SITE INVESTIGATION

(Summarized from with modification: González de Vallejo, and Mercedes Ferrer, 2011. Geological Engineering. CRC Press.)

Aims and importance

- Site investigation is to define the geological and geotechnical properties of the project ground in engineering geological terms, before construction starts.
- Site investigation is essential for any engineering project where the ground will be used as a base for foundation or as a source of materials. Site investigations are essential for accurate budget estimation for any construction project.
- Inadequate site investigations may increase the overall project cost by over 50%. It is generally agreed that sooner or later, the cost of site investigations have to be paid for**.**
- There are no fixed rules for estimating the appropriate cost of geotechnical investigations as every project has its own set of characteristics. These depend on:
  1. The type of ground
  2. The scale of the project
  3. The degree of geological complexity and its influence on the construction conditions.
- As a rough guide, for large projects investigation should be budgeted as 15–20% of the total project cost, and around 10% or less for smaller projects.
- The general aim of site investigation is to identify and quantify the ground conditions that may affect the engineering structure. The objectives of site investigation should be:
  1. Establish the viability of the site for the proposed works in terms of its geological, geotechnical and geo-environmental conditions.
  2. Establish which locations within the site offer the most favorable conditions
  3. Identify any geological hazards and instability problems present in the area.
  4. Determine the geotechnical properties necessary for the structural design and construction and environmental acceptability.
- In Site investigations should be carried out at each stage of the project as follows:
  1. Preliminary and desk-based studies: viability studies based on information obtained.
  2. Preliminary design: site selection; study of **possible** solutions and **approximate** cost estimates.
  3. Design: **detailed** site description, design, **cost** estimates, completion **dates**.
  4. Construction: design; on-site control and geotechnical monitoring.
  5. Operation: monitoring of ground- structure behavior after construction.
- Site investigations should be carried out at each stage of the project. Each stage needs a certain level and type of site investigation; it means that site investigation can be *programmed* in a work sequence through the whole project progress.
- Most of the site investigation is done through the first three stages. The role of site investigation in the later two stages is monitoring and finding out any problems that may occur during or after construction.
- The following table summarizes the site investigations needed in each stage of the project:

Site investigation procedures		
Project stages	**main activities**	**site investigations**
Preliminary studies	Literature review and desk-based study (previous studies and available data)	1) Topography, relief and land use. 2) Hydrology and hydrogeology. 3) Regional geological maps. 4) Geological history. 5) Seismicity and other geological hazards.
	Aerial and remote sensing interpretation	1) Aerial photographs and remote sensing. 2) Geomorphology. 3) Lithological and structural characterization. 4) Geo-hazards. 5) Geological mapping.
	Walk-over survey and preliminary geological reconnaissance	1) Identification of soils and rocks. 2) Faults and structures. 3) Hydrogeological data and drainage. 4) Geomorphology, slope stability, subsidence, collapses, flooding, land use, etc. 5) Geo-environmental problems. 6) Accesses and sites for borehole drilling, trial excavations and geophysical surveys.
Preliminary design	Engineering geological mapping (scales 1:5,000–1:10,000)	1) Lithostratigraphy and structure. 2) Geomorphology and Hydrogeology. 3) Classification and properties of materials.
	Hydrological and hydrogeological data	1) Identification of karstic areas and areas susceptible to flooding and runoff. 2) Regional and local hydrological data.
	Basic site investigations (*)	1) Boreholes and trial excavations. 2) Geophysical prospecting. 3) Laboratory tests.
Design	Detailed site investigations (**)	1) Boreholes 2) ***In situ*** and laboratory testing.
	Detailed geotechnical mapping (scales 1:500–1:2,000)	1) Detailed geological-geotechnical mapping. 2) Geotechnical properties, classification and zoning.
Construction	Geotechnical validation	1) Detailed geotechnical mapping. 2) Stability of excavations and tunnels. 3) Ground control and improvements. 4) Foundations and ground reinforcement work.
	Ground structure monitoring and control	1) Monitoring equipment installation and instrumental readings. 2) *In situ* testing.
Operation	Monitoring	1) Ground-structure behaviour monitoring.
(*) Basic investigations: mainly to exploratory investigations and identification tests. (**) Detailed investigation: detailed investigations for each structure and for the whole area affected by the project, followed by *in situ* and laboratory testing.		

- Geological field work is both highly cost-effective and also essential for determining which investigation methods to be used and their characteristics.
- The following table shows the influence of geological factors on site investigation planning.

Influence of geological and geomorphological conditions on site investigation planning		
Geological and geomorphological factors	**Typical features**	**factors to be considered**
Sedimentary and metamorphic rocks of sedimentary origin	1. Relatively uniform formations over large areas 2. Well-defined and stratified structures 3. Rocks of marine origin more uniform and continuous than those of continental origin.	1. Greater reliability in extrapolation of geological data. 2. Number of site investigation points usually lower than those for metamorphic igneous rocks. 3. Use of borehole drilling is highly effective.
Extrusive igneous rocks	1. Stratiform structures 2. High heterogeneity and lithological anisotropy.	1. Great number of boreholes is usually required. 2. Limitations in the use of geophysical methods.
Intrusive igneous rocks	1. Non-homogeneous lithological and geometric conditions.	1. Difficult to identify geometric boundaries of intruded bodies. 2. Highly effective use of geophysics.
Tectonic structures	1. Great continuity. 2. Soft and breccia materials filling. 3. Anisotropic conditions at both sides of the structure	1. Structural and geological mapping are fundamental. 2. Use of boreholes and geophysics essential.
Low relief	1. Predominance of alluvial deposits, heterogeneous soils and weathered rocks. 2. Poor drainage.	1. Relatively low drilling costs. 2. Highly effective use of geophysics and penetrometers.
Moderate to high relief	1. Lithological and structural relief control. 2. Rocks, colluvial and alluvial deposits.	1. High drilling costs. 2. Accesses can be very difficult.
High relief and mountain regions	1. Hard rocks. 2. Lithological and structural relief control. 3. Colluvial deposits and slope instabilities.	1. Adverse conditions for site investigations. 2. Difficulty of access. 3. High drilling costs. 4. Weather limitations. 5. Extensive use of photo interpretation and geological mapping.

Planning and design of site investigations

- As mentioned before, the **objectives of site investigation** should be::
  1- Establish the viability of the site for the proposed works in terms of its geological, geotechnical and geo-environmental conditions.
  2- Establish which locations in the site offer the most favorable conditions.
  3- Identify any geological hazards and instability problems present in the area.
  4- Determine the geotechnical properties necessary for the structural design and construction and environmental acceptability
- Each project requires its own particular site investigation planning and so there are no general rules. For planning purposes the following factors should be considered:
  1. Information available from previous studies.
  2. Aims of the project; structural loads acting on the ground.
  3. Regional and local geological conditions.
  4. Site access and physiographical characteristics.
  5. Suitable site investigation methods.
  6. Cost estimates and completion deadlines.

