

CHAPTER FIVE

Engineering Geological site Investigation

- ❑ Knowledge of the sub-surface is imperative for design & construction of foundations for engineering structures
- ❑ The satisfactory design and construction of an engineering structure can be accomplished only when the character of the soil or rock, on which or with in which it is to be built is known.

Definition of site investigation

- *Site investigation deals with collecting all necessary information for safe and economic design, construction and maintenance of civil engineering structures, environmental management, or extraction/development of resources.*

- For **Civil engineering structures such as:**
 - Buildings, industrial and offshore foundations.
 - Reservoirs, fills and embankments.
 - Slopes.
 - Roads, airports and industrial pavements.
 - Bridges.
 - Retaining structures.
 - Tunnels and underground space facilities.
 - For Mining and resource development.
 - For Environment: waste containment systems and site remediation.
 - For Military engineering: recent developments.
- Site investigation involves the appraisal of the general subsurface conditions by analysis of information gained by such methods as;

- Geological and geophysical surveys,
- drilling boreholes, sampling, in-situ testing,
- laboratory testing of samples of the subsurface materials, groundwater observations, visual inspection, and local experience.

❖ **The purpose of site investigation** is to:

- Assess the suitability of a site for the proposed structure
- Evaluate the impact of construction on existing site conditions and existing site conditions on proposed construction
- Anticipate what can be expected during construction
- Develop criteria for design and construction based on site specific physical parameters

❖ **On-site investigations one must include:**

Geology of the project & adjacent areas includes:

- Nature of immediately underlying soil + rock;
- Topography & Vegetation;
- Ground water situations, i.e. seepage ,springs, etc;
- Natural slopes;
- Depth to Bedrock;
- Types of materials to be excavated;
- Stability of any excavations;
- Absence of toxic wastes;
- Position of any Utilities, and
- Permission to access property.
- All these factors influence site selection/ rejection.

Elements of an investigation

1. Formulating an investigation
2. Data collection
3. Data interpretation
4. Understanding the role of measurement and scales
5. Making data manageable for analysis
6. Applying analysis techniques and
7. Communication

1. *Formulating an investigation*; An investigation starts from formulating or framing the questions to be answered related to:

- amount of information needed.
- Scope of the investigation
- The size of the area depends on the scope
- Time available or required to complete the investigation
- Time is a function of the need of the engineer, the season and location.
- If the scope of the investigation is wide, the time required for investigation is longer

2. Data collection : It needs two kinds of studies:

Office study and Field study

A. Office study

- Gathering all the existing information useful to the investigation like geomorphology, hydrogeology, geology, population, accessibility, aerial photography, etc.
- Office study reduces time of field work if conducted properly
- Office study/data collection is completed once
- The available sources have been tapped
- The information extracted and the data organized in a usable form
- Finally compare the available data with what is required and it gives a guide to select the appropriate methods for acquiring data.

B. Field study

- Involves generating new data through exploration and testing
- Surface exploration ,Such as locating springs, seeps, mapping landslides, measuring the structural parameters of rock outcrops, etc.
- Data collected are usually transferred to a map base.
- The map may be the end product of the investigation or serve as a means of recording data to establish the spatial distribution of certain information.
- Sampling produces either qualitative or quantitative results.
- Decide in-situ or laboratory testing! Need a careful consideration by eng. geologist.
- Laboratory testing - unable to reflect the influence on strength exerted by the number, spacing, and character of discontinuities in the rock mass.

- Documentation is important to data collection in both office and field
- Field notes and drilling logs are very important
- Field notes should document pertinent observations and should indicate where and when the observation was made.
- A sketch or cross-section to show the setting is helpful.
- Always record the units for any measurement.
- Use a consistent approach to numbering the samples taken.

3. Data interpretation

- With out interpretation of the data collected investigation is incomplete.
- Interpretation starts with analysis of the data in light of the questions posed for the investigation.
- Analysis results serve as the basis for developing conclusions and recommendations.

- In actual investigation data analysis usually occurs throughout data collection.
- Avoids collecting extraneous (failure) data or not initially recognized as pertinent to the investigation.

