**UNIT – VIII TUNNELS**

CONTENTS………………………

 INTRODUCTION

 PURPOSES OF TUNNELLING

 EFFECTS OF TUNNELLING ON THE GROUND

 LINING OF TUNNELS

 GEOLOGICAL CONSIDERATIONS

 LITHOLOGY OF ROCK FORMATIONS

 GEOLOGICAL STRUCTURES.. Joints at the tunnel site

 Tunnels in faulted strata

 Tunnels in folded strata

 GROUNDWATER CONDITIONS

 TUNNEL SUPPORTS

 OVERBREAK

Questions:

1. Describe the geologic parameters of rock tunneling?
2. Explain in detail purposes of tunneling and also effects of tunneling on the ground ?
3. Explain the role of Geological considerations for the construction of tunnels in detail?
4. Write a brief note on: (a) purposes of tunneling

 (b) effects of tunneling on the ground

 (c) Lining in tunnels

5. Write a short note on: (a) Tunnels in faulted strata

 (b) Tunnels in folded strata

 (c) Over break

**UNIT – VIII TUNNELS**

**Terminology**

**Tunnel:** An underground passage for vehicles or pedestrians, especially one which is created by digging into earth.

**Axis:** The lengthwise course of a tunnel, especially along the center line.

**Cross section :** The shape of a tunnel for eg: horseshoe, round or square.

**Excavation:** The process of digging or the hole which results.

**Muck:** Debris removed during excavation.

**Grouting:** Unstable rock and soil is strengthened by the injection of chemicals, cementious materials .

**Lining:** Materials used to finish the inside surface of the tunnel.

**Overburden :** The soil and rock supported by the roof of a tunnel.

**Portal:** The open end of a tunnel. Usually includes a wall to retain the soil around the opening.

**Adit**: Main entrance location of a tunnel

**Profile:** A side view of the tunnel.

**Shaft:** A vertical, underground passage from the top to the bottom where there is initially no access to the bottom.

**Tunnel Boring Machine (TBM):** A tunneling machine which has cutting teeth at its front. It creates the tunnel opening while passing the waste material through the rear.

**Ventilation:** Circulation of fresh air is called as ventilation.

Tunnels are underground passages through hills or mountains used for several operations. Tunnels are made by excavation of rocks below the surface or through the hills.

Like other engineering structures, tunnels too need favourable geological conditions at their sites for achieving success. In case of tunnels also, success means safety, stability and economy.

To achieve these objectives, careful geological examinations should be made with reference to the rock types occurring at the site ( lithology of rock-formations ), structures associated with them and the prevailing ground water conditions.

The construction of underground tunnels, shafts and passageways are of course essential but these are dangerous activities. Working under reduced light conditions, limited access; the exposure to air contaminants and the hazards of fire and explosion, underground construction workers face many dangers.

**GEOTECHNICAL INVESTIGATIONS**: A tunnel project must start with a comprehensive investigation of ground conditions by collecting samples from boreholes and by other geophysical techniques. Involvement of machinery and methods for excavation and ground support, which will reduce the risk of encountering unforeseen ground conditions.

**PURPOSES OF TUNNELLING:** Tunnels are constructed for several operations:

* **In mining practice**: Adits and shafts for reaching the work spots and for the transport of workers and materials.
* **In certain mines:** tunnels are made to extract coal from coal seams
* **In hydroelectric projects**:Diversion tunnels for channel diversion ( by diverting the normal flow of river water through the tunnels ) and for power generation.
* **For water supply and sewage disposal:**  For supply of drinking water or sewage disposal purposes, tunnels are made.
* **Transportation**: to lay roads or railway tracks to regularize the traffic and transportation of goods**.**
* **For laying cables and service lines:** These are utility tunnels for laying cables and for transport of oil/gas through pipelines.
* **To reduce the distance:** To reduce the distance between places of interest across natural obstacles like hills, to save time and to provide conveyance.

Eg (1) In Bihar, between Hazaribagh and Gaya the eastern railway passes through a number of tunnels across the hills of the Chota Nagapur Plateau.

Eg (2) A number of tunnels of 1 km in length or less were driven in the Deccan Traps between Bombay and Pune railway line.

Eg (3) In Jammu and Kashmir, 2 parallel tunnels of 2440 mts long were made between Jammu and Srinagar in the Pir Panjal mountain range.

Eg (4): the under sea tunnels made between France and England and between some islands of Japan.

