15. How do you measured RQD in Rock exposure and Drilled core samples? [2072 Ashwin]

Ans: There are method for RQD measurement.

For Exposed rock:

We determine the RQD value for exposed rock by the relation suggested by Plamstrom as shown below:

$RQD = 115 - 3.3Jv$

Where

J_v= sum of the number of joints per unit length for all joint (discontinuity) sets known as the volumetric joint count.

For drilled core sample:

We determine the RQD value as the sum of the length of rock core bits longer than 10 cm expressed as a percentage of the total length.

$$RQD=\frac{\text{Length of core plece} > 10\text{cm length}}{\text{Total length of core run}} \times 100\%$$

16. Mention conditions for wedge failure from Rock Mass. [2072 Ashwin]

Ans: The Condition required for wedge failure from rock mass are enlisted below:

- Dip Direction of hill slope/ cut slope and intersection of discontinuities planes must be in same direction.

- Dip amount of cut/ Hill slope must be greater than that of dip amount of intersection of discontinuities.
- Dip amount of discontinuity plane must be greater than frictional angle.

17. What are the conditions of plane failure of Rock Slope. [2073 Bhadra]

Ans: The condition required for plane failure of rock slope are enlisted below:

- Dip Direction of hill slope/ cut slope and direction of discontinuity planes must be in same direction.
- Dip amount of cut/ Hill slope must be greater than that of dip amount of discontinuity.
- Dip amount of discontinuity plane must be greater than frictional angle.

18. What are the Parameters of Q- system for Rock Mass classification? [2073 Bhadra] Ans: See 6.1.3.4 (Six parameters)
19. How do you Calculate RQD from Drill core Method? [2073 Bhadra] Ans: See Q.N. 15
20. Write down the Importance of RMR system in Rock Mass classification. Discuss the excavation and support system in fair Rock class according to RMR. [2073 Magh]

Ans: The importance of RMR system in Rock Mass Classification are:

- It helps to analysis the strength of intact rock material.
- It is used to design support required during underground excavation.
- It is used to analyze the condition of discontinuities.
- It is used to make excavation in rock.

For Second part see Q.N.13

What are the parameters for RMR system of Rock Mass sification? Describe meaning w.r.t shear parameter? hadra] Ans: For first part see 6.1.3.3

CHAPTER-7

GEOLOGY AND CONSTRUCTION MATERIALS

7.1 INTRODUCTION

The supply of raw material for any civil engineering construction depends on the geology of the borrow area. From civil engineering point of view rocks are used for various purposes. The bulk of the production consists of crushed rock or natural aggregate and these are used mainly for road construction and for concrete. Smaller quantities are produced for granular fill, rail ballast and filter media. Bulk fill of rock, sand, shale or clay is excavated for embankments, dams, breakwaters and general site preparation works. Relatively small quantities of natural rocks are extracted for masonry, roofing, cladding and general architectural purposes. For cement manufacture large quantities of limestone, chalk, clay and shale are extracted.

Proper knowledge of extraction and use of construction material for any construction from geology field is an important sector of economy.

7.2 Aggregate and construction material: Clay, Sand, Limestone & Marbles, Slate & other building stones

7.2.1 Aggregate

Aggregate is naturally occurring inert granular material. Almost all natural aggregate materials originate from bed rocks.

There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of rocks. It may be recalled that igneous rocks are formed by the cooling of molten magma or lava at the surface of the crest (trap and basalt) or deep beneath the crest (granite). The sedimentary rocks are formed originally below the sea bed and subsequently lifted up. Metamorphic rocks are originally either igneous or sedimentary rocks which are subsequently metamorphosed due to extreme heat and pressure."

Uses of aggregate

- Aggregate used in concrete purpose of providing bulk to concrete.
- Aggregate used in building as roofing and flooring material
- Use in road railways ballast

7.2.2 Clay:

Clay is a must natural building material and has very good physical and biological properties that has been used since ancient times as building material.

- Clay building materials can be used for a variety of applications. They can be used for walls, façades and roofs as well as for gardens, terraces and open spaces.
- Clay has good insulating properties
- It is used for marking bricks that are used in wall.
- Clay building material are stable and durable.
- Clay brick and tiles are aesthetic and versatile

7.2.3 Sand

Sand is a loose, fragmented, naturally-occurring material consisting of very small particles of decomposed rocks, corals,

or shells. Sand is used to provide bulk, strength, and other properties to construction materials.