- Site investigation surveys must include the following:
  1. Geological description of the area.
  2. Main lithological groups.
  3. Geomorphological and hydrogeological conditions.
  4. Identification of possible engineering geological problems and geohazards.
  5. Main engineering geological properties and data to be obtained.
  6. Environmental conditions for fieldwork.

- Depending on the above data, different techniques or methods will be selected, taking the following criteria into account:
  1. Decision on and scope of methods for obtaining geotechnical parameters required and their limitations.
  2. Schedule of work and completion dates.
  3. Cost-benefit ratio of the investigation techniques used.

- Site investigation design must be able to combine the following successfully:
  1. Adequate planning, taking in consideration logistical aspects, such as site access and climatological conditions.
  2. Appropriate investigation methods
  3. Reliable and representative data
  4. Relevant results
  5. Clearly written reports

Preliminary investigations (the first phase of investigation)

- The aim of preliminary investigations is to get a general engineering and geological understanding of the project area. This first phase includes:
  1. Desk-based studies (all previous studies and available data)
  2. Aerial photo and remote sensing interpretation.
  3. Walk-over surveys.

Project stage	main activities	site investigations
Preliminary studies	Literature review and desk-based study (previous studies and available data)	1) Topography, relief and land use. 2) Hydrology and hydrogeology. 3) Regional geological maps. 4) Geological history. 5) Seismicity and other geological hazards.
	Aerial and remote sensing interpretation	1) Aerial photographs and remote sensing. 2) Geomorphology. 3) Lithological and structural characterisation. 4) Geo-hazards. 5) Geological base mapping.
	Walk-over survey and preliminary geological reconnaissance	1) Field check on the identification of soils and rocks. 2) Field check on Faults and structures. 3) Hydrogeological data and drainage. 4) Geomorphology, slope stability, subsidence, collapses, flooding, land use, etc. 5) Geo-environmental problems. 6) Accessibility of the site and possible locations for borehole drilling, trial excavations and geophysical surveys.

- From these preliminary studies, site investigation can be planned and geological factors assessed, including any geohazards and environmental restrictions which may affect the viability of the project.

- **1- Desk-based study**
- Before any field work is carried out, all available information related to the project and the construction site should be examined
- The main sources of desk-based studies are listed in the following table:

Sources of information for desk studies	
subject	**information**
Topography	—Topographical maps. — Aerial photographs and digital elevation data.
Photo interpretation and remote sensing	— Aerial photographs. — Satellite images.
Geology	— Geological maps. — Geological surveys and reports. — Aerial photographs. — Soil survey maps.
Geotechnics	— Geotechnical publications. — Geotechnical reports. — Geotechnical maps.
Hydrogeology and hydrology	— Hydrogeological maps. — Topographical maps. — Aerial photographs. — Well and borehole data. — Hydrogeological reports. — Flood risk maps.
Meteorological data	— Rainfall and temperature records.
Seismological data	— Earthquakes records and seismic codes.
Mining and quarrying	— Industrial rocks information. — Mining and quarrying records. — Available maps.
Land use	— Urban and land use planning maps and reports.
Environmental and natural resources	— Environmental maps and environmental impact studies.
Pre-existing constructions and services	— Industrial and building records.

2- Aerial photo and remote sensing interpretation

- Aerial photo interpretation was one of the most widely used methods in geological mapping. Since the 1970s, remote sensing became a powerful tool in geological interpretation and mapping.
- There are two main types of satellite data:
  a. **Optical satellite data**: that record the sun electromagnetic waves reflected from the earth's surface, e.g. Lansat, Spot and World View images. These data are widely used in rock discrimination and geological mapping up to 1:500 scale.
  b. **Radar satellite data**: there are two types of radar data:
     - **Digital elevation data (DEM):** showing the topography of the earth's surface (e.g. SRTM and Aster GDEM data of resolutions 90 and 30 m, respectively). These data can be used to construct **topographic contour** maps and **drainage** mapping and analysis. Spot and other satellites provide DEM data of higher resolution,
     - **Synthetic aperture radar (SAR):** in which the radar waves penetrate the ground surface to few meters. This data can be used to discriminate soil types and detect the shallow structures affecting soils that are not clear in the optical data
- One of the principal characteristics of satellite images is the historical images. (Multi-temporal) that makes them extremely useful in studies of dynamic processes such as sediment deposition in delta areas, historical urban extensions and changes in vegetation cove.

3- The walk-over survey

is one of the most important tasks carried out at the preliminary stage. The following field studies should be carried out:

1) Geological data

a) Types of materials, lithology and composition, lithological contacts, and sedimentary structures.
b) Geological structure and tectonic contacts, degree of fracturing, fault zones, areas with **neotectonic** (earthquake) activity.
c) Definition of the sequence of geological events.
d) Effect of weathering.
e) Geomorphological conditions, morphological evolution and ground surface processes.

2) Geotechnical description of soils

The geotechnical field description of soils should be based on the following sequence:

a) The soil composition is determined using the Unified Soil Classification System, differentiating soils according to grain size distribution (mechanical analysis).

b) The color of soil observed in the site may indicate important properties; e.g. a yellowish red color indicates intense weathering and the presence of iron oxides; a dark brownish-green color and black indicate the presence of organic material

c) Soil structure is described as: homogeneous; stratified; banded; laminated.

d) The density of granular soils and cohesion can easily be determined in the field with simple tests.

e) A soil could be described as e.g.: a fine sandy clay, light grey in color, with low compressibility, firm and homogeneous when seen fresh at natural moisture content

3) Geotechnical description of rock masses

This includes three areas:

a) Characterization of the intact rock,

b) Description of discontinuities and characterization of the rock mass.

c) The data-collection processes.

4) Hydrogeological and hydrological data

a) Water tables, inspection of wells and springs.

b) Location of aquifers, permeable and impermeable materials, areas of swampland, etc.

c) Location of recharge and drainage areas.

5) Ground instabilities

a) Signs of landslides or rock falls.

b) Areas of intense erosion.

c) Areas affected by subsidence, sinking processes and cavities.

6) Observation of structural damage in surrounding areas

Detection of any structural damage of buildings, bridges, tunnels, or embankments in the vicinity of the site is important. Attention must be paid to the appearance of cracks and other signs of deformation.

7) Other items to be considered in Carrying out site investigations:

a) Establishing land ownership, permission for access and presence of underground utilities (cables, pipes, etc.).
b) Location of roads and access routes for carrying out site investigations, especially boreholes.
c) Availability of water and electricity, and authorization for use.
d) Selection of possible sites for boreholes, trial excavations, geophysical surveys and field tests.
e) Assessment of risks to personnel.