**CLASSIFICATION OF TUNNELS:**

Depending on the nature & competency of the ground, tunnels are classified as:

*Hard rock tunnels*: The tunnel alignment is essentially through competent rock mass with little or no ground water seepage.

*Soft rock tunnels:* The tunnel alignment is through unconsolidated or highly weathered material which always encounter the groundwater problems.

**EFFECTS OF TUNNELLING:** When tunnels are made through weak or unconsolidated formations, they are provided with suitable lining for safety and stability. Lining may be in the form of steel structures or concrete.

* Due to heavy and repeated blasting during excavation of a tunnel, numerous cracks and fractures develop which reduces the compactness in rocks. In addition, rock become loose/more fractured which allow water movement .
* Lining of the tunnel helps in checking the leakage of groundwater into the tunnel.
* Fault zones and shear zones are naturally weak and tunneling through them further deteriorates and cause stability problem.
* Fall of rocks takes place even in hard rocks like granite though devoid of bedding or foliation and this process is known as **Popping.**
* Roof may collapse due to stress and strain of the region due to overburden.
* Poisonous gases encountered during the excavation of tunnels, sometimes.

ROAD TUNNELS IN INDIA:

|  |  |  |  |
| --- | --- | --- | --- |
| **Tunnel** | **Length** | [**State**](http://www.lotsberg.net/data/india/list.html#Legenda) | **Notes** |
| Rohtang | 8 820 m | HP | Under the 3978 above msl high Rohtang pass on Manali - Leh road  |
| Banihal | 2 576 m | JK | Jammu - Kashmir road. 2209 m above sea level |
| Jawarhar | 2 500 m | JK | Srinagar - Jammu |
| Kamshet-I | 1 843 m | MH | Mumbai - Pune Expressway.  |
| Bhatan | 1 658 m | MH | Mumbai - Pune Expressway |
| Gokhale Nagar | 1 000 m | MH |   |
| Khambatki - Ghat | 890 m | MH |   |
| Madap | 646 m | MH | Mumbai - Pune Expressway |
| Kamshet-II | 359 m | MH | Mumbai - Pune Expressway |
| Khandala | 330 m | MH | Mumbai - Pune Expressway. |
| Aodoshi | ? m | MH | Mumbai - Pune Expressway. Only for Mumbai bound traffic |

**LINING OF TUNNELS:** When tunnels are made through weak or loose or unconsolidated formations, they are provided with suitable lining for safety and stability. Lining may be in the form of steel structures or concrete.

The main purposes of lining are to resist the pressures from the surroundings (from the roof or the sides or the floor) and to protect the shape of the tunnel. Lining also helps in the leakage of ground water into the tunnel . Thus lining is a an effective remedial measure to overcome the various drawbacks resulting from underground tunneling either geologically or non-geologically.

Lining provides a regular shape to the tunnel as the excessive excavated portions ( ie over break ) are filled by concrete. Lining being a very expensive treatment, needs to be provided only at such places where the rocks are not capable of supporting themselves,., where the rocks are weak and likely to collapse.

Lining is also provided in such places where the seepage of water into the tunnel occurs and creates problems. The zones of faulting or shearing also need suitable lining to impart strength to them. Strong and complete lining is required in hydropower tunnels which carry water under great pressure and even minor leakages can prove hazardous.

**GEOLOGICAL CONSIDERATIONS:** Geological considerations of tunneling depend on various geological factors prevailing at the site. The geological considerations in a civil engineering project (ie tunneling) include

Lithology of rock formations;

Geological Structures and

Groundwater conditions.

**1. LITHOLOGY OF ROCK FORMATIONS :**  Massive **Igneous rocks** ( ie plutonic and hypabyssal rocks ) are in general compact and competent and no lining is required for the tunnels designed. Volcanic igneous rocks being often vesicular, porous and permeable posses a threat of water seepage in the tunnel. However, sometimes, the vesicular character is also competent and suitable for tunneling.

Eg: 20 tunnels were excavated for Bombay–Delhi railway line through amygdaloidal / vesicular basalts.

**Sedimentary rocks** are less competent. However, sandstones with siliceous matrix may be considered . If the sandstones have carbonate or iron oxide as cementing material ( poorly cemented ), the tunnel lining needs reinforcement otherwise they are undesirable.

Eg: In the Himalayan Ramganga diversion tunnel, a poorly cemented sandstone formation, had caused a roof fall.

