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Table of Content

1. Learning outcomes

After studying this module, you shall be able to:

- Know different types of linear openings and their utility with special reference to transportation tunnels, their types and parts.
- Understand importance of geomorphological and geological investigations for the selection of site and alignment for transportation tunnels.
- Identify different methods of tunnel construction and use of engineering classification of rock mass in tunnel design and predict tunnel support system.
- Know about major tunnels of India

2. Introduction

Tunnels are linear opening below the ground or through natural obstacles and act as an element of transport. The other horizontal variants of tunnels include water pressure tunnel, used for carrying water from reservoir to power generating unit, *driftis* smaller version of tunnel can be used as starting point for larger diameter tunnel, *adit*, a linear small opening as an approach to the tunnel for carrying out forward exploration and to act as conduit for men and machine. *Half tunnelto* act as underground by pass, *Chunnelor* subaqueous tunnel or bridge. Most of the above-mentioned linear openings are straight to curvilinear and horizontal to slightly sloping. Its vertical variants such as shaft and raise are used for taking men and machine in underground mines and also to provide ventilation for all kinds of underground openings. Tunnels and shafts are important part of all variants of underground mining (Fig. 1).

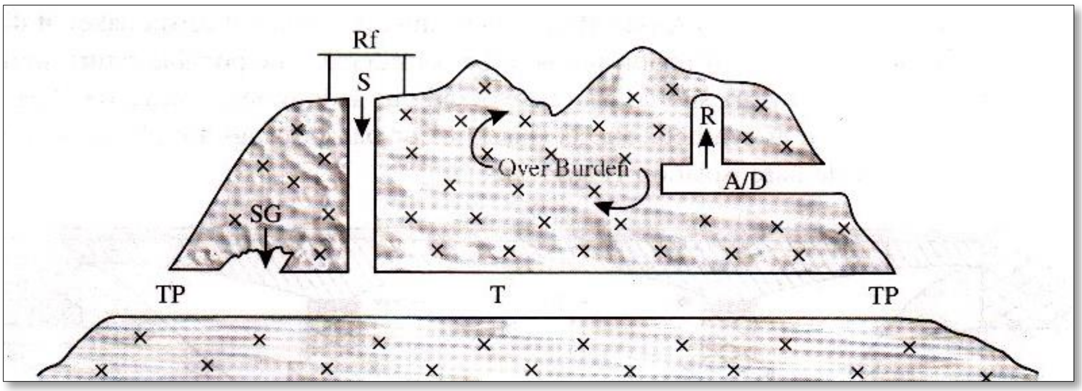

Fig. 1 Different kinds of linear openings through a natural obstacle. Horizontal linear two end opening, tunnel portals (TP), one side opening, adit or drift (A/D). Vertical double end opening, shaft (S) with roof cover (Rf), and one end opening raise (R). Irregular opening, stope (SG), in a massive rock.

Underground power stations, railway stations, waste disposal sites (nuclear waste), bunkers and other strategic storage structures, involving excavation of rectangular openings termed as caverns (Fig. 2) also require to have geological and geotechnical explorations similar to tunnels.

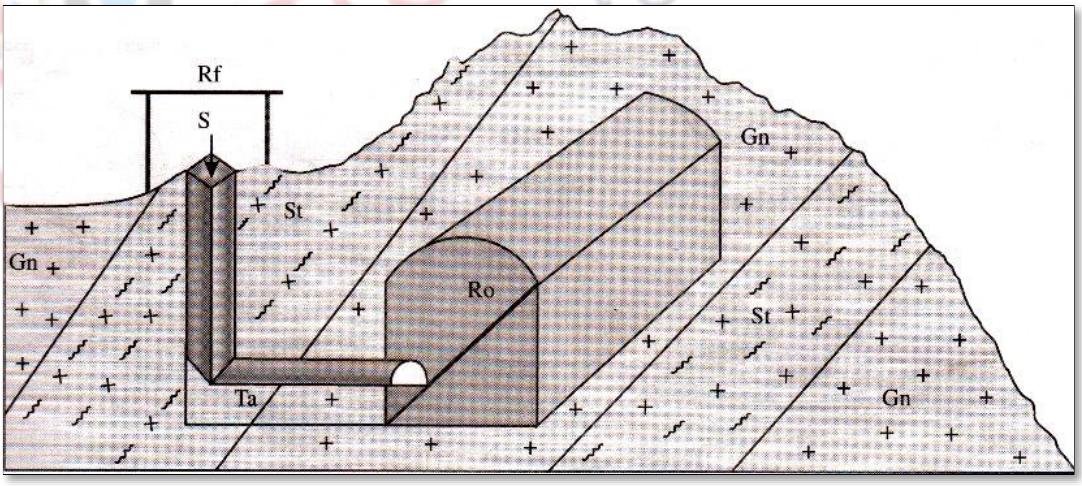

Fig. 2 Rectangular opening with approach shaft (S) with roof (Rf), and tunnel (Ta) in inclined metamorphic rocks (Gn-Gneiss, St-Schist).

The alignment of a tunnel, probable support system, method of excavation, type of explosives, problem of groundwater, workability and disposal of rock waste, all need detailed geological investigation before starting the tunnel excavation or construction. The cross sectional and linear dimensions of tunnels will depend upon natural obstacles they have to go through and purpose of the tunnel and accordingly will be subjected to different kinds of geological problems.

3. Parts of Tunnel

The terminology used in tunneling industry is similar to mining industry. The typical cross sections and parts are shown in Fig. 3. Most of the transport tunnels in soil have *square sections* and in rocks arch or *horseshoe* shaped sections. Water carrying tunnels are invariably have *circular section*. Mostly tunnels run as single tube but twin tubes tunnels are not uncommon for example a tunnel, between England and France below English Channel.

