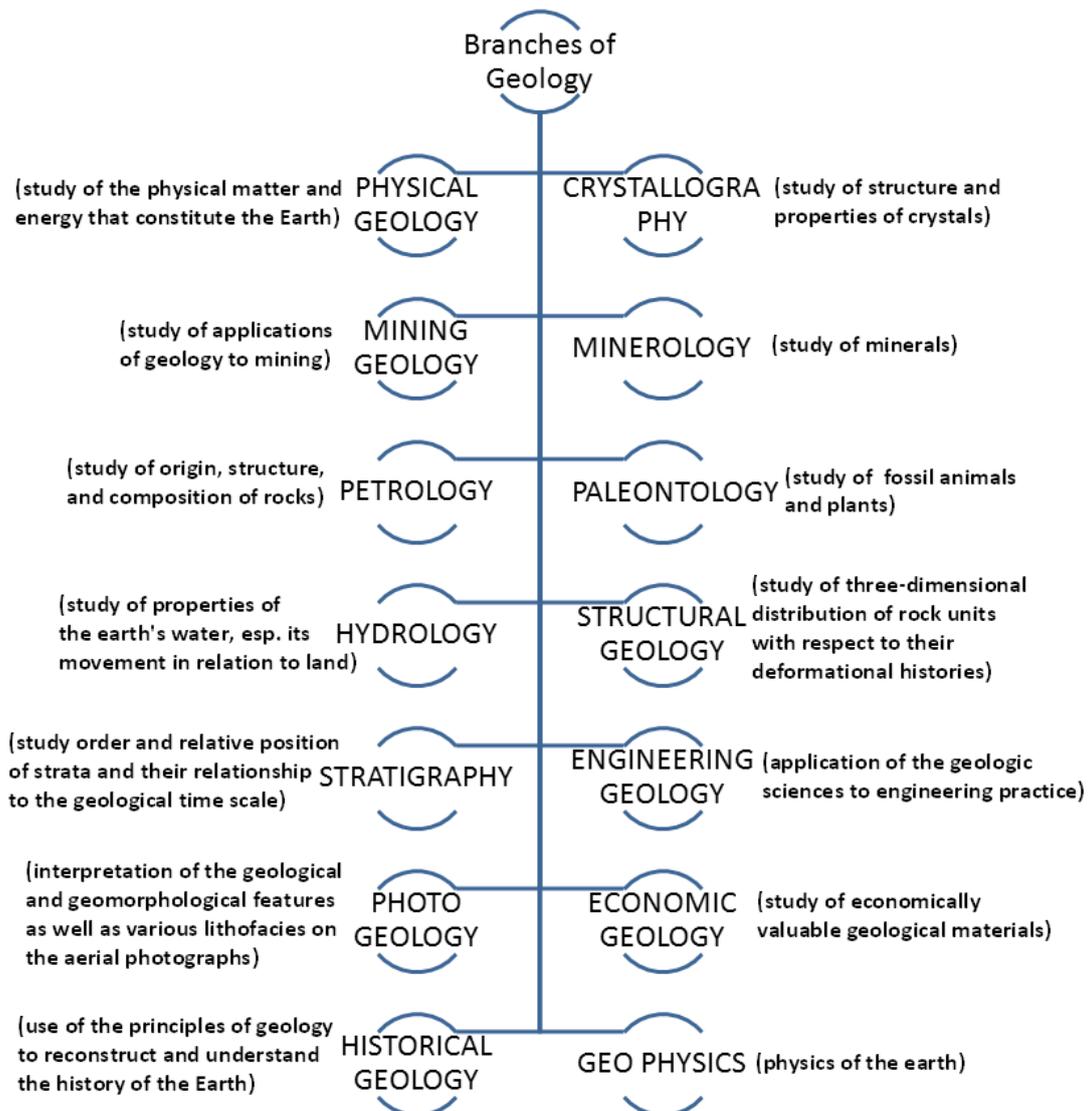


INTRODUCTION: (Importance to a Civil Engineer):

The earlier studies of Civil Engineering couldn't see the design of a structure should be preceded by a careful study of its environment, particularly foundations material on which the structure was to be placed. When the St. Francis Dam in Southern California failed in 1928 with a loss of many lives and damages in millions of dollars, the civil engineering profession awoke to the idea that the careful design of a structure itself is not all that is required for the safety of structures. After the failure of St. Francis Dam, the need of environment exploration with proper interpretation of the results was understood by all.