Limestones may expect seepage problems. Among limestones, dolomitic limestones are harder and more durable. On the other hand, calcareous limestones or porous limestones are naturally weaker, softer and are unsuitable for tunneling by virtue of their tendency to corrode. Shales are the lest competent because of the clay content. The presence of Clay layers are troublesome as they have low strength.

Among the **metamorphic rocks**, Quartzites and gneisses are massive and competent. Phyllites and Schists are problematic due to the presence of foliation and presence of susceptible minerals like mica and clay. Depending the orientation of cleavage of minerals in case of slates may be considered. Marbles are reasonably competent by virtue of their high compactness and granulose structure.. But their susceptibility to corrosion and softness necessitates lining.

**GEOLOGICAL CONSIDERATIONS FOR EFFECTIVE TUNNELLING**

**Importance of Rock Types**

**SUITABILITY OF IGNEOUS ROCKS:** Massive igneous rocks, i.e., the plutonic and hypabyssal 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, after tunneling, do not succumb to collapse, or to any other deformation.



**SUITABILITY OF 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.

Poorly cemented or argillaceous sandstones, however, are weak and undesirable, particularly if they get saturated with water or are thin bedded. Shales, by virtue of their inherent weakness and lamination, may get badly shattered during blasting. Mudstones are weaker than shales as they are less compacted.

Among limestones, dolomitic limestones 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. Conglomerates need not be considered seriously due to the presence of pebbles and unconsolidation.

**SUITABILITY OF METAMORPHICROCKS:** Metamorphic rocks such as gneisses are nearly similar to granites in terms of their competence, durability and workability. Schists, Phyllites, etc., which are highly foliated and generally soft, are easily workable but necessarily require good lining.

Quartzites are very hard and hence very difficult to work. Marbles are reasonably competent by virtue of their high compactness and granulose structure. Slates are rather soft and possess slaty cleavage. Hence they are weak and require lining.

1. **GEOLOGICAL STRUCTURES :**

Strike and Dip orientation; Joints, Faults, Folds etc are the most common structural features associated with rocks.

If the tunnel alignment coincides with the strike of the formations, is acceptable if the formations are competent but in the case of less competent formations, the tunnel alignment should be a short span.

**(A) Joints at the tunnel site**: Closely spaced joints in all kinds of rocks are harmful ( eg Koyna third stage tail tunnel has been excavated through a closely jointed basalt causing roof fall with heavy copious leakage of water ). Joints which strike parallel to the tunnel axis for long distances are undesirable whereas the joints which are perpendicular to the tunnel axis have a limited effect.

In sedimentary rocks, the presence of joints may be due to folding ( occur along crests and troughs ) or faulting is undesirable.

In metamorphic rocks, such as granite gneisses and quartzites are competent even if the joints present due to their competent nature. Schists and Slates with joints will become very incompetent and require lining.

**(B) Tunnels in Faulted Strata**: Faults are harmful and undesirable because of the following problems:

Fault zones are places where the displacement of rocks occur and lead to discontinuity in the tunnel alignment. The fault zones are places of intense fracturing which means physical weakness in rock masses. Fault zones allow percolation of groundwater which may cause for collapse of walls. Eg: Koyna (Maharashtra state) third stage tunnel collapsed about 15 mts along a fault zone.

Fault zones are normally avoided along tunnel alignments. However, if they cannot be avoided, the fault zone has to be extensively treated with concrete grout and a strong lining has to be provided.

Problems are severe if the tunnel alignment coincides with the strike of the fault. If the tunnel is located in the foot wall of a fault, the roof portion of the tunnel becomes instability and needs reinforcement. In case of Hanging wall, less effect can be observed.

**(C) Tunnels in Folded Strata:**  Folded rocks are always under considerable strain. When excavation for tunnels are made in folded rocks, such rocks get the opportunity to release the strain ( stored energy ). Such energy cause the rock falls or bulging. In folded regions, the tunnel alignment may be advisable to have the tunnel located on the limbs than at the core if possible.

Tunnel alignment parallel to the axis of a fold: This is desirable when tunneling along limbs is considered. Rock masses may be in a highly fractured condition along crests, hence there may be frequent fall of rocks from the roof. Tunnels along troughs encounter harder formations and difficult to excavate. If bedding planes are inclined, groundwater percolates and these aquifers are punctured during the process of tunneling.

Tunnel alignment perpendicular to the axis of a fold: This is undesirable because different rock formations are encountered along the length of the tunnel due to heterogeneity in physical properties of rock.