The top most mast of the tunnel is called as *portal*, as seen from inside the ceiling is called as *roof* or *back* of the tunnel. The tunnel sides are its wall and the bottom ground is termed as *floor* or *invert*. The line where arch meets the wall is called as *springline.*

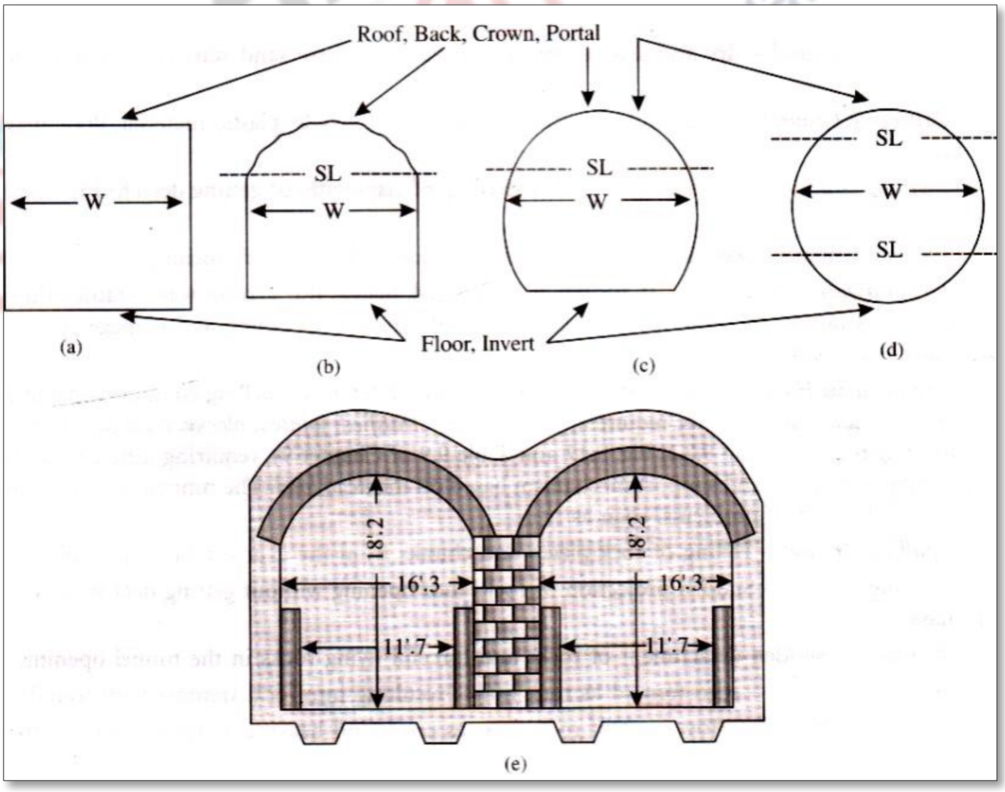

Fig. 3 Different kinds of tunnel cross-sections and parts of the tunnel. Square cross-section (a) for soft ground, Arch (b) and Horse Shoe (c) shaped transportation tunnel and circular cross (d) section of water pressure tunnel. (e) A twin tube tunnel cross section.

4. Tunnel Nomenclature

The tunnels are made in unconsolidated medium (soil) as well as in consolidated medium (rocks). The purpose of underground tunnel in soil is to ease out traffic congestion on the surface, for example Calcutta Metro, is made by *cut and cover* method and is termed as *soft ground tunneling*. For this a trench like opening is created of required dimension, ground foundation is laid for rail or bus roads followed by erection of wall to be covered by roof slab and finally the sides and top is filled back by the soil. The cross section of such tunnels is usually square shaped. Tunnels in rocks, as subsurface element of transport or through natural obstacles are termed as hard ground tunneling and involve different kind of *mining* methods. The excavated material is called as *muck* and its removal is called as *mucking*. The emphasis in this chapter is given to tunnels in rocks but some problems and their solutions for soft ground tunneling are also discussed apart from the hard ground tunneling.

4.1. Problems in Soft Ground Tunneling: The removal of soil, if not naturally well compacted may show following problems:-

Ravelling Ground- chunks or pieces of material drop from the excavated walls during excavation.

Running Ground- dry and less compacted gravel and coarse sand start coming in the opening.

Squeezing Ground- Moist soil moving into opening, slowly as plastic material, floor may also heave.

Swelling Ground- Soil moving in due to swelling of clays without getting detached to main mass.

Flowing Ground- Wet saturated soil flowing as slurry in excavated opening.

Groundwater Incursion- If tunnel is excavated below the groundwater table then groundwater is bound to come in the opening. Sometimes due to piping surface water may also flood the opening.

4.2 Problems in Hard Ground Tunneling: Rocks offer different tunneling conditions starting from *intactground*, which do not require any support to *stratified*, *jointed*, *blocky*, *crushed*, *swelling* and *squeezing* rocks, requiring different kinds of tunneling operations and support mechanism based on the *dead load*. The tunneling operation in rocks have their own set of problems, such as:-

Spalling Ground- Falling of rock pieces and chunks from the exposed back and walls.

Popping Ground- Sudden projection of rocks into opening without getting detached from rock mass.

Blowouts- sudden detachment of rocks and forceful flying rocks in the tunnel opening.

Bumping Ground- Also termed as rock bursts resulting into local tremors with sound.

Squeezing Ground- Movement of rock mass as creep and heaving of tunnel floor in the opening.