Geology (in Greek, Geo means Earth, ology means study of or Science of) is a branch of science dealing with the study of the Earth. It is also known as earth science. The study of the earth comprises of the whole earth, its origin, structure, composition and history (including the development of life) and the nature of the processes.

Branches of Geology:



Relevance of geology to civil engineering:

Most civil engineering projects involve some excavation of soils and rocks, or involve loading the Earth by building on it. In some cases, the excavated rocks may be used as constructional material, and in others, rocks may form a major part of the finished product, such as a motorway cutting of the site or a reservoir. The feasibility, the planning and design, the construction and costing, and the safety of a project may depend critically on the geological conditions where the construction will take place. This is especially the case in extended 'greenfield' sites, where the area affected by the project stretches for kilometres, across comparatively undeveloped ground. Examples include the Channel Tunnel project and the construction of motorways. In a section of the M9 motorway linking Edinburgh and Stirling that crosses abandoned oil-shale workings, the realignment of the road, on the advice of government geologists, led to a substantial saving. In modest projects or in those involving the redevelopment of a limited site, the demands on the geological knowledge of the engineer or the need for geological advice will be less, but are never negligible. Site investigation by boring and by testing samples may be an adequate preliminary to construction in such cases. The long term economics depends on the engineering safety of the manmade constructions. Durability and maintenance free service of the dams, canals, structures like aqueduct etc. is only possible if engineering safety of them is assured. As every structure is related to rock beneath, proper geological investigations are of utmost importance.

Engineering geology importance:

Engineering geology provides a systematic knowledge of construction material, its occurrence, composition, durability, and other properties. Examples of such construction materials are building-stones, road materials, clays, limestone, and laterite.

The knowledge of the geological work of natural agencies such as water, wind, ice and earthquake helps in planning and carrying out major civil engineering works. For examples, the knowledge of erosion, transportation, and deposition helps greatly in solving the expensive problems of river control, coastal and harbour work and soil conservation.

The knowledge about groundwater that occurs in the subsurface rocks and about its quantity and depth of occurrence is required in connection with water supply irrigation, excavation and many other civil engineering works.

The foundation problems of dams, bridges, and buildings are directly concerned with the geology of the area where they are to be built. In these works, drilling is commonly undertaken to explore the ground conditions. Geology helps greatly in interpreting the drilling data.

In tunnelling, constructing roads, canals, and docks and in determining the stability of cuts and slopes, the knowledge about the nature and structure of rocks is very necessary.

Before starting a major engineering project at a place a detailed geological report, which is accompanied by geological maps and sections, is prepared. Such a report helps in planning and constructing the project.

The stability of the civil engineering structures is considerably increased if the geological features like faults,¹ joints,² folding,³ and solution channels etc. in the rock beds are properly located and suitably treated.

In the study of soil mechanics, it is necessary to know how the soil materials are formed in nature.

For a major engineering project, precise geological survey is carried out and results thus obtained are used in solving engineering problems at hand. The cost of engineering works will considerably be reduced if the geological survey of the area concerned is done before hand.

1- fault: a fracture or fracture zone in rock along which movement has occurred. 2- joint: a fracture in rock along which there has been no displacement. 3- fold: a bend or flexure in a rock unit or series of rock units that has been caused by crustal movements.

Engineering Geologist Vs Civil Engineer:

The engineering geologist presents geological data and interpretations for use by the civil engineer. The civil engineers have to deal mostly with soil and rocks, timbers, steel, and concrete. In a great majority of civil engineering, projects and the designs, involve the soils and rocks almost directly.

