UNIT-VI APPLIED GEOLOGY

6.1. GEOLOGY OF DAM SITE (IDEAL AND NON IDEAL CONDITIONS)

Dam Failure: Common causes of dam failure include:

- Geological instability caused by changes to water levels during filling or poor surveying (Malpasset Dam).
- Sliding of a mountain into the reservoir (Vajont Dam – not exactly a dam failure, but caused nearly the entire volume of said reservoir to be displaced and overtop the dam)
- Extreme inflow (Shakidor Dam)
- Internal erosion or piping, especially in earthen dams (Teton Dam)
- Earthquakes

Geology of Dam Sites • The Success of a dam is not only related to its own safety and stability but also to the success of associated reservoirs. In other words, on construction, if a dam stands firmly but if its reservoirs leaks profusely then such a dam is to be treated only as a failure because the purpose for which it was constructed was not served.

Therefore, utmost care is needed in planning for the success of both the dams and the reservoir. • Careful geological studies bring out the inherent advantage or disadvantage of a site and such studies go a long way either in reducing or in increasing the cost of a dam considerably.

The Important Geological requirements which should be considered in the selection of a dam are as follows: •
Narrow River Valleys
• Occurrence of the bedrock at a shallow depth.
• Competent rocks to offer a stable foundation
• Proper Geological Structures

Narrow River Valley

At the proposed dam site, if the river valley is narrow, only a small dam is required, which means the cost of dam construction will be less. On the other hand, if the valley is wide, a bigger dam is necessary which means the construction cost will be very high.

Therefore, it is preferable from the economy point of view, to select such a site along the river valley which has the least areal cross-section (i.e.. the narrowest part of the river). • But such sites should not be blindly selected without further investigations, because sometimes they may have severe defects which may lead to serious leakage from the reservoir and may affect the safety of the dam.

Bedrock at Shallow Depths

To ensure its safety and stability a dam has to necessarily rest on (Physically) very strong and (Structurally) very stable (i.e. bedrocks). If such competent bedrocks occur near the surface or at shallow depths, the foundation cost of the dam will naturally be less. On the other hand, if competent bedrocks occur at great depths, the cost of the foundation will be very high because it involves extensive work of excavation of loose overburden and concrete refilling.

The Thickness of sediments or loose overburden along the river valley depends on the nature and the stage of development of the river. In other words, strong and fresh bedrocks may occur at or near the surface, therefore only small dams may be suitable theese to serve a limited purpose.

The general occurrence of material like clay, silt, sand and gravel along the river bed, naturally makes it difficult to assess the thickness of loose overburden by mere surfacial studies. Therefore to know the bedrock profile, geophysical investigations such as “Electrical Resistivity studies” or “Seismic refraction Studies” are carried out carefully. The data recorded in the field during investigations are interpreted and the required bedrock profile is visualized.

Competent Rocks for Safe Foundation:

If Igneous rock occurs at the selected dam site, they will offer a safe base, and weak sedimentary rocks, particularly shale's, poorly cemented sandstones and limestone's shall naturally be undesirable to serve as foundation rocks.

The suitability or otherwise of a site to serve as a foundation for major dams depends on factors such as :

- The existing rock type at the dam site.
- The extent of weathering it has undergone
- The occurrence of intrusions
- The extent of fracturing
- The extent of geological structures, the mode and number of rock types concerned.

Suitability of Igneous Rocks

- Among the rock types, the occurrence of massive plutonic and (or) hyperbyssal igneous rocks is the most desirable at the dam site because they are very strong and durable due to their dense character.

Interlocking texture, hard silicate mineral composition, occurrence of negligible porosity and permeability, absence of any inherent weak planes, resistance of weathering and their tendency to occur over wide areas. Thus all plutonic rocks like Granites, Syenites, diorites and gabbros are very competent and desirable rocks. However, volcanic rocks which are vesicular or amygdaloidal, are not equally desirable, obviously because these character contributes to porosity, permeability and hollowness which, in turn, reflect the strength of the rocks.

Of Course, it is necessary that such rocks should not have been affected by any intense weathering or fracture or dykes or adverse geological structures like shearing, faulting and jointing.

Suitability of Sedimentary Rocks

In this case of sedimentary rocks, the bedding and its orientation, thickness of beds, nature and extent of compaction and cementation, grain size, leaching of soluble matter, porosity and permeability, associated geological structures and composition of constituents (i.e. Sediments, cementing material, etc.) influence the strength and durability of different sedimentation rocks.

Based on aforementioned details, it may be stated that:

Shales are not inherently incompetent but they also form slippery bases. Therefore they are most undesirable at dam sites.

Among Sandstone, well-cemented siliceous type are competent and suitable for the dam construction. Laterites and conglomerates are undesirable at dam sites
Limestones are competent if they are massive, i.e.. unaffected by the solution phenomenon, Hence they are undesirable at dam sites.