Swelling Ground- Volume expansion of moist rocks rich in clay and its movement in tunnel opening.

Groundwater Incursion- Seepage of surface water or groundwater.

Under and over break- Breakage of rocks less or more than what is required.

Many of the above-mentioned problems are due to *Pressure Relief Phenomena,* which is related to stresses stored in the rocks caused by overburden rocks and/or current tectonic stresses present in that area. These stresses, as such are not capable of inflicting any deformation but when an opening is created the residual or stored stresses tend to realign and get released by popping, blowouts, bumping and squeezing phenomenon.

5. Tunnel Excavation

Tunnels can be excavated by mining method or by employing machines. Mining method involves drilling and blasting while machines are used for ripping and boring in rocks.

5.1 Mining Method: The old and conventional method of making tunnel by drilling horizontal holes and blasting it with explosives either as full face in good rocks, top heading and benching in moderate strength rocks or as top heading and bench drilling in weak rocks (Fig. 4a-c). The stages include:

Marking→Drilling→Charging→Blasting→Ventilating→Mucking→Recuperating→Supporting→Marking

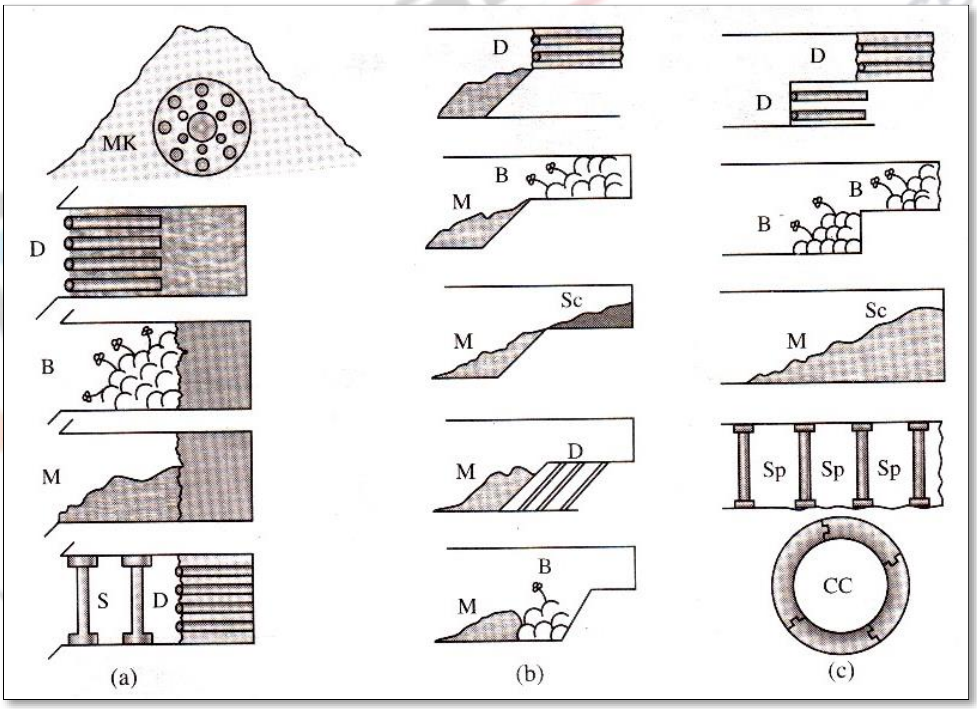

Fig. 4 Tunneling procedures; (a) Full face for strong rocks (b) Top heading and bench for rocks of moderate strength and (c) Top heading and bench drilling for weak rocks. MK- Marking, D- Drilling, B- Blasting, M- Mucking, Sc- Scrapping, Sp- Support by posts and CC- Support by concrete shells.

Now days Jumbo Machines with 2 to 5 arms (Fig. 5) are used to drill holes on the rock face as per blasting plan. A circular cut or very closely spaced drill holes are made in the center of the face so that during blasting rocks should find ready space to collapse. Otherwise, the perimeter of the tunnel will face the brunt of blasting and will not only result into over break but also weakening of rock mass (*dead zone*) around the tunnel opening. In fact some drill holes are purposely left blank (stemming) near the perimeter to control the over break. Drilling and blasting can create noise, vibrations and damage the rocks depending upon the blasting power and rock mass properties. Nevertheless, drilling and blasting technique can be used for all kind of rocks, in all kind of terrains and are the only viable option for large size rectangular caverns.

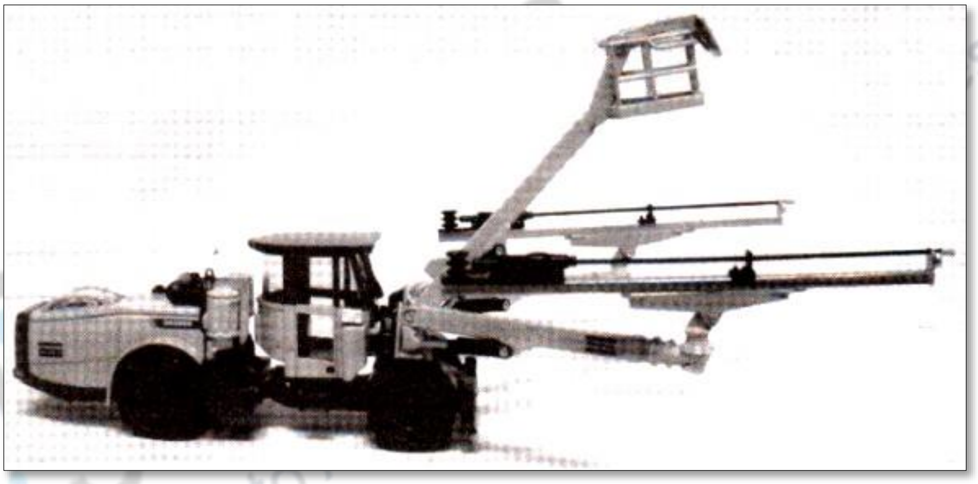

Fig. 5: Truck mounted driller for making 45mm dia bore hole of 1 to 3m length.