Civil engineering is to construct the structure and facilities for transport, water supply, hydropower, flood control, environmental protection, sewage and waste disposal, urban development and more. In above fields, civil engineers construct and maintain waterways, highways, railway, pipelines, dam and reservoirs and tunnels.

Role of the engineer in the systematic exploration of a site

The investigation of the suitability and characteristics of sites as they affect the design and construction of civil engineering works and the security of neighbouring structures is laid out in British Standard Code of Practice for site investigations (BS 5930:1981, formerly CP 2001). The sections on geology and site exploration define the minimum that a professional engineer should know.

The systematic exploration and investigation of a new site may involve five stages of procedure. These stages are:

1. Preliminary investigation using published information and other existing data;
2. A detailed geological survey of the site, possibly with a photo-geology study;

3. Applied geophysical surveys to provide information about the subsurface geology;
4. Boring, drilling and excavation to provide confirmation of the previous results, and quantitative detail, at critical points on the site; and
5. Testing of soils and rocks to assess their suitability, particularly their mechanical properties (soil mechanics and rock mechanics), either in situ or from samples.

In a major engineering project, each of these stages might be carried out and reported on by a consultant specialising in geology, geophysics or engineering (with a detailed knowledge of soil or rock mechanics). However, even where the services of a specialist consultant are employed, an engineer will have overall supervision and responsibility for the project. The engineer must therefore have enough understanding of geology to know how and when to use the expert knowledge of consultants, and to be able to read their reports intelligently, judge their reliability, and appreciate how the conditions described might affect the project. In some cases the engineer can recognise common rock types and simple geological structures, and knows where he can obtain geological information for his preliminary investigation. When reading reports, or studying geological maps, he must have a complete understanding of the meaning of geological terms and be able to grasp geological concepts and arguments. For example, a site described in a geological report as being underlain by clastic¹ sedimentary rocks might be considered by a civil engineer to consist entirely of sandstones. However, clastic sedimentary rocks include a variety of different rock types, such as conglomerates, sandstones and shales² or mudstones. Indeed it would not be unusual to find that the site under development contained sequences of some of these different rock types—say, intercalated beds of sandstone and shale, or sandstone with conglomerate layers. Each of these rock types has different engineering properties, which could affect many aspects of the development work such as core drilling into, and excavation of, the rock mass, and deep piling into the underlying strata.

The systematic testing of the engineering properties of soils and rocks lies between classical geology and the older disciplines of engineering, such as structures. It has attracted the interest of, and contributions from, people with a first training in either geology or engineering, but has developed largely within departments of civil and mining engineering.

- 1- Clastic rocks are composed of fragments, or clasts, of pre-existing minerals and rock fragments.
- 2- Shale is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals.

BRIEF STUDY OF CASE HISTORIES OF FAILURE OF SOME CIVIL ENGINEERING CONSTRUCTIONS DUE TO GEOLOGICAL DRAW BACKS:

This is one of the most common causes of dam failures and has to do with the geology of the dam site. Includes with the following considerations

1. Failure due to earthquake
2. Failure due to landslide

3. Failure due to chemical weathering¹ of foundation rocks (Effect Of Alkali-Silica Reaction, Sulfate & Chloride On Concrete)
4. Failure due to physical weathering (temperature variations, or by heavy rain, or by physical breaking)
5. Failure due to increase of fractures in geological structures (fault, folds & unconformities²)

Brief study of case histories of failure of some civil engineering constructions:

1. Kaila Dam, Gujarat, India

The Kaila Dam in Kachch, Gujarat, India was constructed during 1952 - 55 as an earth fill dam with a height of 23.08 m above the river bed and a crest length of 213.36 m. The storage of full reservoir level was 13.98 million m³. The foundation was made of shale. The spillway was of ogee shaped (S-Shaped) and ungated. The depth of cutoff was 3.21 m below the river bed. In-spite of a freeboard³ allowance of 1.83 m at the normal reservoir level and 3.96 m at the maximum reservoir level the energy dissipation devices first failed and later the embankment⁴ collapsed due to the weak foundation bed in 1959.