4. Understanding the role of measurement and scales

- It is important to understand the relationship of data to scales of measurement.
- The different scales of measurement available are:
 - . Nominal scale, identification of rock type for collected samples, saturated, unsaturated
 - . Ordinal scale, ordered values of data, low, moderate, high, etc.
- Interval scale, order among data & relative difference within that order, zero point arbitrarily set permitting –Ve values to be obtained, e.g. Temp.
- Ratio scale, have a fixed zero point, e.g. length, volume, weight, etc.

5. Making data manageable for analysis

- Analysis begin with reducing raw data to a manageable form.
- Once reorganization is complete, analysis techniques can be applied to the data.
- Results obtained are evaluated with each other & with other data or criteria to the questions being addressed by the investigation.
- Reorganizing data involves preparing tables, graphs, measured profiles, cross-sections, etc. that permit comparison and examination. Then reorganize into maps that would permit comparisons among these factors.

6. Applying analysis techniques

- Analysis techniques may be: Mathematical analysis techniques or Statistical analysis techniques
- Choosing analysis techniques must be sufficiently familiar with the underlying assumptions of each techniques.
- Last step in interpretation is conclusions and recommendations

Where there is some uncertainty exists recommend for further detail investigations(additional drilling)

7. Communication ; *Final step in an investigation*

- The answers developed by the investigations should be transferred to the user for action.
- The user may be: individual, company manager, governmental board, court, etc.
- No single way of communication is appropriate in all cases.
- Presentation to the public, oral communication, written in a defined format, etc.
- Conclusions should be supported by data & analysis.
- Keep data separate from interpretations
- To have confidence in the conclusions, the user must be able to see how the data supports the conclusions.
- Assist reader or listener in understanding your findings by stating logical consequences of your conclusions (especially for less-technical background)
- Use pictures, diagrams and other nonverbal means of communicating your findings to supplement written or spoken words.

Stages/phases of site investigation

- Two basic types of engineering geological investigations

1. Regional study ; Address questions of land and resource allocation

- Provide information for land use planning
- Involves large areas & information developed lacks the detail needed to base engineering design
- Useful for broad-decision making purposes required in regional planning
- Maps and inventories are the result of regional study.

2. Site investigation Commonly associated with engineering geology study that provides a description of the state of physical characteristics of the site in most economical manner.

- Concentrates on geologic information that affect the design and construction of a particular project at a specific location

There are three phases of site investigation:

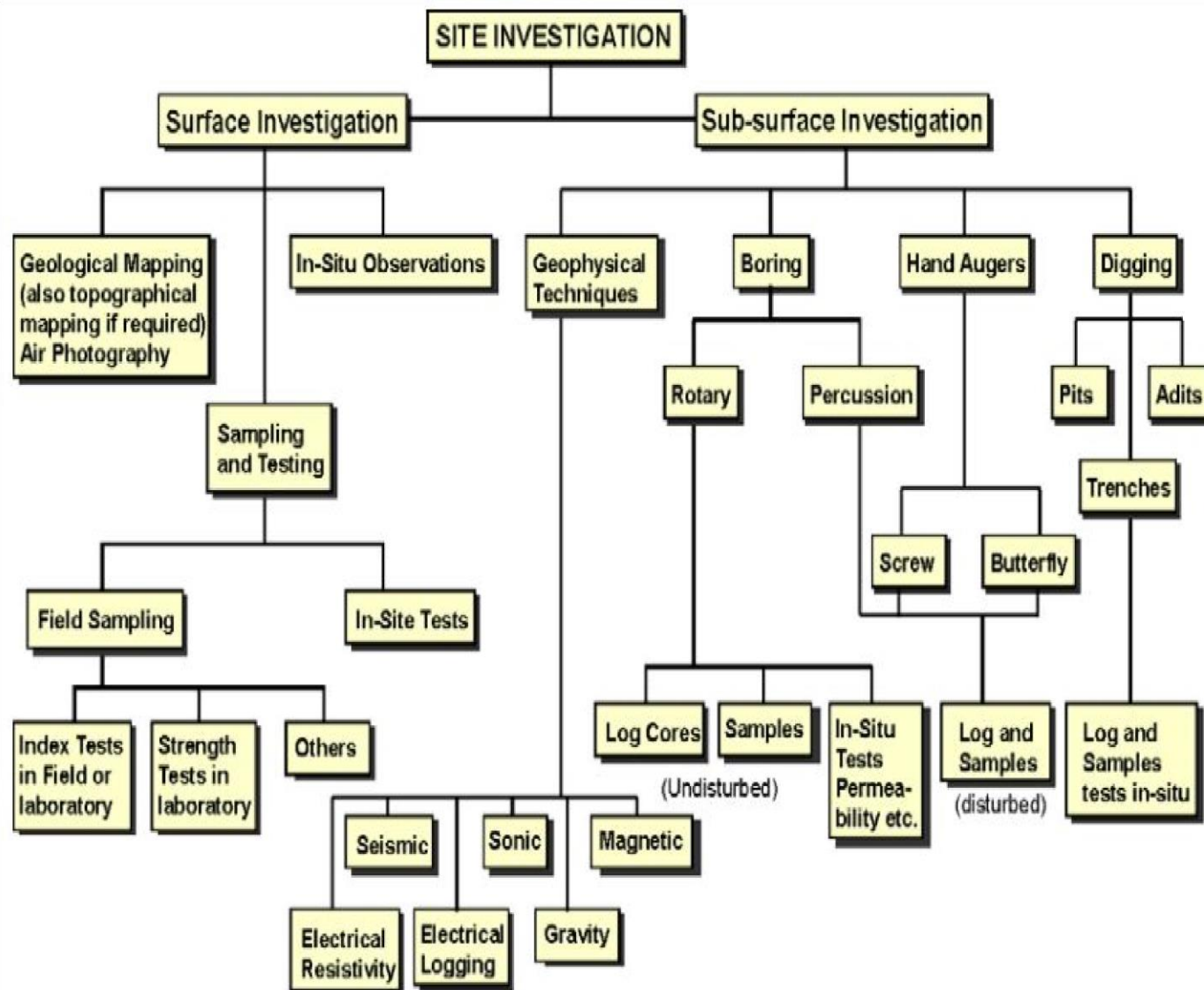
1. Initial or preliminary or reconnaissance) study
2. Detailed study (Site exploration)
3. Implementation (construction/monitoring)

1. Preliminary or reconnaissance study

- Involves collection of sources of information
 - Literatures, maps, aerial photo, reports, etc.
 - Collection of data from man's activities: Wells, Quarries, Mines, etc .
 - Walk over the site: fieldwork for 1-15 days,
 - To know surface relief ,distribution of soils & rock types
 - Surface drainage characteristics
 - Earlier uses of the site, evidence of underground working
 - providing geologic information for reasonable cost estimate ,e.g. time, instruments, borehole, geophysics, pit, etc.

2. Site exploration/ main investigation stage

- It is Intensive and Detailed investigation of a site
- ***Two main goals;***
 1. Determining & interpreting surface & subsurface conditions that influence design & construction
 2. Evaluating the behavior, characteristics & engineering significance of earth materials present or those intended for use in construction, examples building/Investigation a road route
- ✓ Exploration along the route would include areas that require special designs, Wet areas needing drainage, stream channels needing bridges or large fills, & rock outcrops requiring blasting might be among the factors identified during exploration, *General organization of Site investigation (After Fookes, 1987).*



Two types of site exploration/ Detailed investigation

1.Surface and

2.Subsurface exploration

- 1. *Surface exploration:*** surface information (soil & rock) understand geological processes which formed the soils and rocks (natural outcrops, river cut, etc)
- 2. *Subsurface exploration;*** to know thickness of overburden/ soil, in the absence of exposures permitting identification of underlying bedrock,
 - ✓ *if there is uncertainty of the relation of springs & seeps to the regional groundwater table.*
 - ✓ *If there is a need to identify nature of discontinuities and orientations in the subsurface.*

Methods of subsurface exploration

✓ **Direct Methods and Indirect Methods**

- Test Pits/Trenches
- Boreholes/Probes
- Cores
- Geophysical Techniques

3. Implementation studies

- ❖ Preliminary & detailed study results are continually revised & involve the recognition & monitoring of the geologic conditions / may differ from what was expected (changed condition).
- Basis for changing the project design to avoid major problems in project performance.
- All problems encountered during construction are studied at this stage
- Preparation of an in-constructed geologic map.
- Some times continue into the post-construction period (regulatory requirements).