5.2 Machine Tunneling: Mechanized tunneling involves machines with large sized drill bits and is tailor made for different type and sized tunnels. The important ones are *Raise Borers* for boring in upward direction, *Shaft Borers* for boring in downward direction, *Road Headers* and *Tunnel Boring Machine* (TBM) for boring in horizontal direction (Fig. 6). The important issues are rate of tunneling, debris clearance, tunneling cost, mechanical breakdowns, wear and tear of bore heads. Shaft borer can be used for vertical elements of tunnel such as ventilation shaft to bore from ground surface to downward, but has a major problem of debris clearance. Raise borer is a better choice as debris clearance is somewhat easy, but for this seating of machine is to be made underground to start the work. Road headers with rotary milling head is the best choice for small tunnels in weak to moderate strength rocks (<60 MPa UCS).

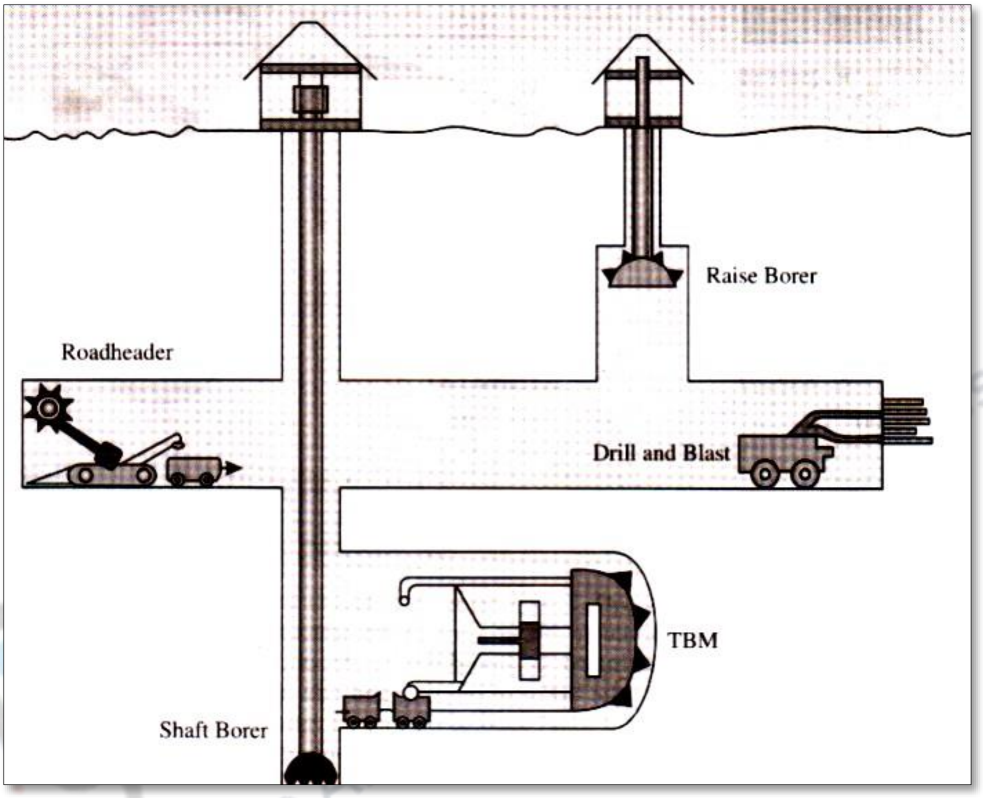

Fig. 6 Different boring machine, shaft and raise borer, road header, drilling and blasting boomer and tunnel boring machine.

The costliest of all these are TBM, which are being used successfully in all kinds of rocks to be holed for, tunnel length more than a km to be cost effective. The rate of tunneling may vary from 10m per day in hard rocks and 30m per day in soft rocks. The rotating head may come of diameters to give 7 to 9m opening with tightest possible curve of 300m radius. The machine has inbuilt provision of providing circular concrete support made of readymade circular segments.

6. Temporary and Permanent Support Measures

During excavations depending upon soft or hard ground tunneling various measures can be taken to avoid collapses. Depending upon the soil type and its texture it can be stabilized by spraying chemicals. To solve the problem of groundwater incursion pumping of water is the most viable option to lower the groundwater table well below the tunnel floor in some extreme cases soil freezing can also be applied. The most common method is to install support instantaneously during the excavation. The traditional support method include *timber frame sets* comprising of accessories such as *cap*, *post*, *sill*, *lagging*, *breasting soldier*, *raker* etc. as shown in Fig. 7.