8) Preliminary site investigation report must include:

- Engineering geological report based on all preliminary studies.
- Potential problems and geological-geotechnical factors that may affect the project objectives.
- Proposal for detailed site investigations.

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Engineering geophysics

- Geophysical prospecting covers a series of techniques for investigating the subsurface based on detection of variations in its physical parameters and their correlation with geological characteristics.
- Such techniques are used in investigations of large areas to complement on-Site tests and direct investigation techniques (e.g. borehole drilling and trial pits).
- Their application in geological engineering requires **specialists** familiar with the geotechnical characteristics of the materials.
- These techniques are used to determine the following:
  1. The thickness of overburden;
  2. The position of the water table;
  3. The location of cavities or other anomalies in the ground;
  4. Structure of the substratum (e.g. stratification and folds);
  5. Location of subsurface faults
  6. The geotechnical properties of materials;
- Geophysical methods can be grouped into two main groups:
  A. Surface geophysics
  B. Borehole geophysics

A- Surface geophysics

- Common surface geophysical methods are:
  1. Electric (resistivity),
  2. Seismic (velocity of seismic wave propagation),
  3. Electromagnetic (electrical conductivity and magnetic permeability),
  4. Radar; Ground Penetrating Radar (GPR)
  5. Gravity (density),
  6. Magnetic (magnetic susceptibility)
  7. Radioactive (natural or induced radiation levels).
- Field work in some surface geophysical methods **can be seriously affected** by the presence of power lines, railways, moving vehicles or very heterogeneous ground.

1- Electrical methods:

- This method measure the **resistivity** of subsurface rocks to direct electric current. Resistivity is a property of rocks and soils that depends on lithology, microstructure and, above all, **water content**.
- It is frequently used in geological engineering. It is very effective in the determination of water table depth, and subsurface water saturated zones.

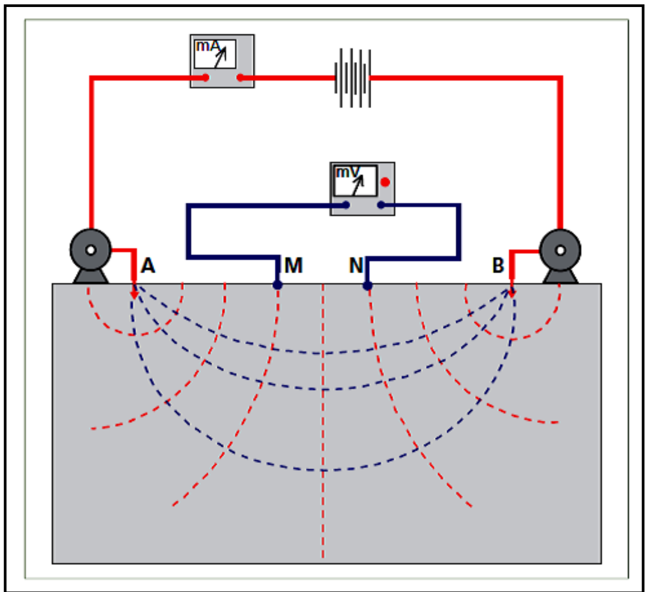


Fig.1. Measuring ground resistivity using electrical methods

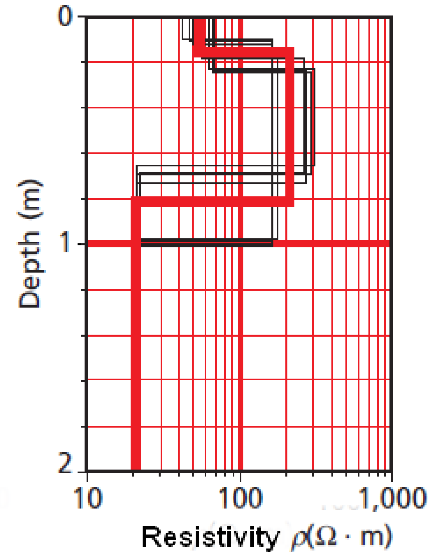


Fig.2. Example of electrical sounding record

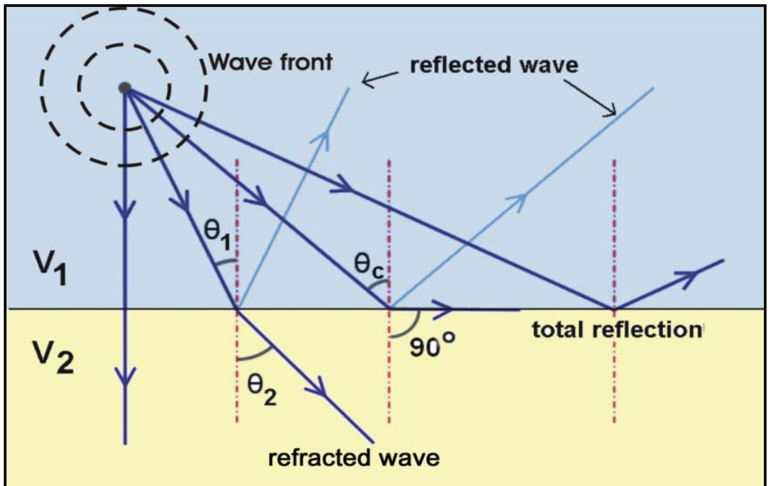
Resistivity in the substratum is measured in the following steps (Fig.1):

1. A continuous current of intensity (I) is passed through the ground by two electrodes, A and B, connected to an energy source.
2. The difference in potential ΔV generated by passing the current is measured between two electrodes, M and N.
3. The resistivity of the depth of the ground affected by the current is measured.
4. A greater distance between electrodes A and B implies a greater depth of material affected by the current. Accordingly, the AB separation is progressively increased and the resistivity is measured at each step,
5. An electrical sounding record (Fig.2) is produced that represents the variation of resistivity of rocks and/or soils with depth.
6. The electrical sounding record can be interpreted in terms of lithology and geotechnical characteristics of subsurface material.

2- Seismic methods:

- Seismic methods are used to study the propagation of artificially-produced seismic waves through the ground and establish their relationship with the geological structures and lithology.
- Propagation velocity depends on the elastic constants and density of the medium. Different geological masses have different seismic wave transmission velocities. At lithologic contacts, or separation surfaces, waves are refracted, reflected or diffracted.

- **There are two main seismic methods:**
  1) **<u>Seismic reflection method,</u>** records the reflected waves
  2) **<u>Seismic refraction method</u>**, records the refracted waves.