Suitability of Metamorphic Rocks
Among the metamorphic rocks:
"Gneisses" are generally competent like granites, unless they possess a very high degree of foliations and are richly accompanied by mica-like minerals.
Quartzites are very hard and highly resistant to weathering. They are neither porous nor permeable.

Marbles, like quartzite, are compact, bear a granulose structure, are not porous, nor permeable and reasonably strong too. But by virtue of their chemical composition and minerals they are unsuitable at dam sites.
Slates bear a typical slaty cleavage. Hence this rock is soft and weak and undesirable at dam sites.

After learning the suitability of the occurrence of different varieties of common rocks at dam sites, it should be remembered that all types of rocks exhibit within themselves some variations in their chemical and mineral composition.

Finally it may be said that most of the igneous and metamorphic rocks, when fresh and free from structural defects, have enough strength to bear the loads involved in dam of all sizes with surplus safety factor too.

Effects of Associated Geological Structures
For the stability of a dam, the occurrence of favorable geological structure is a very important requirement. Under structural geology we have learnt that those rocks bear certain inherent or original physical properties, such characters get modified either advantageously or disadvantageously when geological structure occurs in those rocks.

Cases of Undisturbed i.e. Horizontal Strata
This geological situation is good at the dam site because the load of the dam acts perpendicular to the bedding planes, which means that the beds are in an advantageous position to bear the loads with full competence.

Further, the seepage of reservoir water that may take place beneath the dam is effectively prevented by the weight of the dam which acts vertically downwards.

Thus the possible uplift pressure which is dangerous to the stability of the dam is effectively reduced.

Cases where Beds lie Perpendicular to the length of the valleys
Tilted Beds
Beds with 10 0 to 30 0 inclination in the upstream directions , Such a situation is ideal because the resultant force acts more or less perpendicular to the bedding plane which are dipping in the upstream side.

Beds with Steep Upstream Dip

Such a situation is not bad but not as advantageous as that of the previous situations, for obvious reasons, i.e. in this case, there shall be no uplift on the dam site and no leakage of water from the reservoir, but due to steep dip the bedding planes are not perpendicular to the resultant force, this means the rock will not be as compatible as in previous case.

Sites Beds with Steep Downstream Dip

For obvious reasons this situations has all the disadvantages of the previous case. Further, here the resultant force and bedding planes are nearly parallel, which means that the beds will be even less competent.

Beds which are Folded

Folding of beds, which occurs on a relatively large scale, is generally less dangerous than faulting. Unless the folds are of a complex nature. • However, it should be borne in mind that unlike simply tilted strata, the folded rocks are not only under strain but also physically fractured along the crests. Hence grouting & other precautions may have to be considered, depending on the context, to improve the stability and competence of rocks at the site.

Beds Which are Faulted

Occurrence of faulting irrespective of its attitude (i.e.. Strike and Dip), right at the dam site is most undesirable. If the faults are active, under no circumstances, can dam construction be taken up there. This is not only because of the fear of possible relative displacement of the site itself but also due to the possible occurrence of earthquakes.

Further, if the fault zone is crushed or intensely fractured, it becomes physically incompetent to withstand the forces of the dam. Thus locations of the dam sites on a fault zone is undesirable for different reasons.

Beds Which Have Joints

Among the different geological structures, joints are the most common and are found to occur in all kinds of rocks, almost everywhere.

But Since the rocks with these joints are not under any strain, and also because of the scope to overcome their effects easily by simple treatment, they are not considered as serious defects. Grouting is generally capable of overcoming the adverse effects of joints because it fill the gaps of joints, increase compactness and competency of the rocks & reduce porosity & permeability.

6.2. GEOLOGY OF RESERVOIRS

From the Geological point of view, a reservoir can be claimed to be successful if it is watertight (i.e.. if it does not suffer from any serious leakage of water) and if it has a long life due to very slow rate of silting in the reservoir basin. The reservoir, when filled, gives chances for reactivation of underlying inactive faults. This in turn, gives scope for the occurrence of seismicity and landslides in that region.

Effect of Evaporation

The natural process of evaporation reduces the quantity of water in the reservoir. Through unwanted, this process is unavoidable. Since reservoirs are open and extended over larger areas. The magnitude of evaporation will be extensive. Of course, such loss shall be less if the topography is such that a reservoir covers a small area but has a great depth to provide adequate capacity.

Reservoir Water- Tightness and Influencing factors

When a river flows over such loose soil or fractured ground, it is natural that some water of the river percolates (or leaks) underground. Before the construction of the dam, this leakage shall be less and limited only to the extent over which the river flow occurs. But when the dam is constructed, the impounding water accumulates in large quantity in a reservoir which covers a very large area.