2. Kodaganar Dam, Tamil Nadu, India

This dam in India, was constructed in 1977 on a tributary of Cauvery River as an earthen dam with regulators, with five vertical lift shutters each 3.05 m wide. The dam was 15.75 m high above the deepest foundation, having 11.45 m of height above the river bed. The storage at full reservoir level was 12.3 million m³, while the flood capacity was 1275 m³/s. A 2.5 m freeboard above the maximum water level was provided. The dam failed due to overtopping by flood waters which flowed over the downstream slopes Hydraulics of the embankment and breached the dam along various reaches. There was an earthquake registered during the period of failure although the foundation was strong. Water gushed over the rear slopes, as a cascade of water was eroding the slopes. Breaches of length 20 m to 200 m were observed. It appeared as if the entire dam was overtopped and breached.

3. Tigra Dam: (Sank, Madhya Pradesh, India, 1917)

This was a hand placed masonry (in time mortar) gravity dam of 24 m height, constructed for the purpose of water supply. A depth of 0.85 m of water overtopped the dam over a length of 400m. This was equivalent to an overflow of 850 m³/s (estimated). Two major blocks were bodily pushed away. The failure was due to sliding. The dam was reconstructed in 1929.

1 - Wear away or change the appearance or texture of (something) by long exposure to the atmosphere. 2 - A surface of contact between two groups of unconformable strata (continuous deposited strata). 3- the amount of watertight surface between a given level of lake, sea or river water and the lowest possible entry point during flooding or large waves. 4 - A wall or bank of earth or stone built to prevent a river flooding an area.

4. Vaiont Dam (USA)

This is an arch dam, 267 m high. During the test filling of the dam, a land slide of volume 0.765 Mm^3 occurred into the reservoir and was not taken note of. During 1963, the entire mountain slide into the reservoir (the volume of the slide being about 238 Mm^3 , which was slightly more than the reservoir volume itself). This material occupied 2 km of reservoir up to a height of about 175m above reservoir level. This resulted in a overtopping of 101m high flood wave, which caused a loss of 3,000 lives.

5. Baldwin Dam (USA)

This earthen dam of height 80m, was constructed for water supply, with its main earthen embankment at northern end of the reservoir, and the five minor ones to cover low lying areas along the perimeter. The failure occurred at the northern embankment portion, adjacent to the spillway¹ (indicated a gradual deterioration of the foundation during the life of the structure) over one of the fault zones. The V-shaped breach was 27.5 m deep and 23 m wide. The damages were estimated at 50 million US dollar.

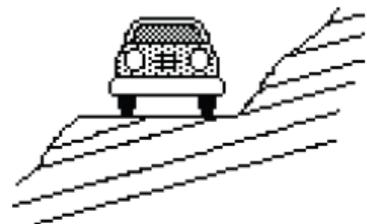
GEOLOGICAL CONSTRAINTS IN CIVIL ENGINEERING (Case Histories of Civil Engineering In Respect of GEOLOGY):

The geology of an area dictates the location and nature of any civil engineering structures.

Roads and Railways

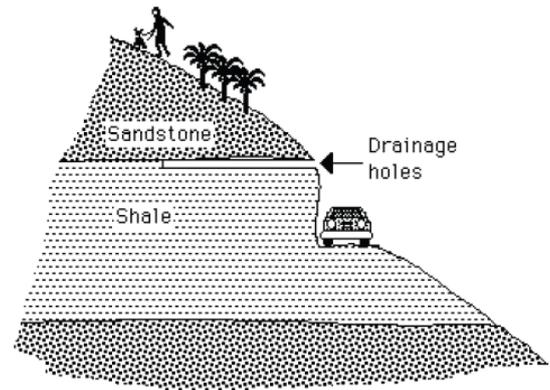
Problems for a road or railway project may be caused by any of the following geological features:

- Faults
- Junctions between hard and soft formations
- Boundaries between porous and impermeable formations
- Spring-lines
- Fractured granites
- weathered schists²
- Landslip areas
- Areas where beds dip towards the road or railway, as shown in the adjacent diagram.