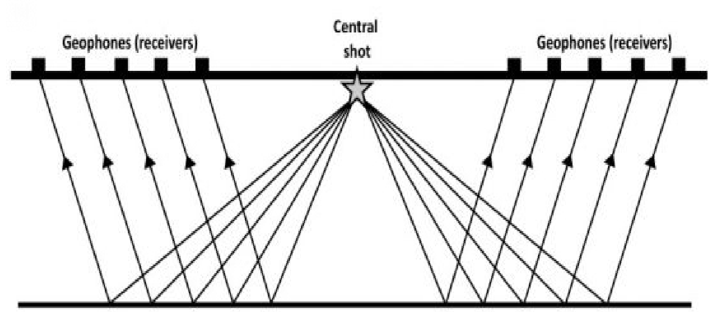


Wave propagation along the contact between two media,

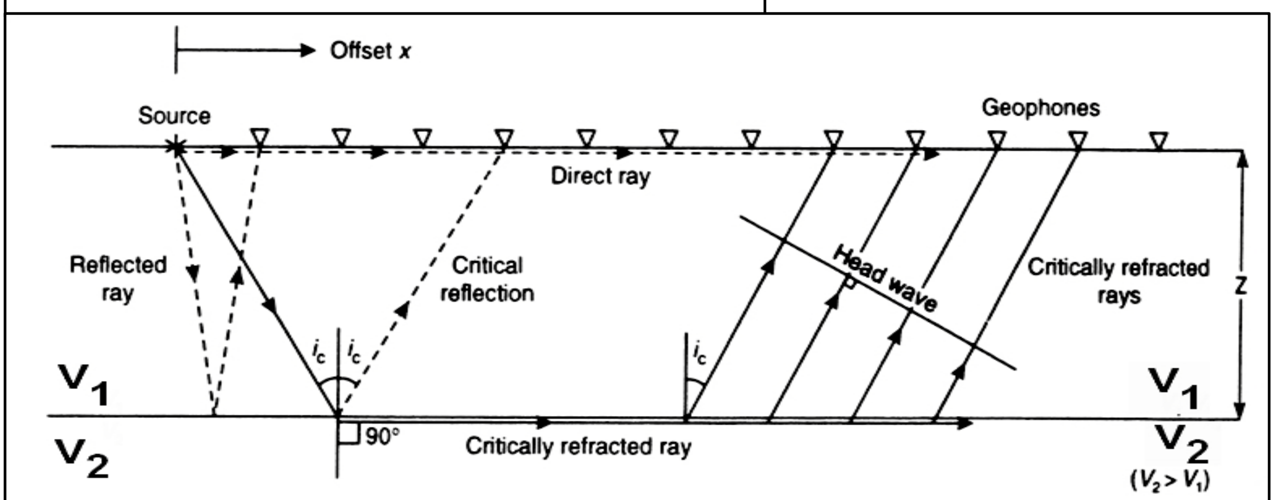
$V_2 > V_1$

θ_c = critical incidence angle

- Waves of incidence angle=90 pass through the boundary without reflection or refraction.
- Waves of incidence angle $\theta_1 < \theta_c$ are both reflected and refracted at the boundary.
- Waves of incidence angle = θ_c are partially reflected back and partially refracted along the boundary.
- Waves of incidence angle > θ_c are totally reflected without refraction.



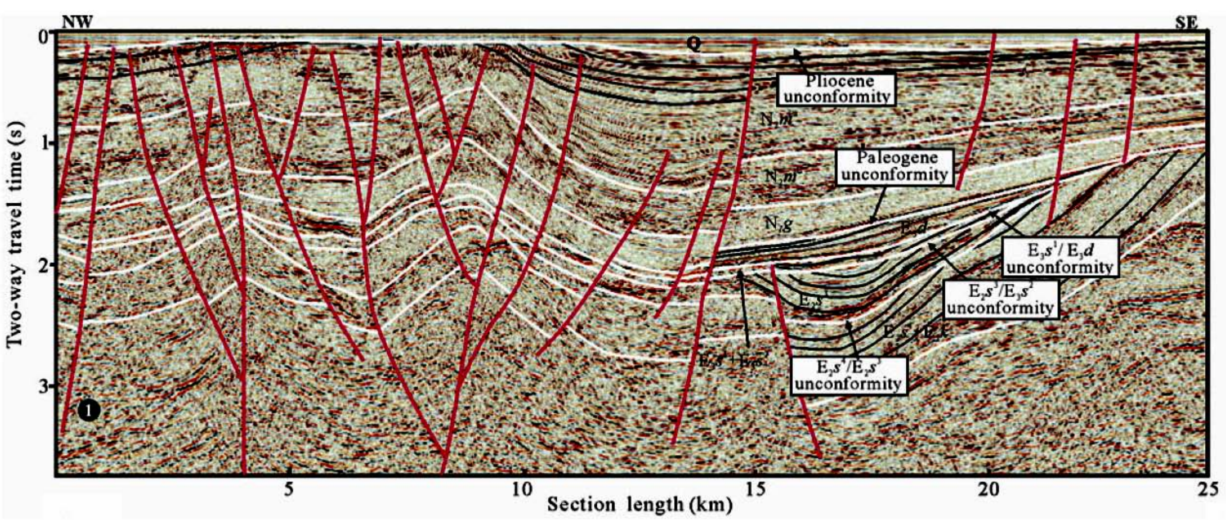
Seismic reflection method



Seismic refraction method

Waves refracted along the boundary generate seismic waves (head waves.) in the lower-velocity (upper) layer that reaches the earth's surface and recorded.

- **Limitation of <u>refraction</u> seismic method**
  a) The velocity of subsurface layer must increase with depth; true in most cases. Thus, **refraction method will not easily detect the slow velocity layer**.
  b) The subsurface layers must be of sufficient thickness to be detectable.
  c) Data collected directly over loose soil or sediment or in the presence of excessive cultural noise **may result in poor results**.
- **Seismic <u>reflection</u> survey** are used for delineation of near-surface geology for engineering studies within depth of up to 1km. Shallow seismic reflection is very useful in <u>mapping stratigraphy</u>, structure such as faults, hydrogeology, and detection of depth of bedrocks. Reflection method can **detect the slow velocity layer**.
- **General Methodology**:
  1- Geophones are arranged on the ground surface along a straight line (traverse) or along a network design.
  2- Seismic waves are generated by applying an appropriate energy source (with a hammer, gun, weight drop or explosives).
  3- The seismic waves reflected or refracted from successive reflectors at depth are recorded by a series of geophones as a two-way time (the travel time taken by the wave to arrive to the geophone).
- <u>The traverse lines must be oriented based on the pre-knowledge of the main structural trends detect on the surface of the ground</u>.
- The data collected from the geophones network are plotted as a series of seismographs, in which the two-way time can be <u>reinterpreted as depth values</u>. The seismograph represents a cross sectional view of the subsurface reflectors beneath a certain line or traverse..
- The seismograph can be interpreted in terms of geological contacts and affecting structures as shown in the following diagram.