❑ *Engineering Geological Site investigation of different civil and hydraulic engineering structures, includes:*

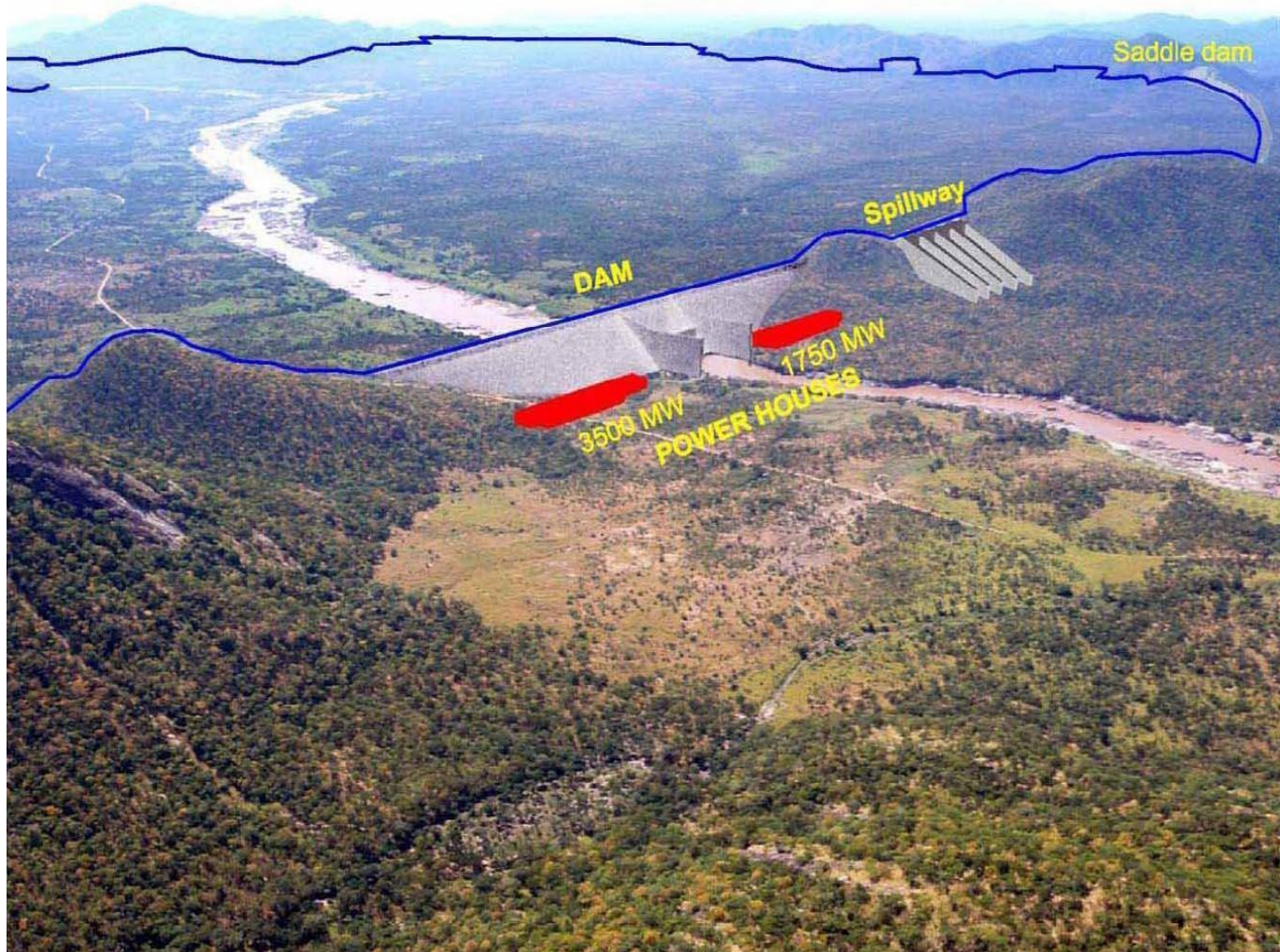
- Dams
- Bridges
- High way/Road
- Building
- Tunnels etc
- Dam and Reservoir