1 - A passage for surplus water from a dam. 2 - A coarse-grained metamorphic rock that consists of layers of different minerals and can be split into thin irregular plates.

If the terrain and proposed route are such that these features cannot be avoided, construction of suitable safety features is required. Earthwork construction must include an embankment to stabilise areas of landslide. Lightweight material on a concrete raft may be needed where the road traverses deep, compressible deposits.



Drainage holes can be drilled into rock to ensure that water is drained from potential slip surfaces, such as bedding planes. Unless water is properly drained from a rock embankment, pressures will build-up within and behind the rock, eventually causing it to fracture and collapse. The Thredbo Village land-slide (1997) is an Australian example of a catastrophic geological slope failure due to the build-up of water within rocks and soil.

The Adelaide to Crafers Highway Project:

Because the terrain in the vicinity of the Adelaide-Crafers tunnels is so steep, the project encountered many civil engineering challenges. Notably, the steepness of the terrain increases the probability that rock-falls and landslides will occur.

The Crafers Highway is located on the western margin of the Mt Lofty Ranges, The ranges themselves were formed by movement along fault lines. The highway crosses three major faults, and there are many smaller faults in the area. These faults can and do have a major impact on road-cutting stability.

Many of the rocks are siltstones or mudstones — often described generically as ‘slates’ — which show slaty cleavage. The area is geologically complex, consisting of ‘slates’ and quartzite with variable strengths ranging from low to very high. The amount of weathering of the rock also varies considerably. Some sections are very weathered, while in others the rock is fresh and unaltered. Sometimes joints are closely spaced, whereas in some areas others there are very few.

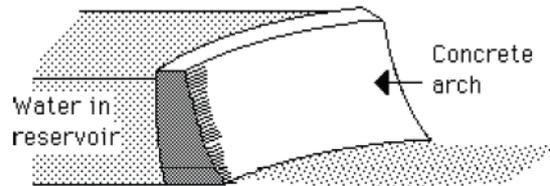
Consequently, some of the road cuttings have been reinforced to prevent rock-falls. Various treatments can be seen as you drive along the highway. In some places wire mesh has been used, while other faces have been sprayed with concrete — a treatment known as ‘shotcrete’. Similarly different support types were used in the tunnel when different rock types were being tunnelled. When the tunnel excavation was completed, a permanent concrete lining was installed.

Dams:

Geological investigations of a site proposed for construction of a dam must be complete and detailed. Features such as rock-types, geological structures, weathering, fractures and

fissures must all be considered. The main considerations are that the material on which the dam rests must be able to carry the weight of the structure without failing. The geology upon which the dam is built must also be impervious¹ to water. The abutments², (the rock faces to which the dam wall is attached) must also be impervious and strong enough to support the dam wall, especially in the case of an arch dam (where more force is transmitted to the abutments).

Left: Cross-section through an arch dam.



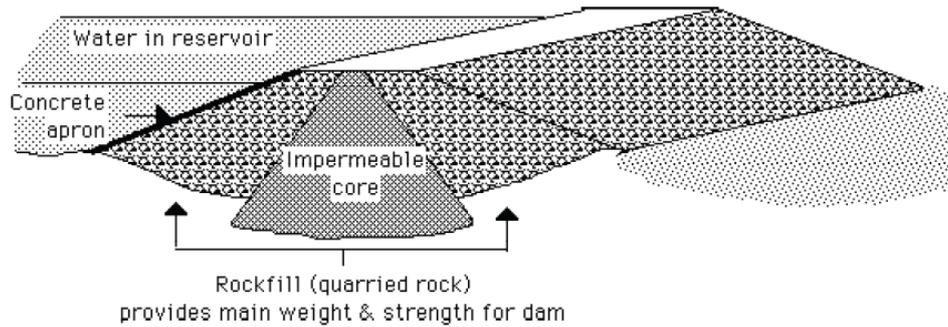
Failure of a dam can be due to many factors including:

- Earthquakes
- A sudden drop in water level
- Inadequate protection of the reservoir side of the dam from wave action
- Insufficient spillway capacity, so that water flows over the whole of the dam surface, with consequent erosion

1 - Not allowing something to pass through; not penetrable. 2 - A structure built to support the lateral pressure of an arch or span, e.g., at the ends of a bridge.

The type of dam selected depends largely on the nature of the surrounding rocks. If they are strong and stable, an arch dam, such as the one shown below can be constructed. This type of dam requires a minimum of construction materials, but the concrete must be of high quality. The Barossa Reservoir Dam (the Whispering Wall), The Roosevelt Dam are examples of an arch dams.

An earth and rock fill embankment dam, as shown in the diagram below must be constructed where the surrounding rocks are not strong enough to support an arch dam. This type of dam is more expensive to build, requiring much more material. The main weight and strength of the dam is provided by compacted quarried rock. The core is made of impermeable material, such as clay, bitumen¹ or concrete.



Cross-section through an embankment dam.

1 - A black viscous mixture of hydrocarbons obtained naturally or as a residue from petroleum distillation.

Kangaroo Creek Dam

Construction of the Kangaroo Creek Dam was first proposed around 1945. Tests of the surrounding rocks, mainly schists and gneisses¹, were carried out and it was concluded that they would be strong enough to support an arch dam. However, the project was shelved (sloped downwards). During the 1950s, an arch dam was constructed in Europe in an area where the geology was similar to the Torrens Gorge. The geologists did not realise that there was a fault at right angles to the foliation planes of the schist. This dam collapsed in 1958, and several hundred lives were lost.

When construction of the Kangaroo Creek Dam was again proposed in the 1960s, a careful assessment of the surrounding rocks was made. The investigation took about 18 months. Eventually it was decided that the foundation rocks on the south bank of the proposed site were unstable to a considerable depth, and not strong enough to support an arch dam.

A much larger and more expensive earth and rock fill embankment dam was subsequently built.

Building Foundations

Since the type of rock and soil inevitably affects stability of buildings, the quality of the foundation rock must be investigated before construction commences. This rock must not be weak, crushed, water saturated or have been subjected to chemical weathering. The presence of fractures, faults, joints, cleavages, etc may indicate that the site is unsuitable for building. The possibility of soil-creep, slope movement, landslides etc must be borne in mind and factored into the design of any building foundation. Obviously, buildings should not be situated too close to the coast, especially where the sea level is rising relative to the land.

Rock and soil tests are taken before homes are built. For larger buildings, deep holes may be drilled to test the strength and stability of the rocks under the proposed building. The type and strength of foundations required are determined from the results of these tests. People who build houses in areas of clay soil are likely to find that windows and doors stick and that cracks appear in brick walls. Piers under the house move and concrete slabs may crack. This is because clays swell when wet and shrink after drying. Adelaide's 'Bay of Biscay' soils, which underlie some of the north-eastern suburbs, contain a type of clay called