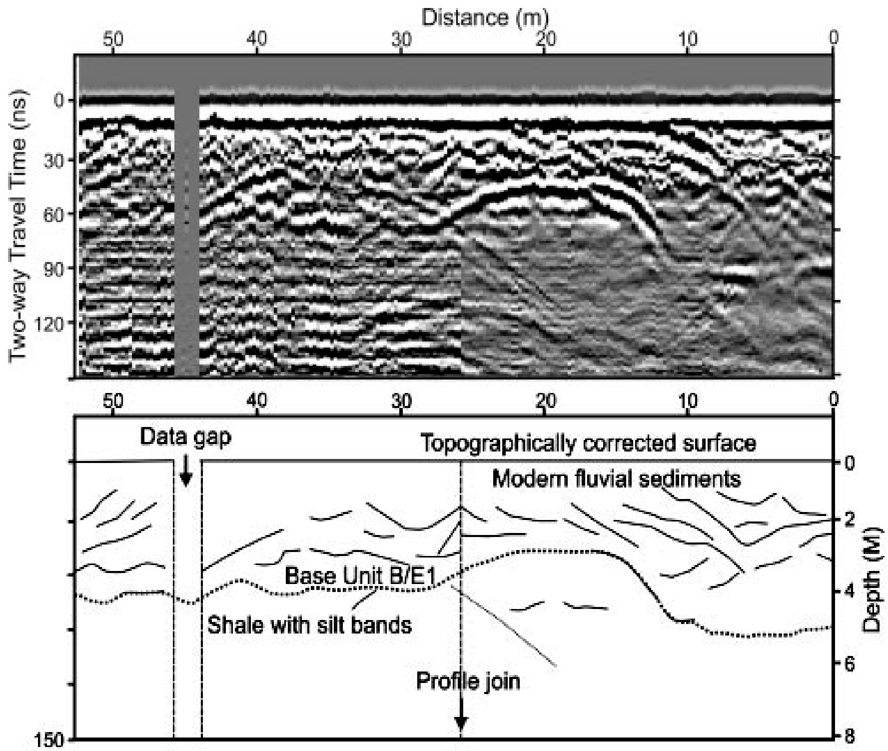
- **In engineering geology:**

  Seismic velocity can be correlated to rock hardness. This is an important parameter of rock lithology to predict its resistance to excavation. Several geotechnical parameters can be evaluated from the recorded seismic data. **The determination of the geotechnical properties of subsurface rocks from seismic data is a new important trend in petroleum studies.**

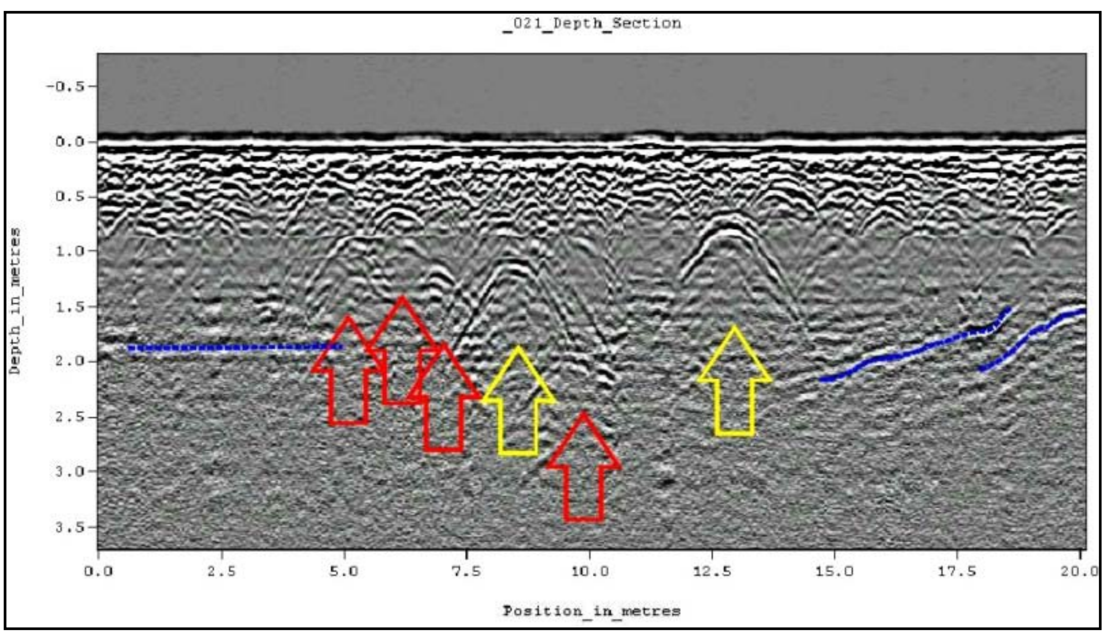
3- Ground Penetration Radar (GPR)

- Ground Penetration Radar (GPR) uses radar waves to obtain high resolution profiles for the subsurface reflectors. Its main advantages are the speed of data collection, and ease of use.
- The depth of penetration of the waves is not large as in seismic methods, but the obtained records are more detailed.
- Georadar equipment consists of four main elements: transmitter antenna, receiver antenna, control unit and recording unit.
- The depth of penetration depends on the frequency of the transmitted waves. Lower frequencies penetrate to higher depth.
- The transmitter antenna of the equipment can be chosen of a certain frequency suitable for the desired penetration depth.

- The obtained GPR profile can be interpreted in terms of geological contacts and structures in the same way in seismic profile, as shown in the following profiles.



- One of the most important advantages of GPR profiles is the ability of detection of <u>subsurface **cavities and utilities**</u>,