1.OFFICE WORK ; A review of local geological, geotechnical and geohazards investigation:

- Related reports, Standards, manuals, codes etc.
- Layout Plan and other drawing related to the dam and reservoir
- Topographic and geological Maps of the area
- Standard data sheets for logging and in situ testing, Sampling and ground water measurement .

- ***Investigation of Reservoir Sites*** ;In an investigation of a potential reservoir site, consideration must be given to the amount of:
 - *Rainfall*
 - *Runoff*
 - *Infiltration, and*
 - *Evapotranspiration.*
- ❖ The factors which influence the reservoir are: ***Climate, Topography, Geological condition, Vegetation cover/land use and land cover.***
- ✓ ***The two basic type of data needed for reservoir design are:***
- ✓ ***Topographical maps***
- ✓ ***Hydrological records:*** amount of water available for storage purpose. *flood peaks and Volumes of water, Rainfall, and Stream flow records.*

Fig. Topographical map of GR Ethiopian dam.



Engineering geological investigations

- Reconnaissance investigations
 - Preliminary studies of the project
 - Compilations of previous works and basic mapping
 - includes the collection and review of existing data
 - a site visit to assess engineering and geomorphic feasibility of the site
 - Cover a greater area than the proposed dam
 - Survey of dam-site area
 - Geophysical investigation
 - Preliminary subsurface exploration

A site visit shall be conducted

- **to assess the engineering significance of the geologic setting,** topography, site drainage, soil and rock materials, and other conditions in the area that can affect the suitability of the site for its intended use...
- **the local physical resources in the area,** including sediment, soils, surface waters, and ground water are identified, as well as offsite resources that may be impacted by project implementation...
- **the resources are assessed in terms of the potential adverse impacts** that operation of the proposed project, structure, or practice may have on them....
- ***the reconnaissance shall include determination of whether any conditions will affect the site.***

Requirements for geologic reconnaissance

- Consideration of
 - how operation of the proposed project... structure,
 - practice might adversely impact local resources, particularly soil, surface waters (including the sediment-water balance), and groundwater.
- Before going to the field,
 - all available pertinent technical materials,
 - regional geologic maps, topographic maps, well logs, aerial photographs, satellite imagery, soil surveys, water quality reports, mineral resource surveys, and published and unpublished reports) of the site or similar sites are reviewed

Results of the geologic reconnaissance

- used to assess the need for more detailed investigation and whether additional technical expertise is needed...
 - are based on site complexity and experience of personnel in the project area
- findings, conclusions, and recommendations for additional investigation are reported
- Documentation includes a geologic map prepared and the map is filed with the geologic report

Preliminary geologic investigation

- ***is conducted to provide sufficient information upon which***
 - reliable project cost estimates can be made in the planning phase of a project,
 - to determine the need for additional investigation
- All outcrops, cut banks, and other surface exposures are thoroughly inspected.
 - Erosion conditions, landslides, seeps, springs, and other pertinent conditions in and adjacent to the watershed
 - the information is gathered in the context of site feasibility for project implementation and engineering performance

Preliminary geologic investigation

- The need for detailed subsurface investigation must be determined.
- The investigation must be sufficiently detailed to furnish the planning team with information for making sound preliminary designs and cost estimates.