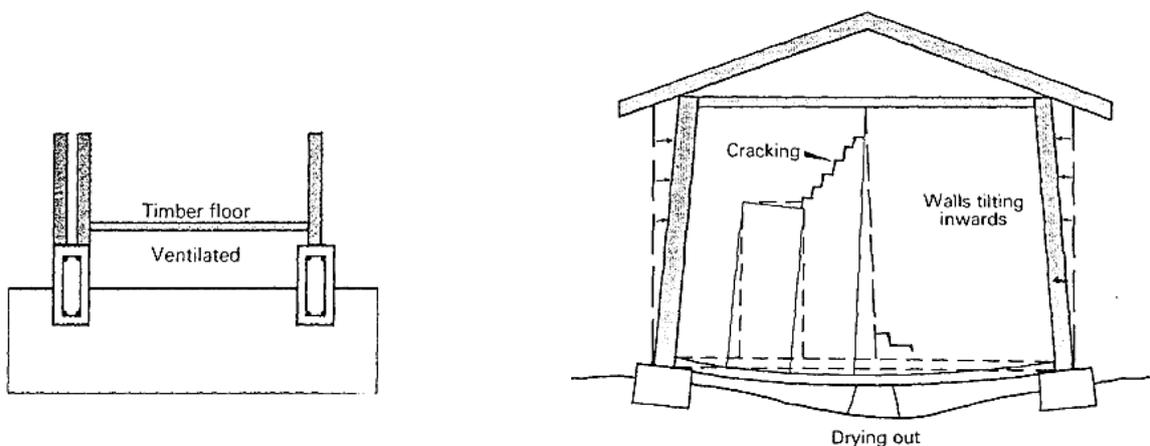
montmorillonite which swells to almost twice its dry volume when wet. This is responsible for many cracks in older buildings. These soils are said to be expansive.

1 - A metamorphic rock with a banded or foliated structure, typically coarse-grained and consisting mainly of feldspar, quartz, and mica.

Two other types of problem soils are collapsing soils, which settle rapidly on wetting, and compressible soils that consolidate and settle slowly over several years.

The footing is that part of a house that is in direct contact with the soil or rock forming the foundation. Strip footings were the earliest type used. These consisted of concrete strips beneath the walls of the house.

Strip footings proved to be unsuitable in areas of expansive soil, as the soil under the house dried out and shrank (shrink), causing the problems shown in the diagram below.



Cross-section through strip footings

SLOPE FAILURE

The term slope failure covers a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. The photograph below shows the Thredbo landslide (30 July 1997) where 18 people died.

Causes of Slope Failure

Gravity

Although gravity acting on an over-steepened slope is the primary cause of a landslide, other contributing factors include:

- Earthquakes that create stresses causing weak slopes to fail.
- Volcanic eruptions that produce loose ash deposits and debris flows.
- Vibrations from machinery, traffic, blasting, and even atmospheric thunder that may trigger failure of very weak slopes.
- Excess weight from accumulation of rain, snow, the stockpiling of rock or ore, or from built structures that may stress weak slopes to failure.

Relief

Slope failure occurs in hilly or mountainous regions all over the world — essentially wherever there is any significant topographic relief. In Australia, significant landslides coincide with mountainous areas.

Water

Rock and soil slopes are weakened through saturation by melting snow or heavy rain. Water filling the pores of permeable materials allows the grains to slide past each other with little friction. Water acts as a lubricant increasing the ease of movement of rock and soil particles (and therefore slope failure). Slope material that becomes saturated with water may develop a debris flow or mudflow. The resulting slurry of rock and mud can pick up trees, houses, and cars, causing the blocking of bridges and tributaries and increasing the likelihood of flooding.