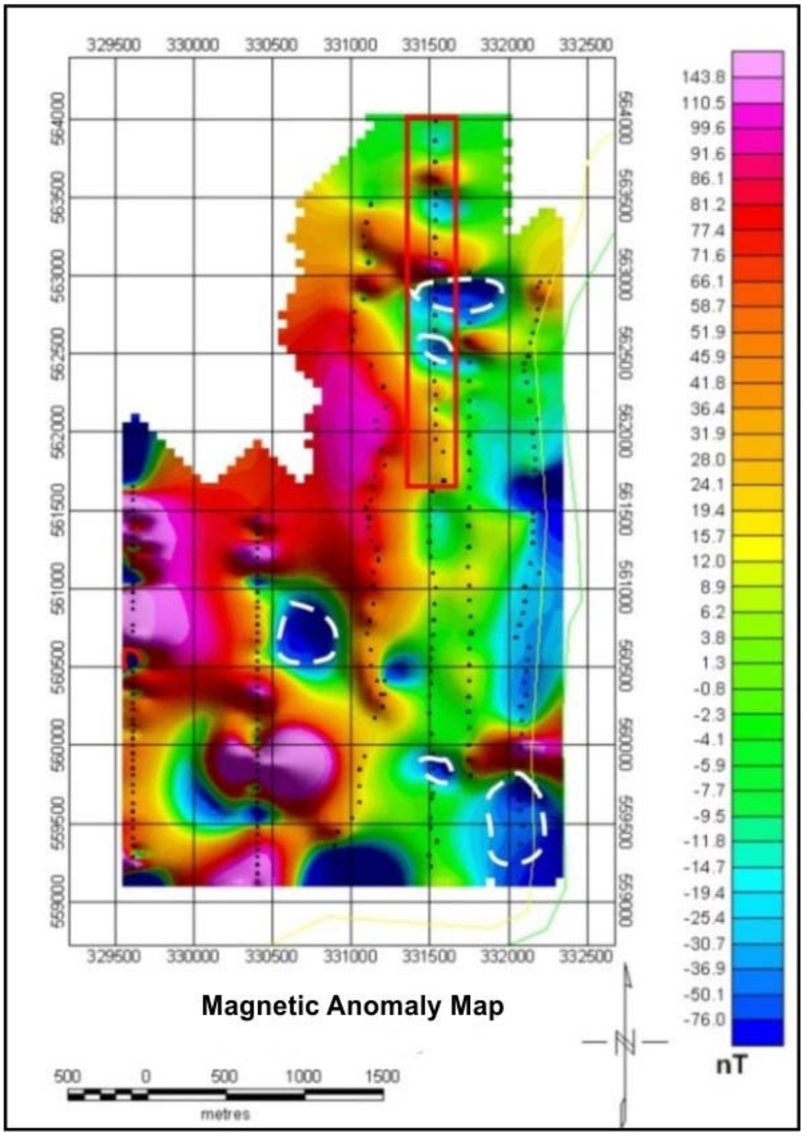


4- <u>Gravity methods:</u>

- Gravity methods measure the gravity anomaly at cerain points. Gravity anomaly is the difference between the earth's <u>gravitational field</u> at a certain point and the theoretical value that point should have.
- Anomalies reflect the heterogeneity in the density of the subsurface material, and are positive or negative depending on whether a body is of greater or lesser density than that of the theoretical values.
- Data are collected along linear traverses of regular spacing of stations using an instrument termed "**<u>gravimeter</u>**".
- Gravimetric methods are useful for localizing any phenomenon in which density variation is important. In geological engineering gravimetric methods have many applications, including detecting cavities and calculating their volume and tracing structures,

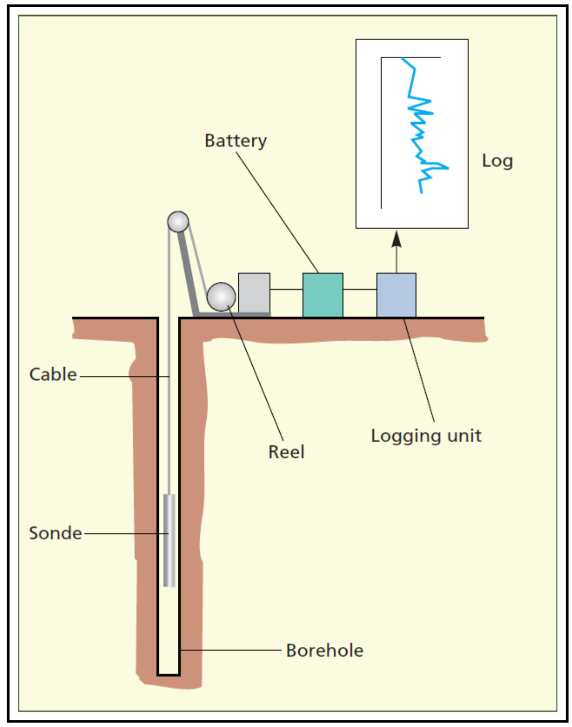
5- <u>Magnetic methods</u>

- These are used for studying <u>local variations in the earth's magnetic. Field</u>. Anomalies are due to differences in the magnetic <u>susceptibility</u> of subsurface soils and rocks.
- The instrument used is termed "**<u>Magnetometer</u>**".
- The results obtained are usually interpreted <u>qualitatively</u> as they cannot be interpreted quantitatively directly from field data.
- In geological engineering their usefulness is **<u>very limited</u>,** the main applications being the location of features such as <u>metal pipes</u> under the ground, faults, dykes and mineralized masses.



