Engineering Geology

UNIT – 4

Topics Covered – Geological investings for site selection of Dams & Reservoir, Tunnels, Bridges and roads in hilly areas

❖ Geological Investigation for site selection of Dams & reservoirs

Dams

- Dams are barriers constructed across a river valley to impound water.

- Dams are built mainly for controlling floods, irrigation, electricity generation and for urban water supply.

- Dams may be constructed for a specific use or it may be 'multipurpose' which serves more than one use.

- Dams are generally classified according to its use, hydraulic design, construction design and material used in it.

Reservoir

- A reservoir generally means an enlarged natural or artificial lake, storage pond created using a dam to store water.
- Reservoir can be created by controlling a stream that drains an existing body of water.

Geological investigation for dam site & reservoir

- **Topography**: Topography in large measures dictates a first choice of dams. Generally a dam site is ideal where a valley is constricted with steep rock slopes. A narrow stream flowing between high, rock walls would naturally suggest a concrete overflow dam whereas a low, rolling plain would suggest an earth-fill dam.

- **Geology and foundation condition**: Foundation condition depend upon the geological character and thickness of the strata which are to carry the weight of the dam, their inclination, permeability and relation to underlying strata, existing faults and fissures.

- **Foundations** are better on igneous rocks and hard metamorphic rocks like granite, gneiss, quartzite etc. than on sedimentary rocks like shale, phyllite, slate and schist etc.

- The removal of disintegrated rocks and sealing of seams and fractures by grouting will frequently be necessary.

- Rocks like limestone are usually cavernous with numerous solution channels. These channels not only provide path for water percolation but also may collapse and destabilize the setting.

- Weathered rock pose serious problems of instability and require special treatment. The weathering of rocks give rise to formation of clays and gritty soils where the weathering is complete.

- ***Gravel Foundation,*** if well compacted, are suitable for earth-fill, rock-fill and low concrete gravity dam.

- ***Silt or fine sand foundation*** can be used for the support of low concrete gravity dam but not rock-fill dam. The main problem is settlement, excessive percolation loss, and need of protection of the foundation at the downstream toe from erosion.

- Poorly consolidated sediments like silt, sand and gravel have low bearing strength and become weaker still when moistened.

- **Clay foundation** can be used for the support of earth-fill dam but require special treatment. There may be considerable settlement of the dam if the clay is unconsolidated and the moisture content is high.

- Occasionally situations may occur where reasonably uniform foundations of any of the foregoing descriptions cannot be found and where a *non-uniform foundation* of rock and soft material must be used if the dam is to be built. Alteration of hard and soft rocks do not provide safe condition for the foundation of dam.

Geological structures

- Generally dam axis should be chosen perpendicular to the strike of the geological structures.

- Steep beds upstream is favourable for foundation, if bed dips moderately upstream, the day may shear off along the bedding plane.

- Dam founded on the limb of an anticline dipping upstream is favourable but on the limb of a syncline with a downstream plunge is unsuitable.

- Fault zone is an unstable zone. If permeable bed is present and dam rests on beds dipping moderately downstream, water can percolate through the beds and fault. It is difficult to seal a fault zone and prevent leakage.

- Highly jointed rocks even though hard may be worse than a soil foundation. It reduces the strength of rock and creates problem related to leakage.

- Valley slopes along the dam axis should be free from existing any type of landslides or possible unsuitability of slopes.

- Earthquake shocks cause slope failures, landslides, loss of contact of the dam with its abutment, sliding of dam itself and failure of dam.

- *Seismic zonation map* must be consulted during the site investigation. In seismically active area, it is necessary to assess the degree of earthquake tremors and design must include provisions for the added loading and increased stresses.

- Recognition and delineation of active faults and analysis of historical records of past occurrences are among many seismological investigations to be carried out.

- Construction of a dam requires large quantity of *construction materials* like soil, rock, concrete and aggregates. The most economical type of dam will often be the one for which materials are to be found in sufficient quantity with a reasonable distance from the site. So availability of such materials nearby the proposed site should be assessed.

- *Permeability test* of the foundation material should be carried out during site selection. Water tightness of the dam is an important factor so permeability of foundation material should be within tolerance limit.