Undercutting

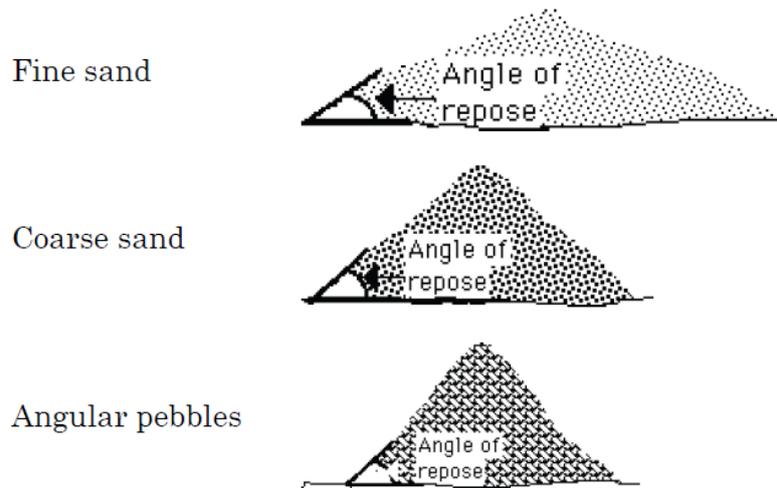
Undercutting is erosion of material at the foot of a cliff or steep bank — e.g. on the outside of a meander. Ultimately the overhang collapses and the process is repeated. Undercutting caused by rivers, glaciers, or ocean waves creates over-steepened slopes, which are prone to failure. Human activities, such as quarrying and road construction also result in undercutting.

Rock Types

In unconsolidated material, that is material not held together by cement or by a strong interlocking crystal structure, landslides start after a significant part of the whole rock mass is saturated with water and therefore lubricated. A single shock or vibration can trigger the down-slope movement of an entire unstable hillside. Any area of very weak or fractured materials resting on a steep slope will be likely to experience landslides.

Slope Angle

A pile of sand always assumes the same angle of slope, whether it is a few centimetres high, or a huge sand dune. The angle that the sand makes with the horizontal is called the angle of repose. It is about 37° for fine sand, and steeper for coarse sand and angular pebbles, as shown in the diagrams below.



If a slope is steepened beyond this natural angle, for example for a road cutting, it then becomes unstable and the slightest vibration may lead to slope failure. The angle of repose is reduced if the sand or unconsolidated rock material becomes water-saturated. Moreover, the angle of repose is significantly reduced underwater.

IMPORTANCE OF PHYSICAL GEOLOGY

As a branch of geology, it deals with the “various processes of physical agents such as wind, water, glaciers and sea waves”, run on these agents go on modifying the surface of the earth continuously. Physical geology includes the study of Erosion, Transportation and Deposition (ETD).

The study of physical geology plays a vital role in civil engineering thus:

- (a) It reveals constructive and destructive processes of physical agents at a particular site.
- (b) It helps in selecting a suitable site for different types of project to be under taken after studying the effects of physical agents which go on modifying the surface of the earth physically, chemically and mechanically

IMPORTANCE OF PETROLOGY

As a branch of geology it deals with ‘the study of rocks’. A rock is defined as “the aggregation of minerals found in the earth’s crust”. The study of petrology is most important for a civil engineer, in the selection of suitable rocks for building stones, road metals, etc Petrology is the study of the nature of rocks and the processes that form the rocks that comprise the Earth. The rock-forming processes we will consider — those that produce igneous, sedimentary and metamorphic rocks — reflect, either directly or indirectly, the production and redistribution of heat within the earth. Since plate tectonics operates as an efficient heat-loss mechanism for the Earth, the study of petrology is fundamental to understanding the large-scale geodynamics of our planet.

The goals are to give:

- 1) A meaningful sampling of the approaches and philosophy behind petrologic studies for stability of civil engineering constructions;
- 2) An appreciation for the diversity, complexity and geological significance of the rocks that comprise the earth for long durable constructions;
- 3) A basis for understanding the importance of petrology in the civil engg. constructions; and
- 4) To provide you with an opportunity to further development for particular construction.

IMPORTANCE OF STRUCTURAL GEOLOGY

As a branch of geology, it deals with 'the study of structures found in rocks'. It is also known as tectonic geology or simply tectonics. Structural geology is an arrangement of rocks and plays an important role in civil engineering in the selection of suitable sites for all types of projects such as dams, tunnels, multi-storeyed buildings, etc. Structural geology is the study of the three dimensional distribution of rock units with respect to their deformational histories. The primary goal of structural geology is to use measurements of present-day rock geometries to uncover information about the history of deformation (strain) in the rocks, and ultimately, to understand the stress field that resulted in the observed strain and geometries.