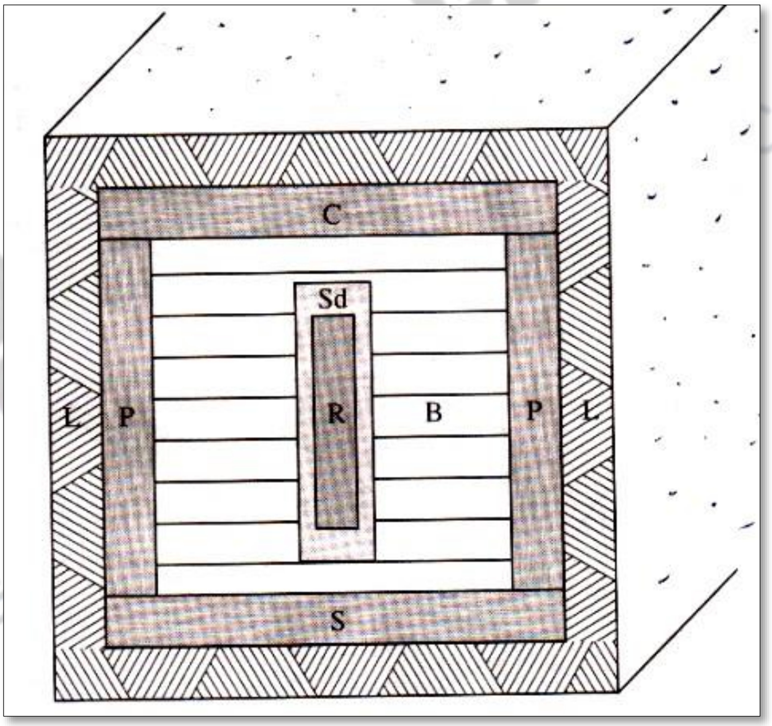

Fig. 7 Different support elements for underground soft ground tunneling. L - Lagging, S- Sill or Strut, C- Cap, P- Post, Sd- Soldier, R- Raker and B- Breasting.

Wooden support system was then taken over by steel *ribs*, *struts* and *posts* (Fig. 8) for circular water pressure and arched and semi-circular cross sections of vehicular tunnels. The spacings of these support elements will depend upon soil and rock mass conditions.

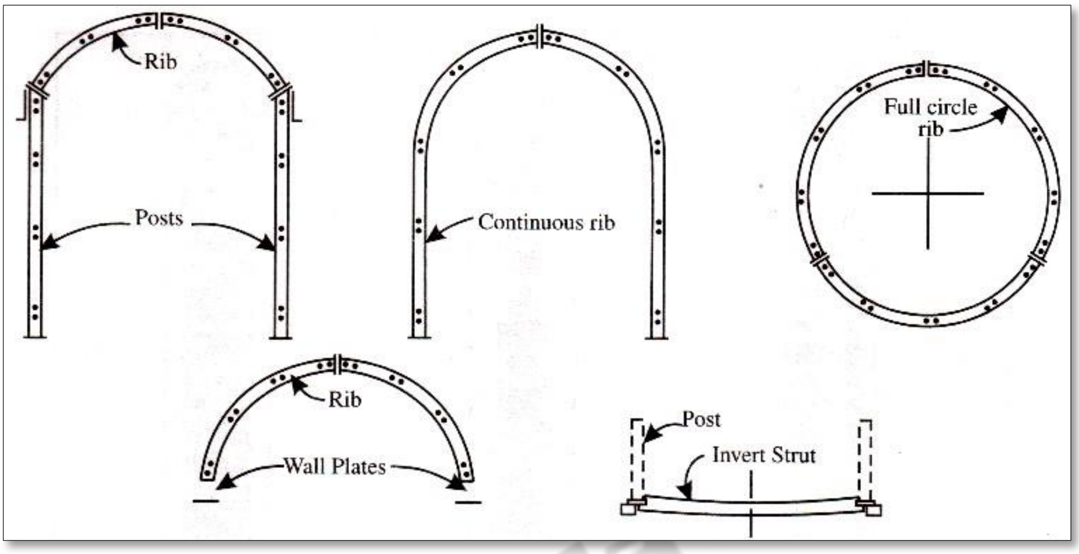

Fig. 8 Different support elements for soft and hard ground tunneling.

Roof bolting as shown in Fig. 9a, is also a common method to stabilize and hold the dead zone of loosened rocks in to some firm strata lying above the back. For local spalling individual bolts and for supporting large section of tunnel pattern bolting is provided. The bolting can be done by drilling holes and by placing bolts with a wedge at far end by hammering. Different types of bolts are in use and the size, numbers and spacings will depend upon the rock mass conditions (Fig. 9b). Most of the bolts are 2-5 m long drive in 35-45 mm holes and can take load up to 100 kN. The *Expansion Shell* bolt is the most used, takes immediate load and is cheap. The *Grouted* bolt is fixed with the help of resin or cement and is strongest. *Swellex* bolts are made of deformable steel tube which can be expanded in hole by applying 30 MPa water pressure.

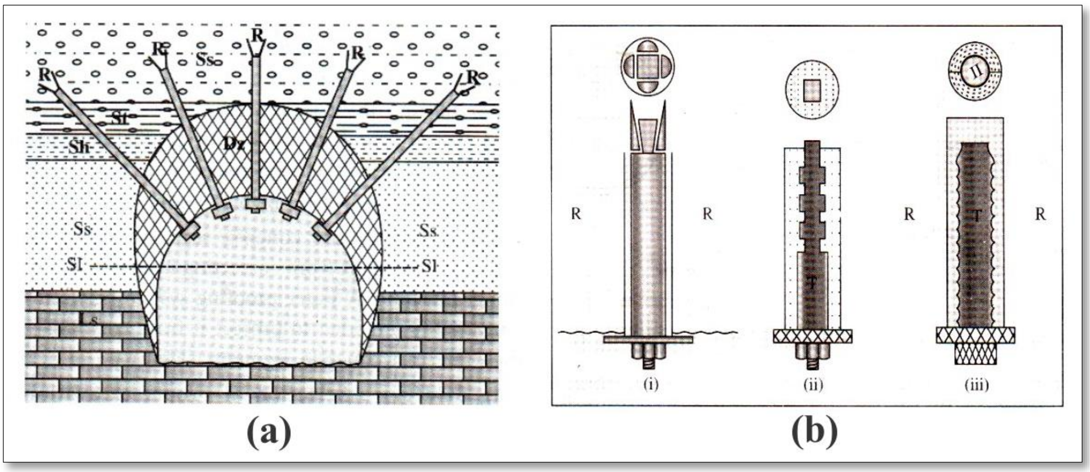

Fig. 9 (a) Schematics of roof bolting by rock bolts (R), in strong rock available, lying deep in the back of the tunnel, through loose (Dz- dead zone) rocks. Rocks in and around opening are weak which include Siltstone (St), Shale (Sh), Limestone (Ls), Sl is Spring line. (b) Different types of rock bolts (i) Expansion Shell Bolt, (ii) Grouted Bolt, (iii) Friction Swellex Bolt.