Further, due to the considerable height of the water in the reservoir, significant hydrostatic pressure develops which will make the leakage more effective on the sides and the floor of the reservoir. Thus, the extent of leakage may become alarmingly great.

Reservoir Influence of Rock Types

Water-tightness of a reservoir basin is also very much influenced by the kind of rocks that occur at the reservoir site. If the rock are porous and permeable, they will cause the leakage of water and hence such rock are undesirable at the reservoir site.

Reservoir and Igneous Rocks:

Intrusive igneous rocks like granite, by virtue of their composition, texture and mode of formation are neither porous nor permeable. Hence their occurs at the reservoir site will not cause leakage of water unless they have other defects like joints, faults, or shear zones. But the extrusive (i.e.. Volcanic) igneous rocks like basalt are not desirable because they are often vesicular.

Reservoir and Sedimentary Rocks:

Wide areal extent and frequency of occurrence, sedimentary rocks are the more important in this regard than igneous rocks. Among the different sedimentary rocks shale's are the most abundant followed by sandstone & limestone.

Shales the extremely fine grained sedimentary rocks. Are highly porous but not permeable. For this reason, the occurrence of shale's at the reservoir site shall not cause any leakage. Of course, at the dam site, its occurrence is considered undesirable because of its incompetency and slippery character. Sandstone is an aquifer and hence it has a tendency to cause leakage. However, careful examination is needed to know whether it causes severe leakage or not, if present at the reservoir site. This is so because the porosity and permeability of different sandstone differ depending on a degree of cementation and composition of the cementing materials of sandstones.

The Occurrence of limestone, the third most common rock of the sedimentary group at the reservoir site is, in general, undesirable. Of course, it may not only have negligible porosity but also possess reasonable hardness and durability. Thus through the compact of massive limestone superficially seem to be water proof, they may be internally cavernous and cause profuse leakage.

Reservoir and Metamorphic Rocks

Gneisses, which are one of the most common metamorphic rocks, behave like granite, i.e.. they are neither porous nor permeable. The schists, on the other hand, by virtue of their excellent foliation and soft and cleavage-bearing mineral content and a source of weakness and leakage problems. The quartzite which are compact, by virtue of their quartz content and granulose structure, are neither porous nor permeable.

Marbles, through compact, by virtue of their calcium carbonate composition and calcite content are not reliable in terms of their water tightness. Slates due to their characteristics slaty due to their characteristic slaty cleavage may tend to cause leakage but their very fine grained nature helps in checking such leakage considerably.

6.3. GEOLOGY OF TUNNELS

Tunnels are underground passages or routes (or passages through hills or mountains) used for different purposes. They are made by excavation of rocks below the surface or through the hills or mountains.

Like dams, bridges and reservoirs, tunnels are also very important civil engineering projects, but with some differences.

Unlike other civil engineering constructions which lie on the surface, generally, tunnels lie underground (i.e.. within the rocks). For this reason, the needs for their safety and stability is more important.

Effects Of Tunneling On The Ground

The tunneling process deteriorates the physical conditions of the ground. This happens because due to heavy and repeated blasting excavation, the rocks gets shattered to great extent and develop numerous cracks and fractures. This reduces the cohesiveness and compactness of rocks. In other words, rocks becomes loose and more fractured and porous. This naturally adversely affects the competence of the rocks concerned.

Geological Considerations for successful Tunneling

As already stated, the safety success and economy of tunneling depend on the various geological conditions prevailing at the site. As usual, the important geological factors which interfere with this civil engineering project (i.e. tunneling) are also lithological, structural and ground water conditions.

Importance of Rock Types

Since tunnels through underground rock masses, obviously the nature of rock types which are encountered along the tunnel alignment is very important for the safety and stability of the tunnel.

In brief, the competent rocks (i.e. those which are strong, hard and massive) will lead to safe but slow tunneling and incompetent rocks (which are loose or soft or fractured), through amenable for easy tunneling, will be unstable and hence require lining. Of Course, if tunnel extends for considerably long distances, the kind or rocks en route may vary from place to place, i.e. Competent at some places and incompetent at some other places.

Suitability of Igneous Rocks at the Tunnel Site

Massive igneous rocks, I.e. the plutonic and hyperbyssal varieties, are very competent but difficult to work. They do not need any lining or any special maintenance. This is so because they are very strong, tough, hard, rigid, durable, impervious and tunneling, do not succumb to collapse, floor bumps, side bulges or to any other deformation.

The volcanic rocks, too in spite of their vesicular or amygdaloidal character are competent and suitable for tunneling. Further, by virtue of frequently present vesicular or amygdaloidal structure, they are more easily workable than intrusive rocks.

Sedimentary Rocks at the tunnel Site

In general, sedimentary rocks are less competent than igneous rocks. Among the different sedimentary rocks.