- Buried channels or valley abandoned by the rivers in the past and now filled with alluvial deposit contain numerous large boulder which allow passage to the impounded water. Careful exploration including drilling and seismic sounding can be used to such hidden topography.

- Construction of a dam modifies the ecosystem and hydrological regimes of both upstream and downstream.

- Erosion and landslide in reservoir basin, evaporation lost, reservoir-induced seismicity, destruction of flora and fauna, resettlement of displaced people which should be investigated and should be kept at minimum.

Treatment of Dam Foundation

- Poor geological condition can be improved by *improving load bearing properties* and *controlling seepage*.

- If the foundation is on the highly jointed rocks, grouting is usually done to seal the joints and fractures thus increasing the strength as well as sealing against seepage.

- In soil foundation, soil treatments methods are applied to increase its strength making it suitable for construction of dam.

- The dam area and reservoir area are made impermeable to water to a certain level by use of natural material or synthetic materials (geo-textiles).

- Grout curtains are used to seal off water to some level around the dam area.

❖ **Geological Investigations for site selection of Tunnels:**

Tunnel

- Tunnel is a nearly horizontal underground passage which is open at both ends.

- Tunnels are of different types according to their uses like traffic tunnel, hydropower headrace tunnel and public utility tunnels etc.

- Tunnels can be driven or holed through a rock or earth mass by method used in mining, including blasting.

- In soft ground tunnels may be excavated by boring machines with the walls being supported by liner plates.

Geological investigations are very essential in selection of tunnel site. Following are the classifications-

(a) Selection of Tunnel Route (Alignment):
There might be available many alternate alignments that could connect two points through a tunnel. However, the final choice would be greatly dependent on the geological constitution along and around different alternatives: the alignment having least geologically negative factors would be the obvious choice.

(b) Selection of Excavation Method:

Tunnelling is a complicated process in any situation and involves huge costs which would multiply manifolds if proper planning is not exercised before starting the actual excavation. And the excavation methods are intimately linked with the type of rocks to be excavated. Choice of the right method will, therefore, be possible only when the nature of the rocks and the ground all along the alignment is fully known. This is one of the most important aim and object of geological investigations.

(c) Selection of Design for the Tunnel:

The ultimate dimensions and design parameters of a proposed tunnel are controlled, besides other factors, by geological constitution of the area along the alignment. Whether the tunnel is to be circular, D-Shaped, horse-shoe shaped or rectangular or combination of one or more of these outlines, is more often dictated by the geology of the alignment than by any other single factor.

Thus, in self-supporting and strong rocks, either, D-shape or horse-shoe shape may be conveniently adopted but these shapes would be practically unsuitable in soft ground or even in weak rocks with unequal lateral pressure. In those cases circular outline may be the first choice.

(d) Assessment of Cost and Stability:

These aspects of the tunnelling projects are also closely interlinked with the first three considerations. Since geological investigations will determine the line of actual excavation, the method of excavation and the dimensions of excavation as also the supporting system (lining) of the excavation, all estimates about the cost of the project would depend on the geological details.

Similarly tunnels passing through hard and massive rocks even when left unsupported may be regarded as stable. However, those passing through difficult grounds, although these might have been massively strengthened by secondary support system, might still collapse or bulge at places or even completely fail, if geological situation is not perceived properly.

(e) Assessment of Environmental Hazards:

The process of tunnelling, whether through rocks or through soft ground, and for whatsoever purpose, involves disturbing the environment of an area in more than one way. The tunnelling methods might involve vibrations induced through blasting or ground cutting and drilling, producing abnormal quantities of dust and last but not the least, interference with water supply system of the nearby areas.

A correct appreciation of geological set up of the area, especially where tunnel alignment happens to be close to the populated zones, would enable the engineer for planning and implementing plans aimed at minimizing the environmental hazards in a successful manner.

Methods:

The geological information required for tunnelling projects may not always be similar to that required for other civil engineering projects. As a matter of practice, the desired geological details for a tunnel project are obtained in two stages using specific methods in each stage. These stages are – preliminary surveys, conducted well before the actual planning of the project; detailed surveys which are conducted almost simultaneously with planning and concurrent explorations which are undertaken during the construction.