The advantages of roof bolting include supporting of roof immediately adjacent to working face, prevent rock slippage, provide much needed arch action, remain firm during vehicular movement allows proper ventilation and better clearance in the opening as compared to steel support. It is also used as advance ground improvement by installing rock bolts by 10^0 in spilling fashion from the tunnel perimeter.

Sometimes, for giving immediate support to loosened rocks due to blasting or to prevent spalling of jointed rocks *Shotcrete* and *Fibercrete* are applied. Depending upon the thickness of weak zones concrete 20 to 200 mm thick is sprayed (*shot*) under pressure at the rate of 5 to 15 m^3/h onto the back and wall of tunnel. It can also be applied with reinforcement comprising welded steel mesh. For weaker and heavily jointed rocks, 50 to 80 kg of steel fibres with lengths 40 to 50 mm is added to per cubic meter of concrete.

After providing initial support precast concrete segments called, *Cast-in-Place* concrete are installed as final lining and support. Apart from correcting irregularities of excavation, it provides sound foundation for tunnel finishing. A water proofing system between the initial support and cast in place concrete is invariably provided to protect it from corroding water. TBMs also have provision of installing these precast concrete segments (Fig. 10).

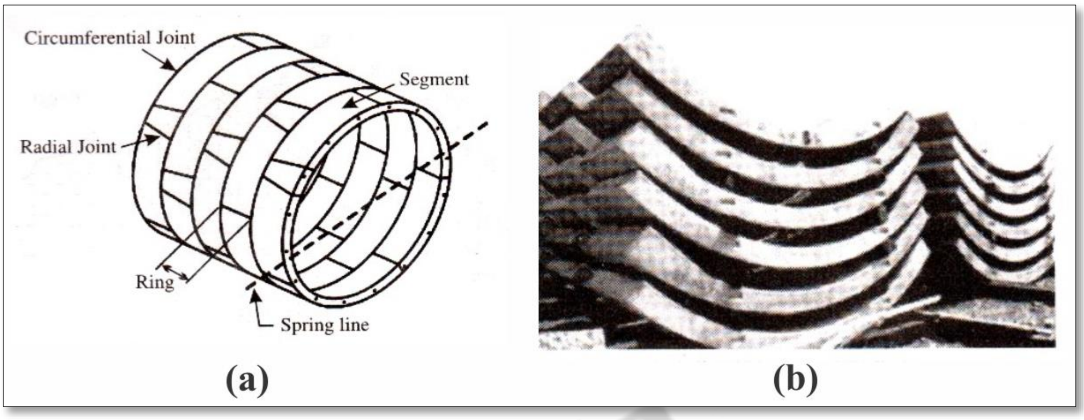

Fig. 10 (a) Schematics of cast-in-place concrete segment; (b) Stacked concrete parts.

7. Special Geomorphological Problems

Tunnels are made either below the ground or through the hills. In both the cases, it will be loaded by overlying rocks depending upon the topography running over them. Fig. 11 show that the regions with high ground elevations will exert high loads due to extra rock mass while low ground will exert lesser load on the tunnel back. Presence of inter mountain valleys with stream or with groundwater will have added problem of water seepage.

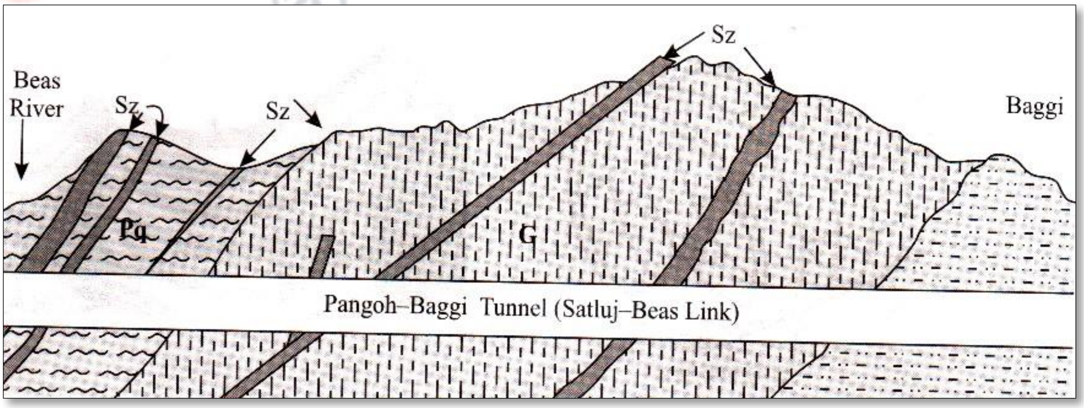

Fig. 11 Section along Pandoh- Baggi water pressure tunnel of Satluj- Beas Link made through mylonitized granite (G), Sericitic quartz Schists (Ss) and Phyllitic quartzite (Pq) with many shear zones (SZ). See that maximum load will lie in the central part of the tunnel due to topography.