Sands are used for building purposes to give bulk to concrete, mortars, plasters and renderings. For example, sand is used in concrete to lessen the void space created by the coarse aggregate. Sand consisting of a range of grade sizes gives a lower proportion of voids than one in which the grains are of uniform size. Indeed, grading is probably the most important property as far as the suitability of sand for concrete is concerned.

7.2.4 Building stones

1) **Limestone**
   - **Rock type**: Non-clastic
   - **Colour**: variable, but found in lighter shades, white to grey
   - **Texture**: Very fine grained
   - **Maturity**: moderately matured.
   - **Mineralogy:**Clacite is chiefly, others quartz, feldspar and clay.
   - **Cementing Material**: Clacareous
   - **Strength**: Low to medium.
   - **Sp. Gravity:** Medium
   - **Porosity:** Highly variable low to medium
   - **Action with acid:** Reacts with vigorously even with cold dilute acid.

     → Massive and compact limestone are sufficiently competent to support civil engineering structures.

     → Being porous in nature limestone are not desirable at the site of foundation.

→ They are suitable as road metal, railway ballast and as a construction material but not durable as compare to other rocks.

→ It is used in manufacture of cement.

2) **Marbles**

- **Rock type:** Para metamorphic rock (Formed by metamorphism of limestone)
- **Colour:** Pure marble in milky white, pleasant shades of green blues, grey also occur
- **Texture:** Granoblastic
- **Mineralogy:** Calcite with small amount of mica, garnet, talc, graphite etc.
- **Grain size:** Fine, Medium or coarse grained, equigrannular.
- **Foliation:** Absent (Low to medium grade metamorphic)
- **Strength:** Medium
- **Porosity:** Medium
- **Sp. Gravity:** Medium

→ It is less porous and dense than limestone but cannot withstand heavy load

→ it is aesthetic beauty and pleasing appearance chooses for face work floor wall panels etc.

→ Marble are used as building stone for temples, ornamental, decorative work.

→ It can use as road metal and aggregate because of economic importance it is not used.

3) **Slates**

- **Rock type:** Argillaceous Low grade metamorphic rock.
- **Color:** Black (uniform) or dark greyish black.

- **Mineralogy:** Mostly contain mica and quartz May contain, chlorite, talc, feldspar.
- **Grain size:** Extremely fine grained
- **Foliation:** Present (clearly visible)
- **Strength:** Low
- **Porosity:** Medium
- **Sp. Gravity:** Medium

→ Being soft and incompetent cannot withstand great load and not suitable for foundation purpose.

→ They are used for roofing and flooring as they can splits into big slabs of uniform thickness.

→ They are not used as road metal concrete aggregate as do not Offers good resistance.

→ When cleavage is not developed, it is used for paving.

→ Being bad conductor of electricity and easy workability used as switch boards.

4) **Sandstone**

- **Rock type:** Arenaceous, clastic rock
- **Colour:** Variable color (red, brown, grey and white)
- **Texture:** Rounded, well sorted
- **Maturity:** Matured
- **Mineralogy:** Quartz is chief component, Feldspar, mica, garnet are found in small amount.
- **Cementing Material:** Siliceous or calcareous.
- **Strength:** Medium
- **Sp. Gravity:** Low to medium
- **Porosity:** Medium

→ Being hard, massive and compact it is used as building stone.

→ The permeability permits the percolation of water which decays the cementing material and result loss in cohesion or binding of sand grain.

→ Argillaceous sandstone are not desirable as it provided a slippery base.

→ Siliceous sandstone is strong, durable and easy to work so used at the site of foundation, for tunneling etc.

7.3 Requirement of selecting borrow areas

Borrow area:

The area from which natural materials, such as rock, gravel or soil, used for construction purposes is excavated.

Borrow area selection affects the feasibility of a project as it defines the amount of available, suitable fill at a reasonable distance from the site

The requirement of selection of borrow area are described below.