A. Preliminary Surveys:

These are conducted by the routine geological, geophysical and geochemical methods. In modern practice and for major tunnelling projects such fast techniques as aerial photography and seismic surveying are commonly adopted in combination with the routine surface methods.

Following geological characters are broadly established for the entire area in which the tunnel project is to be located as a result of preliminary surveys:

(a) The general topography of the area marking the highest and the lowest points, occurrence of valleys, depressions, bare and covered slopes, slide areas, and in hilly regions and cold climates, the snow-line.

(b) The lithology of the area, meaning thereby, the composition, attitude and thickness of rock formations which constitute the area.

(c) The hydrological conditions in the area, such as depth of water table, possibility of occurrence of major and minor aquifers of simple type and of artesian type and the likely hydrostatic heads along different possible routes or alignments.

(d) The structural condition of the rock, that is, extent and attitude of major structural features such as folding, faulting, unconformities, jointing and shearing planes, if developed. Existence of buried valleys is also established during the preliminary surveys.

In addition, such surveys would also reveal occurrence of reserves of rocks that could be beneficially used for construction programmes (lining etc.) in the tunnel project.

It is obvious that with the help of above information, the engineers could propose a number of alternative tunnel routes to connect the two places, and in most cases, even decide about the general run of the tunnel.

B. Detailed Surveys:
Once the general run of the tunnel has been decided, planning for its construction begins. Such plans require fairly accurate data about the rocks or the ground to be excavated for passing through.

Such data are obtained by:
(i) Bore-hole drilling, along proposed alignments and up to desired depths; the number of bore-holes may run into dozens, scores or even hundreds, depending upon the length of the tunnel; rock samples obtained from bore holes are analysed for their mechanical and geochemical properties in the laboratories;

(ii) Drilling exploratory shafts and adits, which allow direct approach to the desired tunnel for visual inspection in addition to the usual advantages of drilling;

(iii) Driving pilot tunnels, which are essentially exploratory in nature but could better be used as a main route if found suitable by subsequent enlargement.

The actual number of bore holes and shafts and adits and their depth and length are decided by the length and location of the proposed tunnel. For tunnels with little overburden, these may be driven close to the proposed tunnel. For very long and deep tunnels, economic considerations limit their number.

Information supplied by them has to be corroborated with that obtained by indirect methods such as seismic surveys. The shafts and adit borings are costly affairs but are very necessary. Often some of these could be merged with the main project subsequently as useful elements, such as for ventilation and allied purposes.

Geological Profile of Tunnels:

When all the geological information gathered from preliminary and detailed surveys is plotted along a longitudinal section, the axis of the proposed tunnel being the section line, a geological profile is obtained. It is the most important geological record available with the project engineer and in fact his single most important guideline in the tunnel project.

Such a profile generally provides information regarding the following aspects of the proposed route:

(i) Location and depth of exploratory bore holes and shafts etc.

(ii) Types of rocks and their geochemical characters such as whether consolidated or unconsolidated, fissured and decayed or fresh;

(iii) Structure of rocks, that is, whether stratified, or massive, horizontal or inclined, and if inclined, degree and direction of inclination; folding and faulting with full details.

(iv) Hydrological conditions along the profile line; whether the line is above or below the water table and its relation to any aquifer that is likely to be intercepted;

(v) Ground temperature conditions, projected down to the tunnel axis based on calculations and observations.

❖ **Geological Investigation for site selection of Bridge**

❖ A bridge may be defined as a structure built over a river, a dry valley, low land or an estuary or any depressed part of the land to provide a link between the two opposite sides. It is essentially a communication link on a road or railway track or a highway. Bridges] especially over major rivers and in hilly and mountainous areas are very important civil engineering structures. Their role in socio-economic development and defence strategies can hardly be overemphasized.

In most cases the location of a bridge is decided more by socio-economic factors than by geological considerations. Thus, there are seven bridges over the River Jhelum connecting the two parts of Srinagar city (in Kashmir) within a total distance of 5 km. On the contrary, there is only one bridge over the River Chenab (at Ramban, Jammu Province) connecting the valley of Kashmir with rest of the country.