The placing of tunnel through the natural obstacle will depend upon the road or rail approach. The tunnel through the mid of the hill will have maximum length as compared to tunnels passing close to the slope. However, tunnels close to the sloping surface will face problems related to weathered rock mass. The problem of mass movements and landslides may also cause problem.

8. Geological Factors

The alignment, length, span and cross section of the excavation will be decided as per the purpose of tunnel. For example, tunnels for carrying water will be different from the road tunnels, which may be different from rail tunnels. In the case of road or rail tunnels, the route alignment and approach will decide the location where bore has to be made. The important geological factors to be taken into consideration are related to rock type, structure, groundwater etc. For this, preliminary surveys are made to make geological profile along the central line of the tunnel. Most of these surveys are carried out on the ground surface and are projected downward at tunnel level. The accuracy of geological survey and geological intricacies of a particular area will decide how correct the projections are. Drilling may be used to check these projections and also to know the ground water conditions. But still during excavations, many unforeseen situations may crop up and take one by surprise and appropriate decision is to be taken then and there. It is said specially for tunneling that:

"*Design as you go, be ready for the worst and hope for the best*."

8.1. Rock Type: Igneous rocks will be the best bet as for as construction of safe tunnel is concerned. As they are three dimensionally large rock bodies, hence the chance is that a tunnel may remain in single rock i.e. granite batholith (Fig. 12a). Volcanic rocks showing flowage plains, cavities, vesicles and interbedded volcanic ash etc., should be thoroughly investigated (Fig. 12b). Non-foliated metamorphic rocks will show behavior similar to massive igneous rocks. Foliated metamorphic and sedimentary rocks are comparatively weak and need proper attention in terms of their treatment and requirement of support.

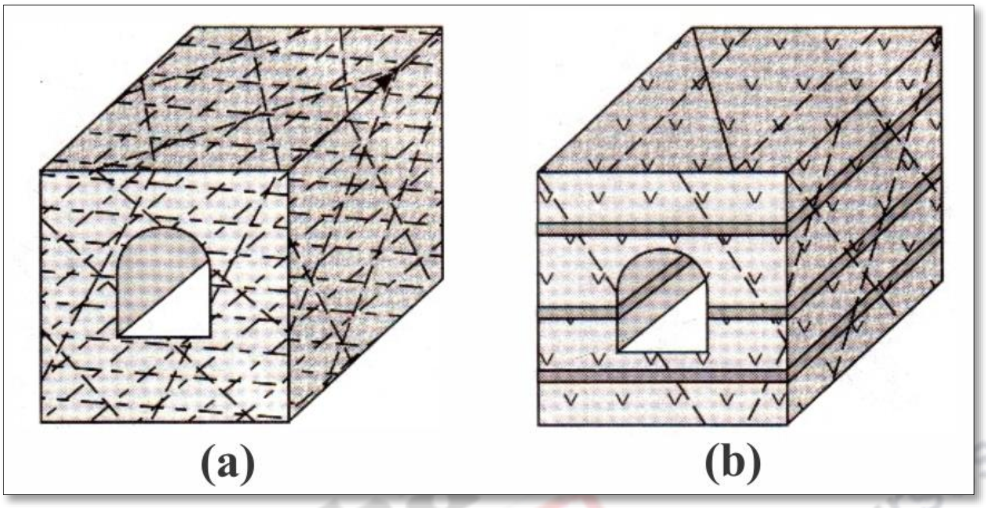

Fig. 12 (a) A tunnel in plutonic igneous rock body, see the criss crossing joints. (b) A tunnel through volcanic rocks with horizontal flowage planes, ash beds and criss crossing joints.

8.2. Weathering State: The weathering state of rocks will depend upon its age and climatic setup of the area. Usually rocks of Archaean and Proterozoic ages are highly weathered as they have been subjected to multi-phase deformation, repetitive and long-term exposure to varying weather and climate through time. The rocks exposed in regions of temperate and humid tropical climate will show high degree of weathering. The severity of weathering will be more near the outer surface of the slope and will diminish with depth. Hence, tunnel portals closer to the topographic surface will face problems related to water seepage and of mass movements, especially in layered rocks (Fig. 13a). Even, massive and strong rocks may have thin scree, which may fall at portals. In this case, tunnel portals are to be protected and should be lined (Fig. 13b).

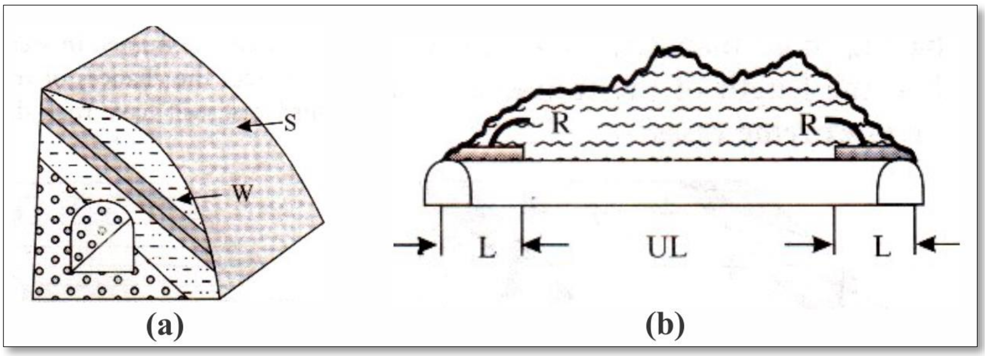

Fig. 13 (a) A tunnel close to slope (S) affected by weathering (W) and as the rock layers are dipping towards slope the land sliding may be a common problem. (b) A tunnel through granite with portals lined (L) and roof is bolted (R), see the interior part is unlined (UL).