Thick bedded, well-cemented and siliceous or ferruginous sandstones are more competent and better suited for tunneling. They will be strong, easily workable and, moreover, do not require any lining. Thus they possess all the desirable qualities for tunneling, provided they are not affected adversely by any geological structures and ground water conditions.

Shales, by virtue of their inherent weakness and lamination, may get badly shattered during blasting. But being soft, they can be easily excavated and hence tunneling progresses faster through shale formations. Proper lining is necessary for tunnels built in Shales.

Among limestones, dolomitic limestone are harder and more durable. They are better than other varieties. On the other hand, calcareous limestones or porous limestones are naturally weaker and softer.

In a majority of the cases, sedimentary rocks. Being relatively softer, facilitate fast progress of work, but by virtue of their weakness requires suitable lining.

Metamorphic Rocks at the Tunnel Site

Among different metamorphic rocks, gneisses are nearly similar to granites in terms of their competence, durability and workability. Hence, they are capable of withstanding the tunneling process without requiring any lining. The gneissose structure may be advantageous in the excavation process. Schists, phyllites, etc, which are highly foliated and generally soft, are easily workable but necessarily require good lining.

Quartzite are very hard and hence very difficult to work they are more brittle too. They are competent and need no lining.

Importance of Geological Structures in Tunnels

Effects of Joints at the Tunnel Site

Most of the rocks in nature possess irregular cracks and regular joints, which are plane of complete separation in rock masses, and clearly represent weakness in them. There will be more qualitively and quantitavely nearer the surface but generally disappear with depth.

Closely spaced joints in all kind of rocks are harmful. However, in general, in igneous rocks, which are exceptionally strong, the presence may not harm their self- supporting character.

In Sedimentary rocks, the occurrence of joints is undesirable because these rocks, which are originally weak and incompetent, become still more weak. As in the case of other rocks, the presence of joints in these rocks also depends on the past tectonic history of the concerned region.

In Metamorphic rocks also, joints are not characteristic, but are frequently present. Granite gneisses and quartzites, being very competent, can remain suitable for tunneling even if some joints occur in them. But schists and slates with joints will become very incompetent and necessarily requires lining.

- Marbles, which possess joints, are unsuitable for tunneling because, in them, joints are root causes for the occurrence of sink holes, solution cavities and channels. Further, as common with other types of rocks, the sheet joints occur in this group of rocks too.

Fault At The Tunnel Site

As in other civil engineering projects, in tunnels too, faults are harmful and undesirable because they create a variety of problems.

The active fault are places where there is scope for further recurrence of faulting, which will be accompanied by the physical displacement of litho units. Hence, such faults lead to dislocation and discontinuity in the tunnel alignment. Therefore, irrespective of the relation of the attitude of the fault with the tunnel courses, the occurrence of any active faults in tunnels is very undesirable.

The fault zones even if inactive, are places of intense fracturing, which means that they are zones of great physical weakness.

Such a remedial measures of lining (with concrete) also becomes necessary fault zones, being highly porous, permeable and decomposed, are the potential zones to create ground water problems.

Folds at the Tunnel Site

Folds represent the deformation of rocks under the influence of tectonic forces. Hence the folded rocks will be under considerable strain. When excavations for tunnels are made in folded rocks, such rocks get the opportunity to release this strain (i.e. stored energy). Such a release may occur in the form of rock bursts or rock falls or bulging of the sides or the floor or the roof. Thus complications of such a kind are likely to occur when tunneling is made in folded regions.

In folded regions, the tunnel alignment may be parallel or perpendicular or oblique to the axis of folds. Further the tunnel may run along the crests or troughs or limbs.

Effects of Undisturbed or Tilted Strata at The Tunnel Site

Horizontal Beds

In cases of horizontal or gently inclined beds, conditions will be favorable for tunneling. But it is desirable that the bed concerned be thick so that the tunnel passes through the same formation. This is preferable because thicker formation are more competent and hence tunnels through them will be safe and stable.

Inclined Beds

The forgoing advantage also occur when the tunnels are made parallel to the strike of massive, thick, inclined beds or when inclined tunnels are made following the directions of the slope.

Tunnels Parallel to the dip

In the latter case, an inclined tunnel driven along the dip of beds must run through the same bed or beds all along its course. The stability of the tunnel in all these cases depends on the nature of the beds which forms the roof. It is relevant to say in this context that the dip and strike galleries in coal mines are driven in this way, i.e. along the true dip and strike, respectively, of the coal seams. These tunnels, therefore, always run along the coal seams and have nearly similar conditions all along their length.

However, when the tunnel is horizontal and runs parallel to the dip direction, then numerous beds will appear along its course. This is undesirable because in such a case the tunneling conditions differ from place to place and this may lead to problems like stability and over break.