Engineering geological investigations

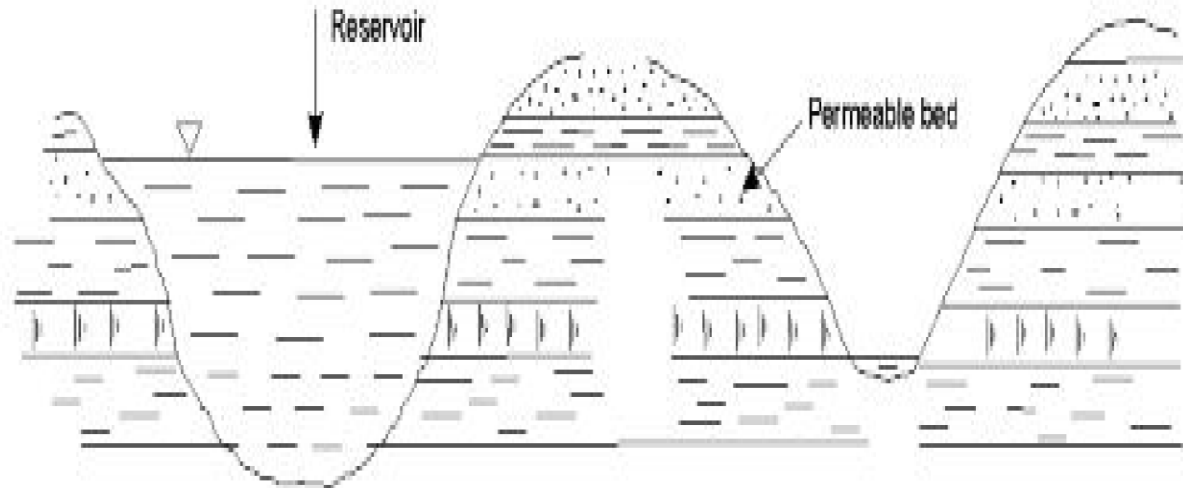
- **Detailed geological investigation**
 - Investigation of dam site
 - Investigation of the reservoir area
 - Water discharge area
 - Deposits of construction material
 - Usually with the scale of
 - 1:1000 and more for dam site
 - 1:5000 or 1:10,000 for reservoir
 - Subsurface exploration
 - Test pits, trenches , exploration drifts, core and percussion boring , permeability and water pressure tests

Cont,...

Detailed geologic investigation

- Detailed investigation includes any combination of the following:
 - seismic evaluation;
 - quantitative or semi-quantitative geomorphic evaluation;
 - developing sediment budgets (including sediment production, transport, and yield);
 - subsurface investigation; boring and geophysical surveys [penetrative exploration or correlation that has nearby outcrops and other physical features]
 - In-situ testing and obtaining samples for laboratory testing and performing in situ field tests.

- **Water can escape through Permeable rock slope**
 - ✓ *Through Continuous Fissures...*
 - ✓ *Water Leakage Through Terrace Deposits*
 - ✓ *Ancient Buried Valleys*



The major important of engineering geological investigations for the reservoir site are:

- ✓ Stability of the reservoir slopes....Important in the safe functioning of the dam.
... .which reduce the storage capacity of the reservoir, and avoid over toppling of susceptible slope.
- ✓ Siltation of the reservoir
- ✓ The rock type, drainage density and gradient of slope.

Example ; vajoint dam, Italy, in 1964 experienced Wave generation in reservoir due to a catastrophic failure of landslide in the reservoir area, killing 2000 people in the low lying areas.

- *proper site selection and designing of a dam ensures the long life of a **dam project**.*
- Some of the geological problems associated with the reservoirs are:
 - ✓ Lava flows
 - ✓ Limestone terrain
 - ✓ Evaporites
 - ✓ Buried channels
 - ✓ Surficial deposits
 - ✓ Faults
 - ✓ Old mine sites

Site Selection Criteria

✓ *Concrete dam site conditions*

- The foundation rocks should be sound and resistant to face static and dynamic forces.
- The valley slopes in the reservoir area and the abutment slopes should be stable.
- The dam foundation should be safe from sliding especially in the case of gravity dam.
- The *rocks in the foundation should be of uniform geological formation* to avoid variation in the modulus of elasticity.