That may be true for most of the other big cities, states and countries of the world. In other words, within big cities divided by rivers or streams, a bridge has to be placed where it is needed, irrespective of the subsurface geology. However, on highways, there is often some flexibility available in the choice of placement of a bridge.

This is unlike tunnels, where alignment is primarily and essentially controlled by geological considerations. But, in the case of bridges also, the design, stability and durability depend, to a great extent, on the subsurface geological conditions that must be properly investigated and cautiously interpreted.

In any major bridge construction project, the designer is keen to place the bridge abutments and piers on as sound, strong and stable rock foundation below as possible.

<u>This being so, the geological characters that need to investigate and thoroughly established are:</u>
(a) The depth to the bed rock;

(b) The nature of the bed rock;

(c) The structural disposition of rocks.

(a) Depth to Bed Rock:
In most cases, the river bed below the water is covered by varying thickness of unconsolidated natural deposits of sand, gravels and boulders.

Such loose materials are not safe as foundations for bridge piers for at least two reasons:
Firstly, piers placed directly on them would be unstable;

Secondly, the cover material is liable to be removed due to scouring by river water.

As such, the pier must be placed on stable foundation, preferably of rock, under a suitable thickness of cover material so that it is safe from scour by river water.

The height of pier from under the span to the foundation level, therefore, depends on the 'depth of the bed rock' below the river water.

Such sound bed rocks might be available within a depth varying from 5 to 20 meters below a river bed or they might not at all be available even up to 100 meter or more. All that depends on the local geology which has to be investigated and understood.

To achieve this, drill holes are made all along the centre line of the proposed bridge, even on the right or left of it, till they reach the sound rock sequence or up to a reasonable depth. Utmost care is needed not to mistake isolated big boulders buried underneath the river bed as the bed rock. Boulders are rocks but they are not bed rocks and cannot be trusted as foundations for bridge piers.

(b) Nature of Bed Rock:
The very first rock encountered below the bed cover material may not be suitable as a foundation.

It should be kept in mind that three types of loads are to be borne by a bridge pier foundation:
i. The compressive, vertical loads due to the weight of the bridge span and that of pier material;

ii. The horizontal loads due to the thrust of the water flowing above as transmitted directly and through the pier;

iii. The dynamic, complex load, often inclined and shearing in character, due to heavy traffic on the bridge.

Consequently, the bed rock selected as foundation for the pier must be strong enough to bear the sum total of all these loads, not temporarily, but throughout the proposed life of the bridge.

The nature of the bed rock is commonly determined through study of petrological characters and engineering properties, especially the strength values, using the core samples obtained during drilling of test bore holes. In fact complete and very useful geological profiles could be prepared all along the centre line of the proposed bridge from the study of such core logs.

These (profiles) would depict complete sequence (and even structural disposition) of the rock formations existing below the surface material up to a desired depth. A decision to place the pier on a particular rock at a particular depth is then matter of judgement and design requirements.

Most igneous and massive type of sedimentary and metamorphic rocks is quite strong, stable and durable as foundations for bridge piers and abutments. The group of weak rocks which might behave badly in the presence of water includes such types as cavernous limestones, chalk, friable sandstones especially with clayey cements, shales, clays, slates, schists and the layers of peat and compressible organic material. Many of them are amenable to treatment by artificial methods.

(c) Structural Disposition:

Ideally, the horizontal attitude and uniformly massive structure with depth are desirable characters in the foundation rocks as these offer inherent resistance against failure. However, even inclined rocks in a confined situation under the bridge piers are considered quite safe if these possess normal strength values.

Folding and faulting might cause some uncertainty in establishing a perfect geological profile but are not otherwise negative factors. Acute fracturing and profuse jointing is, however, undesirable at the foundation levels as these might cause settlement beyond the allowable limits.

When the bridge sites are located in the zones of seismic activity, the foundations are required to be designed for additional seismic loads as specified in the codes of respective areas.

In the glaciated areas, special care must be taken to establish the existence of drowned or buried valleys that might be filled by secondary material of most heterogeneous characters. In such cases a bed rock may be encountered only at great depth and it may be desirable to reach it through piles. In fact, occurrence of drowned valleys is considered one of the major complications in bridge foundations that limit the options of a design engineer.