Magnetic Anomaly Map

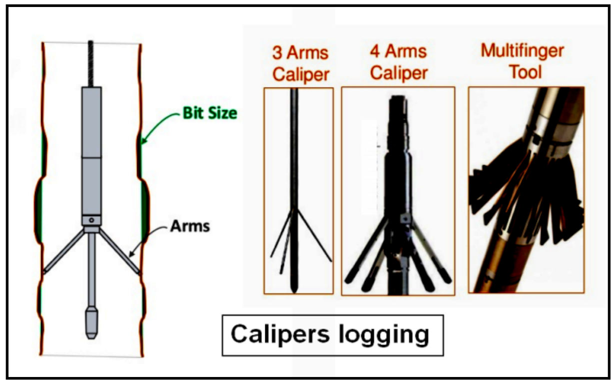
B- Borehole geophysics

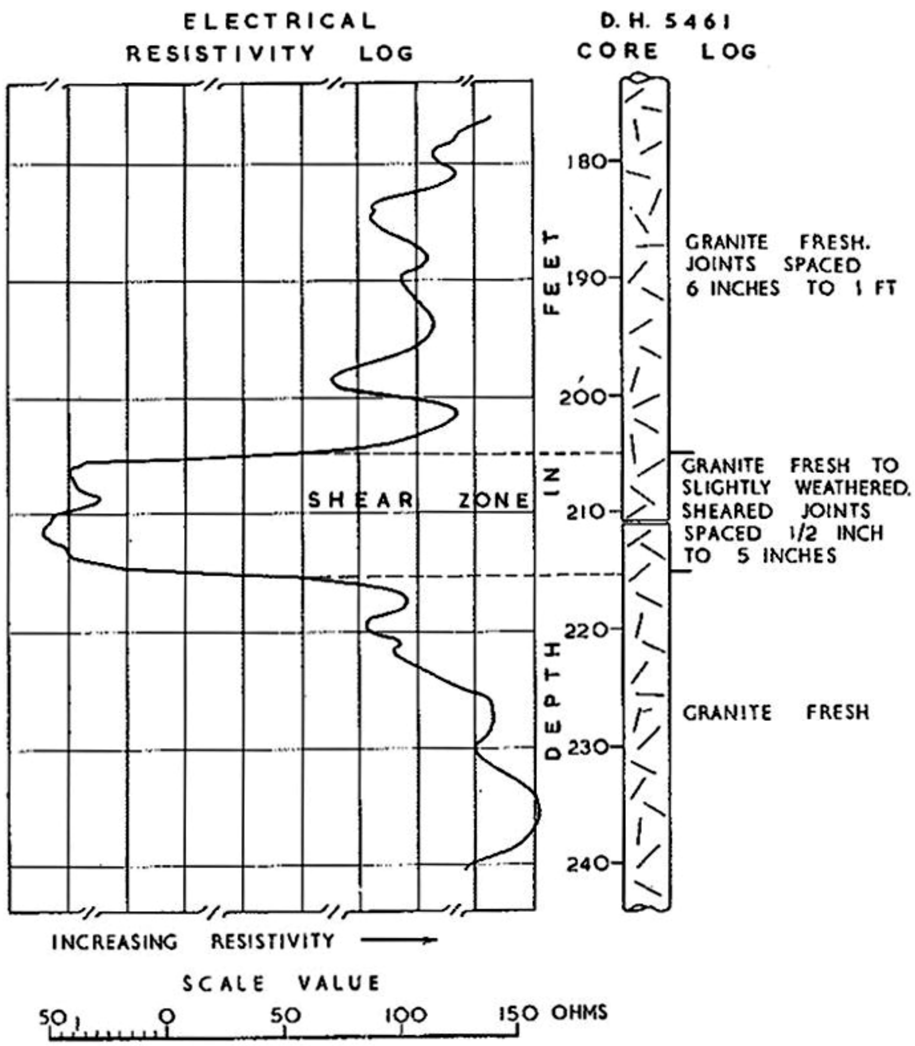


- It is the application of geophysical techniques inside boreholes. It is a useful tool for measuring certain physical properties of the geological formations intersected by the borehole. The information obtained complements core logging and geophysical results at the surface.
- Borehole logging records physical properties of the ground, such as density, porosity, level of saturation, etc., from information supplied by electrical, nuclear or acoustic (sound) methods. Use of this technique is highly recommended in all deep boreholes.
- Logs are obtained by lowering a sonde (sensor) to the bottom of the borehole and taking measurements as it is raised, either continuously or at intervals.
- The equipment has four parts: the measuring instrument or sonde (sensor), the connecting cable and apparatus for lowering and raising it, the battery, and the control and logging unit.
- These techniques only allow the areas around the boreholes to be investigated, which means that results cannot be extrapolated to other areas
- Depending on the measured physical parameter, logs can be classified as follows:
  1. **Electric logging**: measuring electrical resistivity.
     The sonde measures the resistivity of the ground when a current is passed artificially between one electrode in the borehole and another at the surface. Measuring electrical resistivity requires an uncased borehole filled with liquid.
     Another method (Spontaneous potential method) is passive and measures the difference between the electrical potential of an electrode placed inside the borehole, and another at the surface without applying external electric current.
  2. **Nuclear or radioactive logging**: may be passive or active. Passive sondes measure the natural radioactive emissions from the ground surrounding the borehole; active sondes measures the ground's response to being bombarded with gamma rays or a stream of neutrons.
  3. **Sonic or acoustic (sound) logging**: measures the propagation velocity and the attenuation characteristics of the elastic waves in the rocks intersected by the borehole. These can be correlated with the mechanical properties and degree of fracturing of the material

4. **Temperature logging**: **The sonde** records the temperature of the borehole fluid depending with depth.

5. **Calipers logging**: is the most commonly used geometrical logging technique. It gives a continuous graphical log of the borehole diameter as well as data of roughness or irregularities of the walls due to lithological changes, gaps, fractures or dissolved areas.



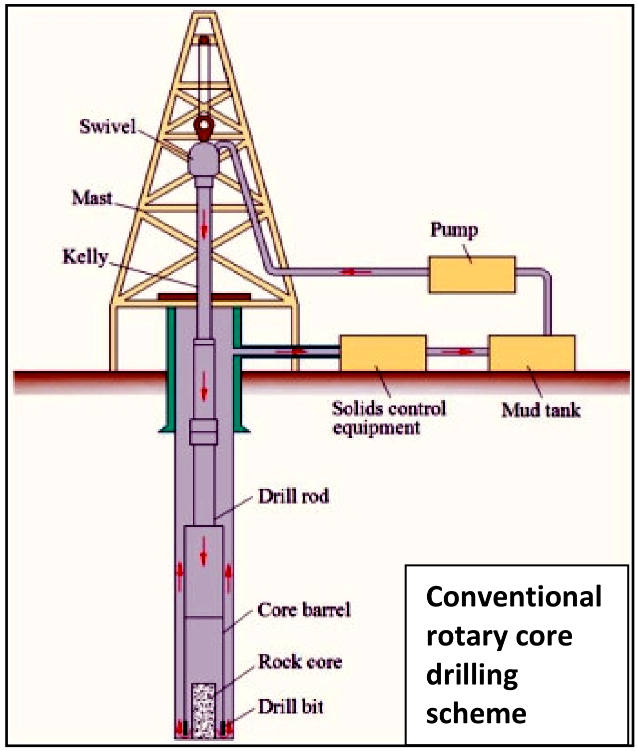


<u>Example of an electrical log in granite indicating a fracture zone of low resistivity.</u>

Boreholes, trial pits, trenches and sampling

1- Borehole drilling

- Geotechnical boreholes are normally small in diameter and are made with lightweight, easily transported equipment. They can be drilled to a depth of around 100 m, after which heavier equipment is used. They can drill through any type of material and samples can be extracted for testing and the ground can be tested inside them.
- Boring procedures depend on the type of material and the type of sampling and testing to be done. The most common procedures are:



Conventional rotary core drilling scheme

a) rotary drilling:

Rotary drilling can penetrate any type of soil or rock at any angle of inclination and to considerable depths . They are not usually deeper than 100 m for geotechnical purposes, although they may be as deep as 500 m. Rotary drilling can produce fragmented samples (ditch samples) or continuous core based on the type of drilling head used (drilling bit). Core extraction is a continuous process and can give a very high percentage of core recovery in relation to the length drilled.

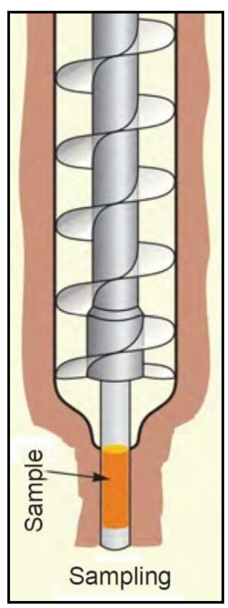
Water or drilling mud is used in rotary drilling as flushing and cooling medium.

b) auger drilling

Auger drilling is suitable for relatively soft and cohesive soils and unsuitable for hard or consolidated soils.

Its advantages include low cost, portability and rapid installation of the equipment.

Auger drilling can be done by hand for shallow depths (2–4 m) and small diameters (2–5 cm), or by power equipment for depths of up to 40 m with diameters from 7 to 20 cm. It is usually done for preliminary survey purposes.



c) percussion drilling.