➤ Site Selection Criteria

- The foundation and the reservoir rim should be watertight.
- The rocks at the site should be resistant to solution erosion.

- ✓ In the arch type dam the abutment should be topographically and geologically favorable to accommodate the thrust and stability of the arch.
- Geological and topographical conditions should permit a favorable location of diversion tunnel, spillway and powerhouse works.
- The construction material should be within an economically justified distance from the project.
- Basic Requirements for Embankment Dams ;The embankment, foundation and abutment must be stable during construction and reservoir operation.
- ✓ Seepage through the embankment, foundation and abutments must be collected and controlled to prevent:
 - excessive uplift pressures
 - Piping and sloughing
 - removal of material by solution
 - formation of cracks, joints and cavities.

Basic Requirements for Embankment Dams

- The design should consider **seepage control measures** such as:
 - foundation cutoffs,
 - Adequate and non brittle impervious zones,
 - transition zones,
 - upstream impervious blankets and relief wells.
- **Site conditions for embankment dam**
- A wide stream valley
- Lack of solid rock abutments
- Considerable depth of soil overlying bedrock
- Poor quality bedrock from a structural point of view
- Availability of sufficient quantities of suitable soils or rock fill
- Existence of a good site for a spillway of sufficient capacity.

- **Geological and geotechnical problems of dam sites Problems related to dams and reservoirs:**
- Stability, settlement/consolidation of dam foundation
- Leakage/seepage..permeability
- Geohazards: landslides and earthquakes
- Sedimentation of reservoirs.

High way/Road

Detail investigation; Deep vertical rotary drilling....pits..trench..subsurface layer

➤ **Field tests ;**Standard Penetration Tests

- ❖ CPT
- ❖ Undisturbed soil sampling
- ❖ Disturbed soil sampling
- ❖ Ground water measurement.

➤ **Laboratory tests ;**

- ❖ Moisture content
- ❖ Atterberg limits
- ❖ Specific gravity
- ❖ Grain analysis
- ❖ Dry-density
- ❖ Unconfined compressive strength

➤ Interpretation of measured results

- ✓ Determination of **bearing capacity** and determination of **foundation types** and levels.

Before construction Some amount of **excavation required for every** building:

- ✓ **Top soil** consisting of organic matter is removed.
- ✓ Below the region of soil erosion (by water and wind)

Engineering geological problems of road construction in tropical and subtropical areas

Many soils can prove problematic in highway engineering, because they **expand and shrink, collapse, disperse, undergo excessive settlement, have a distinct lack of strength or are corrosive**



Erosion and removal of part of the approach road to the Mvoti Bridge, Natal, South Africa.

EQUIPMENT AND METHOD OF EXPLORATION

- The boring,drilling,and excavation

Type of tests required for disturbed samples in laboratory tests ;

- Natural moisture content
- Grain size analysis
- Atterberg limits
- Free swell
- Consolidation tests
- Dry -density
- specific gravity
- compressive strength on rock cores
- Water absorption on rock cores
- Sulfate ,chloride content of soil and water

❑ Geological Investigation For Tunnels

- ❖ Geology determines: the nature, form, and cost of a tunnel e.g. route, design & construction of a tunnel
- Geological, geotechnical, and hydrological factors more than any other factors determine the degree of difficulty and cost of constructing an underground facility/tunnel.
- ❖ *Subsurface geology; pits, Drifts, drilling and Geophysical survey (especially seismic velocity of rocks).*

Preliminary geologic investigation

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 - reliable project cost estimates can be made in the planning phase of a project,
 - to determine the need for additional investigation
- All outcrops, cut banks, and other surface exposures are thoroughly inspected.
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Engineering geological data in Tunnels