Similarly, the factor of scour must never the overlooked. Riverbed materials and rocks under them at shallow depths are liable to removal by scouring. The scour itself is a function of river velocity and direction of the currents on the one hand and nature and degree of consolidation of the rocks on the other hand.

❖ Geological Investigation for Site selection of Roads in Hilly Regions:

Meandering:
Construction of roads in hilly regions is always a job full of many complications. Thus, the most important principle for road alignment based on connecting two visible points by the shortest route is the most difficult to be followed in hilly regions. In fact, the topographic and the permissible factors necessitate, more than often a meandering, zig-zag course.

Aerial Survey:
Similarly, another very important complication is the area that has to be surveyed in the specified time. This will require, obviously, use of some quicker methods of surveying. Hence aerial surveying may become necessary for successful completion of the project in specified time.

Rock Consideration:

If some solid and stratified rocks are encountered along the alignment, special investigations should be carried out to determine:

(i) Dip and strike of the bed;

(ii) Lithological composition of the rocks;

(iii) Presence and nature of faulting, jointing and permeability due to these secondary planes of weakness.

Geological Structures:

The structural features of rocks, especially in those of sedimentary and metamorphic origin, have very important bearing upon the design of cuts as well as on the stability of the road as a whole. A given rock might be quite hard and otherwise sound for a cut as road foundation.

But, if in the same rock some planes of weakness (such as bedding planes, joints, foliation, cleavage) are present in such a way that these are inclined towards the free side of the valley, the rock could likely fail along these planes.

Such structural features include:

(a) Dip and strike,

(b) Joints,

(c) Fault planes.

(a) Dip and Strike:

There may be three possibilities for making a cut in the inclined beds – it can be made parallel, at right angles or inclined to the dip direction.

The relative merits of the cut vis- a-vis its stability would be as follows, assuming other things are favourable:

(i) Cut is Parallel to the Dip Direction:

In such a case , the layers offer a uniform behaviour on either side of the cut and as such the risk of failure is minimal on this account.

(ii) Cut is made Parallel to the Strike:

Cut is made parallel to the strike, that is, at right angles to the dip direction. In such a case, strata plunge across the cut, offering different inclinations of the layers on either side of the cut. On the dipping inside of the cut, there is always likelihood of slips, especially when the planes are inclined steeply and get lubricated very often due to rainwater, or groundwater movement. In some cases where the layers dip into the hill rather than in the road, the cut is considered quite stable.

(iii) Cutting Inclined to Dip and Strike:
In such cases also, the strata will dip across the cutting and the slope of cutting will be unequal on both sides. Hence such a condition would give rise to similar difficulties as encountered in cuts parallel to strike.

When there is no alternative to cuts either parallel to or inclined to strike (other than at right angles), special measure might become necessary to ensure stability of slopes.

(b) Joints:
These influence the stability of the cuts in the same way as the bedding planes. When present in great abundance, joints reduce even the hardest rock to a mass of loosely held up blocks on the side of a cut which could tumble down on slight vibrations.

Further, even if the joints are few, but are continuous and inclined towards the free side of the cut, these offer potential surfaces for slips during the presence of moisture. In major road construction programmes, therefore, jointed rocks have to be provided artificial support by breastwalls and retaining walls for ensuring stability.

(c) Faults:
Faulting generally leads to the crushing of the rock along the fault planes and shear zones. Such a condition is, of course, very unfavourable for a cut when it happens to form upper or lower slope or even base of the cut. It worst type of planes of potential failure.

Groundwater Conditions for Road:

It is always necessary to investigate thoroughly the position of water table of the area. Not only that, water bearing qualities should also be known along the proposed route. It is quite likely that a water bearing zone (aquifer) might be intersecting the base or slopes of an alignment. Specific care and design would be required for these natural water conduits. These are always to be taken as weak and hazardous zones in the road.

It is also known that water exerts important influence on the bearing capacity of the rocks and soil. Hence when the ground is rich with moisture it would not bear the design loads, unless these properties of ground have also been determined in moist conditions. Sometimes there is a condition of free flow of ground-water through the soil. This is quite dangerous for the stability of the road surface laid above such soil.