Boring is carried out by driving a series of steel tubes into the ground with a 120 kg hammer that drops from a height of 1 m in successive hits. Percussion drilling allows soils with a firm or very firm consistency to be bored and is therefore used in both granular and cohesive soils. Boreholes of this type can reach depths of up to 30 or 40 m.

<u>2- Trial excavations</u>

- Trial pits, trenches are examples of trial excavations made mechanically or manually which allow observation of the ground to a certain depth and permit ***in situ*** testing and sampling to be carried out.
- Their main advantage is that they provide direct access to the ground, so that lithological variations, structures and discontinuities can be observed directly and samples of considerable size can be taken for testing and analysis.

<u>3- Geotechnical sampling</u>

The main object of sampling from boreholes or trial pits is to obtain materials for testing in the laboratory that are representative of the ground properties. The samples can be classified into two groups:

a- Disturbed samples: these have undergone modifications in their structure and water content, but preserve their mineralogical composition. Disturbed samples are usually taken from trial excavations and boreholes. These samples are suitable for classification and mineralogical studies.

b- Undisturbed samples: in theory these have not undergone any alteration in their structure or water content. Care is taken to achieve this as far as possible. Samples taken from trial excavations can be taken as a block or from tube samplers. Such samples are needed for tests of strength, deformability and permeability and for soil analysis. Rock samples are covered with a thin layer of molten wax for protection against changes in water content or transportation and handling damage

Undisturbed samples are obtained in two ways:

Block samples. In this procedure a block is cut out of the ground and removed manually. It is immediately sealed with warm wax and wrapped in cheesecloth. The size of sample must be suitable to carry out lab tests; i.e. to cut several cylindrical or rectangular samples for lab tests. The block is usually about 50 x 50 x 50 cm in dimensions.

Tube sample. It is taken in **soils** by an open tube sampler forced into the sides or base of an excavation, either manually in the case of soft soils, or mechanically in firmer soils. The ends of the sampler tube are sealed with paraffin wax just after taking the sample.

Core samples. Core samples are obtained from drilled cores. Cores should be arranged in order in wooden or paraffin-waxed boxes. They are labeled with markers to indicate the depth of any change in lithology or the presence of other significant structural features, such as faults, fractures and cavities.

In situ tests

In situ tests are very important for establishing the geotechnical properties of soil and rock materials such as strength, deformability and settlement of soils. There are many tests that can be carried out in the field; among these are the following:

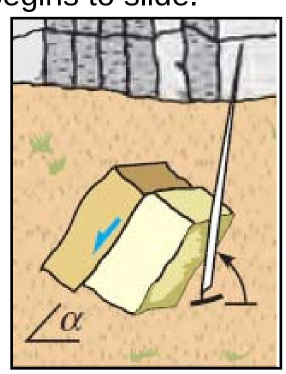
Schmidt hammer test for rocks

This test is used to obtain an approximate estimation of the uniaxial compressive strength of **rocks**. Its main application is for intact pieces of rock, but it can also be used on discontinuities.

The instrument consists of a cylindrical metal device containing a spring that drives a rod (and its hammer) out of the cylinder. When the hammer strikes the rock surface its rebound is measured. The uniaxial compressive strength can be calculated from the resulting rebound values.

Angle of friction of discontinuity test (Tilt test)

Angle of friction is the angle of dip of discontinuity, at which the rock just begins to slide.



This test is used to estimate the angle of friction of discontinuities. A sample rock block containing a non-cohesive discontinuity plane is required to estimate the angle of friction in discontinuities.

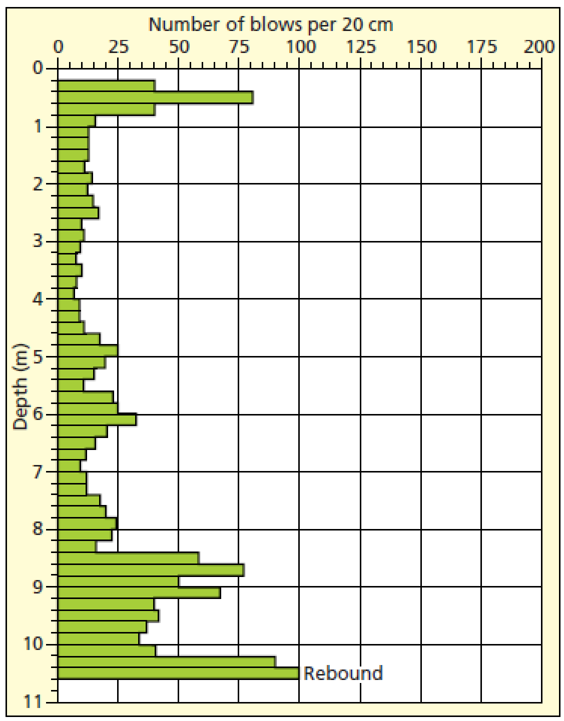
The rock sample is placed on an adjustable testing plane, and then the plane is slowly tilted until the sample starts to slide. As soon as this occurs, the angle of tilt is measured in relation to the horizontal, α, The procedure should be repeated with several rock samples. The value of α is a function of the ratio between the shear stress and normal stress acting on the discontinuity, and is used in slope stability analysis.

Penetration tests for soil (Probing penetrometer tests)

The process is a dynamic penetration test for soils to estimate the **penetration resistance** value (*N)* that can be correlated with geotechnical parameters such as relative density, friction angle, and settlements in granular soils. There are many instruments that can do this job.

In general, the instrument consists of a metal cone attached to a rod that is forced into the ground by means of a hammer. The hammer falls on the metal rod from a height of 50 cm. The number of blows NB is recorded every 20 cm penetration depth.

A graph representing the relation between the number of blows per 20 cm probing depth and the total penetration depth is shown in the following figure.



The **penetration resistance value** (*N)* for each depth interval can be calculated based on the NB values and the specifications of the instrument used,

Settlement test on soils (Plate loading test)

This test is mainly applied to granular soils and to study shallow foundations. The test procedure is to apply a vertical load on a smooth rigid metal plate to determine the settlement in the soil. The plate size can vary between 30 cm and 100 cm and be either circular or rectangular. The load is exerted manually or with hydraulic jacks as shown in the following figures.

The test is done according to a specific procedure through several steps; at each step the load is increased and the settlement of the soil is observed until it is almost stops (settlement rate < 0.02 mm/hr), then settlement distance is recorded. The load in the last step tested should be 3 times greater than the working load of the structure planned to be constructed.

The parameters measured during the test are: time, applied load and settlement at each step. From these parameters the **ultimate bearing capacity** of the soil can be calculated,

The **ultimate bearing capacity** is the value of bearing stress which causes a sudden catastrophic settlement of the foundation (due to shear failure).

The **safe bearing capacity** can be calculated from the ultimate bearing capacity

Safe bearing capacity = ultimate bearing capacity / factor of safety

The factor of safety usually used = 3

The construction load must not exceed the Safe bearing capacity.