1) **Type of Construction Material**

The borrow areas are selected as per the requirement of type of the construction material i.e. aggregate, roofing and flooring stone, building stone. For granular soil (gravel and sand) the borrow area are to be selected as the river bead .for road material the borrow area are to be selected as the near to the road alignment along the streams.

2) **Location**

The borrow areas are locating as far as possible near of construction site

By the reason of the transportation cost the majority of raw material are used with in relatively short distance of their source. If the distance between the borrow area and reclamation site is too long it could affect the economics of the works.

The site for location of the borrow area should be selected that it is least affected by erosion, floods and scouring

3) **Quantities of fill available (size)**

The borrow area should be located so as to endure sufficient quantity of construction material is available in the borrow area.

4) **Geological condition of Borrow Area**

The borrow area should be located at the place of stable geological condition.it should not be located at the slope and unstable geological site and should also be studied to ensure maximum stability and safety

5) **Environmental aspects**

It should be located such as there are no any negative impact in surrounding environment of borrow area. It should not be locate at the valuable farmland and road alignments.

7.4 Searching, Exploration and reverse estimation for construction materials

1. **Searching** g.m.p

Geological search of the construction material for any civil engineering project can be done by desk study of the existing geological maps, aerial photography, Research paper of the particular location at different time and reconnaissance visit of the project area.

The desk study of maps, photograph are help to identify the location of construction material and its potential at the site.

2. **Exploration**

In exploration, the visit to the site is made. It helps in deciding the future program of site exploration.

The aim of exploration is to determine the depth, thickness and extent of composition of construction material. The depth of the bed rock ground water condition is also determined.

The exploration is generally in the form of few boring or test pits. In the detail exploration is to be determine the engineering properties of construction material and it includes extensive boring sampling and the testing of the samples.

3. **Reserve**

Reserve is the deposition of construction material. Reverse is the identified economical resource deposit of sufficient quantity and quality is present of construction material.

There are 2 types of reserve

a. **Proved or measured reserve**

Measured resource that can be extracted economically or The reserve from the resource are obtained as estimated is called proved reserve.

b. **Probable reserve**

The reserve for insufficient data is collected or is based on the limited data is known as probable reserve.

Methods of estimating reserve

- **Cross section method**

The quantity of construction material for the area is calculate by simple Calculation. The depth of deposit of material is determined by boring holes at different depth at different location.

Volume = area × thickness

- **Isopach method**

In this method, the area of reserve is contoured with the block of reserve in different maps like in cross section method to find the amount of reserve.

- **Extended area method**

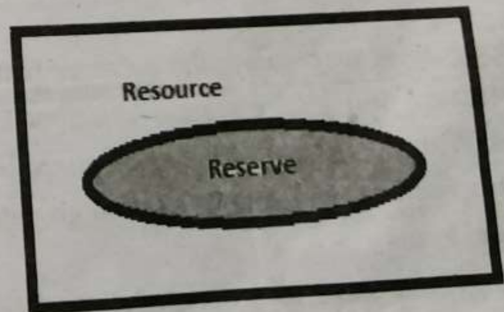
In this method, the reserve is estimated by the determination of area only.

- **Block method**

This particular method is based on the idea of division of the probable area of reserve. Here, the reserve area is divided into many blocks and studied individually.

The difference between resource and reserve are:

S.N	Resource	S.N	Reserve
1.	The term resource refers to the total amount of a material that exists.	1.	Reserves are That subgroup of a resource that have been discovered, have a known size, and can be extracted at a profit.
2.	The resource is always greater amount than reserve.	2.	The reserve may equal or less than resource.
3.	The total amount of a resource can be described and estimated based on information obtained from surveys	3.	The size of reserves can be estimated to a fairly certain degree



7.5 Uses of geological, engineering geological and topographic maps and aerial Photographs in searching of construction materials

1. **Geological Map**
   A geologic map shows the distribution of geologic features, including different kinds of rocks and surficial deposits, faults that displace the rocks and may be indicated by scarps in surficial deposits, and folds that indicate the rocks have been bent.
2. **Topographic map**
   Topographic maps are detailed accurate graphic representation of features appears on the Earth's surface such as road, building , reserve ,lake ,river, stream, mountain valley, wooded and cleared areas, vineyards and orchards.