In anticlinal fold, the central region will be under lesser pressure when compared to synclinal fold where the central region will be under higher pressure in addition to the occurrence of ground water.

However, anticlinal fold is to be considered for tunneling with proper precautions.

*TUNNELS PERPENDICULAR TO THE AXIS OF FOLD*

|  |  |
| --- | --- |
|  Lesser  pressure L  |  Higher  pressure |

1. **GROUNDWATER CONDITIONS:** Ground water problem in the tunneling is the most serious one. If ground water encountered in case of tunneling, the entire water is to be pumped out to keep the working area dry and adds the expenditure on tunneling project.

If the water table lies below the level of the tunnel, no severe ground water problem can be anticipated. But if the tunnel lies below the position of the water table , then the ground water problem is inevitable. .

**TUNNEL SUPPORTS :** Supports are used for keeping the tunnel walls and the roof in safety condition. Several support alternatives are available for use in tunnels. Following are the types of supports:

**Shotcrete** : Shotcrete is mortar or concrete pneumatically sprayed at high velocity through a hose. The process can be a dry process ( Guniting ) or a wet process.

**Rock Bolts**: These are steel bolts designed for holding weak formations together. The bolts are driven into the formations without causing any disturbance. These are used in tunneling for anchoring the tunnel walls to sold rock.

**Wire mesh; Concrete lining; Pre-stressed anchor cables; Steel ribs** etc are also used wherever is necessary.

Some of these types are used in combination also.

**OVERBREAK:** Excavations through hard rocks involves the removal of some of the rocks outside the proposed perimeter of the tunnel.

The quantity of rock removed, in excess of what is required by the perimeter of the proposed tunnel, is known as the over break.

The geological factors which govern the amount of over break are:

1. The nature of the rocks
2. The orientation and spacing of joints or weak zones
3. The orientation of the bedding planes in case sedimentary rocks.

In general, tunnels which pass through a single homogeneous formation without structural defects produce little over break, whereas tunnels which pass through a variety of rocks with structural defects ( like fault zones ) have more over break.

The factor of over break is important because it adds to the cost of tunneling, particularly if lining is required. Hence, it is desirable that over break should be as minimum as possible.

|  |  |
| --- | --- |
| Bumping ground  | Rock displacement and dislodging in tunneling rocks  |
| Circular shape tunnel | Is adopted in case of diversion of water at dam site |
| Discharge tunnels | Tunnels are those which are meant ***for conveying water from one point to another*** under gravity force. |
| Diversion tunnels | By diverting the normal flow of river water through the tunnels dug along the valley sides  |
| Fan cut blasting means  | To get more face for the excavation of rocks  |
| Hokoriku railway tunnel in Japan  | Is 13.87 km through sandstones and granites. |
| Horse shoe shape tunnel; | Is adopted for old tunnel excavations |
| Joints oblique or perpen-dicular to the tunnel axis  | Are obviously have a limited effect  |
| Joints which are parallel to the tunnel axis  | Are undesirable in all kinds of rocks. |
| OVER BREAK  | The qty of rock broken and removed in excess of what is required by the perimeter of the proposed tunnel.  |
| Parallel hole cut blasting means  | Blast holes are placed parallel to each other with a RELIEF HOLE of a larger dimension |
| Popping effect in tunneling | It refers to the phenomenon of fall of rocks which takes place in hard rocks like granite devoid of bedding or foliation.  |
| Pressure tunnels  | Tunnels are those which are used to allow water to pass through them under force***. Used for power generation***  |
| Purpose of lining | Lining refers to the support for the tunnel.  |
| Rock Bursts means  | These occur at great depths with enormous overburden pressure  |
| Smooth blasting means  | Small holes are placed along the circumference of blasting area |
| Suitability of shales | Faster progress but proper lining is necessary |
| Suitability of gneisses & quartzites  | Good in all aspects for tunneling |
| Suitability of Limestone & dolomitic limestones | Durable for tunneling purpose  |
| Suitability of Mudstones | Weaker than shales and undesirable for tunneling.  |
| Suitability of schists & Phyllites  | In competent but require lining for tunneling  |
| Suitability of Conglomerates for tunneling | Undesirable rocks  |
| Suitability of igneous rocks  | Very competent and lining is required |
| Suitability of well-cemented siliceous sandstone | Better suited for tunneling  |
| RQD means | Rock Quality Designation means the ratio of cumulative length of rock pieces expressed as a percentage of total length of the rock  |
| RSR | RSR means the rating of the quality of a rock for tunnel support recommendations. |