- ❖ A rock mass is rarely continuous, homogeneous or isotropic.
 - ❖ Usually intersected by a variety of discontinuities (faults, joints, bedding planes, foliation, etc)
 - ❖ Can be a number of different rock types, subjected to varying degrees of weathering
 - ❖ Mapping of geological structures is an essential component of the design of tunnels
 - ❖ Geological data collection should be systematic in order to ensure relevant data are
- ✓ A complete engineering geological rock mass description contains details of rock material and natural discontinuities Weathering ,Structure, Colour, Grain size
- Intact rock material compressive strength, Rock type,
 - Details of the discontinuities, such as Orientation , Persistence , Spacing, Aperture, Infilling, Unevenness of each set
 - Evaluation of potential influence of groundwater & number of joint sets which will affect stability of the excavation/tunnel complete the description

ROCK MASS CLASSIFICATION

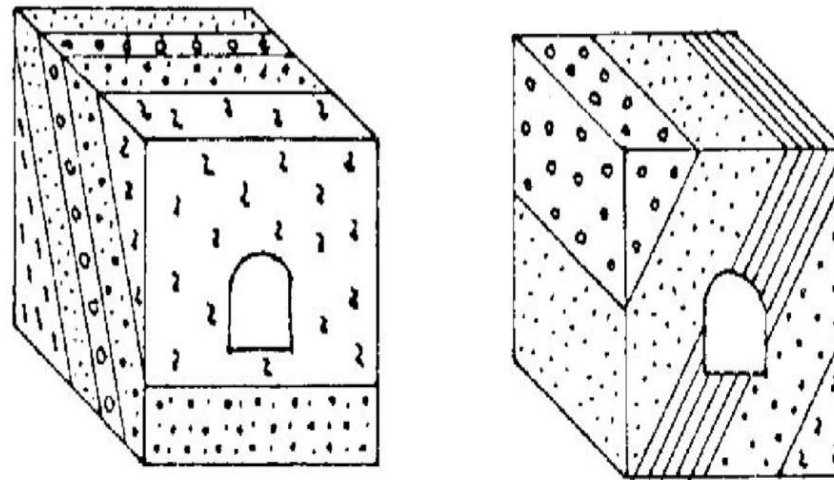
- ✓ Feasibility and preliminary design stages of the tunnel use rock mass classification scheme is important
- ✓ One or more classification schemes used to build up a picture of the composition and characteristics of the rock mass.
 - ✓ To provide initial estimates of support requirements
 - ✓ To provide estimates of the strength and deformation properties of the rock mass.
- ❖ *CLASSIFICATION SYSTEMS;*
 - ✓ *Terzaghi's rock mass classification*
 - ✓ *Rock Quality Designation Index (RQD)*
 - ✓ In the absence of core $RQD = 115 - 3.3J_v$, J_v is the sum of the number of joints per unit length for all joint sets (volumetric joint count)
 - ✓ Geomechanics Classification (RMR)
 - ✓ Rock Tunneling Quality Index (Q) or NGI-Q
 - ✓ Rock Structure Rating (RSR) : more relevant to mining applications

Tunnels in different geological formations

The geological factors which influence tunneling are as follows;

1. **Swelling rocks** -If a tunnel is to be constructed through swelling rocks, it will require special treatment. The examples of swelling rocks are shale, unconsolidated tuff and anhydrite(Gypsum).
2. **Inclined strata** - In inclined rock beds when a tunnel is driven parallel to the strike direction, there is a tendency in the rocks to fall into the tunnel from the side where the beds dip into the tunnel. This is particularly the case hard and soft rocks, such as sandstone and shale are interbedded.

Fig. effect's of inclined rock structure in tunneling



3. Folded rocks - tunnels that are driven through synclinal folds joint blocks form inverted keystones in the arch and cause rock falls.

- In case the rocks happen to be water-bearing, the water flows into the tunnel and causes great difficulties

4. Fault zones –

- ✓ Faults are commonly found associated with a zone of highly crushed rock or clay gouge.
- ✓ The crushed rocks being highly permeable allows groundwater to seep into the tunnel.
- ✓ Besides this they also form unstable roof rock. Jointed rocks

5. Jointed rocks; Joints at one hand may help in excavating the rocks but on the other hand they may present difficulties in tunneling.