q. imp

Uses of geological and topographical map of searching construction material

- A geologic map shows the distribution of geologic features, including different kinds of rocks and surficial deposits, faults that displace the rocks. E.g if rocks are required for construction then location of different rocks and weathering grade of rocks can easily find out from map.
- The topographic map shows the different features such as river streams and also elevation difference of different features. With the help of topographic map the deposition of construction material such as sand aggregate gravel can easily found out.
- The geology map show the orientation and thickness of the rocks at different location with the help of topographic map and geological map the volume of the construction material easily estimated.
- The study of topographic and geological maps together can learn a lot about the characteristics of the structure and to predict the type of soil and distribution in the region

3. **Aerial photographs**
   Aerial photographs are taken from a certain height with the help of aircraft or other flying object.

Use of aerial photographs in the searching of construction material

- Aerial photography became an important part of the mapmaking. Aerial photographs provide physical and cultural landscape of an area at a given time.
- The aerial photography can be used in locations that are difficult, unsafe or impossible to access.

Worked out examples

1. The attitude of sandstone bedrock is N44°W/36°.the difference of top and bottom of bed rock is 82m calculate the reserve of aggregate of aggregate in 2.7km strike length and 0.62km dip length of rock quarry site. [IOE 2075 BAISHAKH] → B

Solution

The orientation of bed rock is N44°W/36°

Dip amount (θ) =36°

True thickness of bedrock = $t \times \cos(\theta)$

$= 82 \times \cos(36°)$

$= 66.340$ m

Area of the bed rock is given by = $l \times b = 2.7 \times 0.62$

$= 1.674 km^2$

Now reserve = area ×thickness

$= \frac{2.674 \times 66.340}{1000}$

$= 0.17739\ km^3$

2. **Apparent dip amounts of quartzite bed rock along N20°E and N65°E are 1:9 and 1:12 respectively. The vertical thickness of bedrock is 105m .calculate the reserve of the construction material for an engineering project of an area of $4.6 km^2$ rock quarry site.[IOE 2073 BHADRA]**

Solution

The apparent dip are given

N20°E at 1:9 and

N65°E at 1:12

The true is 1: 8.9

$Tan(\theta) = \frac{1}{8.9}$

Dip amount $(\theta) = 6.41°$

True thickness = $t \times \cos(\theta)$

$= 105 \times \cos 6.41°) = 104.34m$

Now reserve = area ×thickness

$= \frac{4.6 \times 104.34}{1000}$

$= 0.4799 km^3$

3. **Calculate reserve for aggregate of quartzite bedrock having vertical thickness 300m at S72°W/43° and in an area of $437km^2$.[IOE 2073 BHADRA]**

SOLUTION:

The orientation of bedrock is S72°W/43°

The dip amount is 43°

The true thickness of bed rock is = $t \times Cos(\theta)$

$= 300 \times \cos(43°)$

T=219.40m

Now reservation = area × true thickness

$= \frac{437 \times 219.40}{1000}$

$= 95.877 km^3$

4. **Calculate reserve for the aggregate of bedrock having vertical thickness 18.72m At N42°E/41°.the strike length of bedrock is 55m and the dip length is 27.5 m.**

Solution

The orientation of bed rock is N42°E/41°

Dip amount $(\theta) = 41°$

True thickness of bedrock = $t \times \cos(\theta)$

$= 18.72 \times \cos(41°)$

$= 14.128m$

Area of the bed rock is given by = $l \times b$

$= 55 \times 27.5 = 1512.5m^2$

Now reserve = area ×thickness

$= 1512.5 \times 14.128 = 21368.6m^3$

EXRCISE

1) Write down the uses of Geological and Ttopographical Maps. [2068 Magh] Ans:See 7.5

2) What is Engineering Geological Maps? Describe the Importance of Engineering Geological Maps in selection of burrow area. [2068 Bhadra]

Ans: Engineering geological map is a type of geological map that provides basic information about the geological condition of the site for the use in planning, designing and construction and maintenance of engineering structures.

For second part see 7.5

3) Discuss the use of Topographical Map for the Construction Material survey. [2069 Poush] Ans:See 7.5