8.3. Attitude of Rocks: In the case of stratified rocks the orientation and thickness of rocks in relation to the tunnel alignment plays a very important role especially in redistributing the stresses created during excavation. The *horizontal* rocks or rocks dipping by less than 10^0 stresses created during the excavation. If the rocks are horizontal, with thickness more than the height of the tunnel then the whole tunnel will remain in same rock and will fair good due to '*roof effect*', as loading of tunnel back will also remain same all through its width and length. In the case, rock thickness is less than the tunnel height then more than one rock will run through the tunnel. In such cases, the tunnel should be placed or designed to have its back in the strongest rock (Fig. 14a-b).

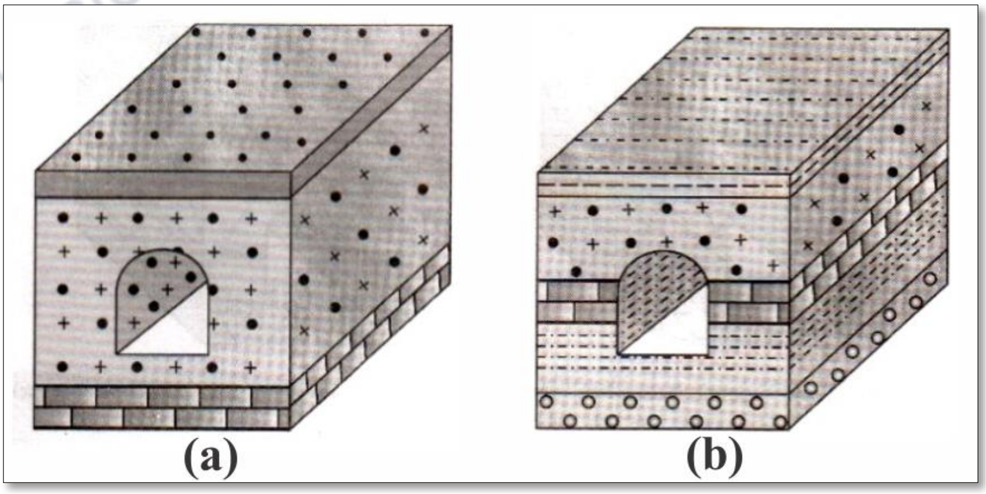

Fig. 14 Tunnel through horizontal rock will remain in same rock (s)

throughout its length, an ideal condition due to roof effect. (a) Thickness more than the tunnel span the most ideal condition. (b) Thickness less than the tunnel span the back of the tunnel should lie in strongest available rock.

The *vertical* rocks may be found in three different fashions with respect to tunnel alignment. First case, striking parallel to tunnel length, second case, perpendicular to tunnel length and third case some angular relationship of strike with tunnel length. The most important fact in vertical rocks in all the three conditions is that rocks will load back of the tunnel heavily, a non-ideal situation essentially requiring proper strengthening and support (Fig. 15a-b). The thickness again will play an important role especially in the first case where thickness may be more than the width of the tunnel. In second case, the chances of having more than one rock bed will be high because it is common to have rock thickness less than the tunnel length. The third case will have rock disposition in between the two extreme cases.

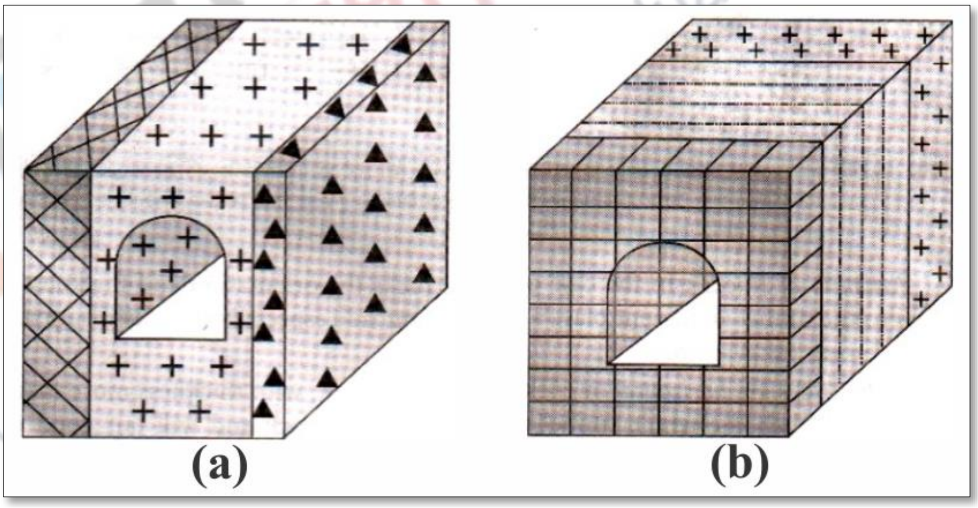

Fig. 15 Tunnel through vertical rock. (a) Rocks striking parallel to tunnel alignment, thickness more than the tunnel span, one rock, throughout its length, a better condition in given situation. (b) Tunnels running across the strike will bring many different rocks along the tunnel length, not a very good condition.

The *inclined* rocks will show varied nature of disposition depending upon its strike and dip with respect to tunnel alignment. The rocks may strike parallel to tunnel length and may dip towards right or left flank of the tunnel (Fig. 16a & b). The load concentration due to in coming rocks will be either in right or left side of the tunnel which need to be taken into account in tunnel design especially the tunnel wall in which the rocks are day lighting.

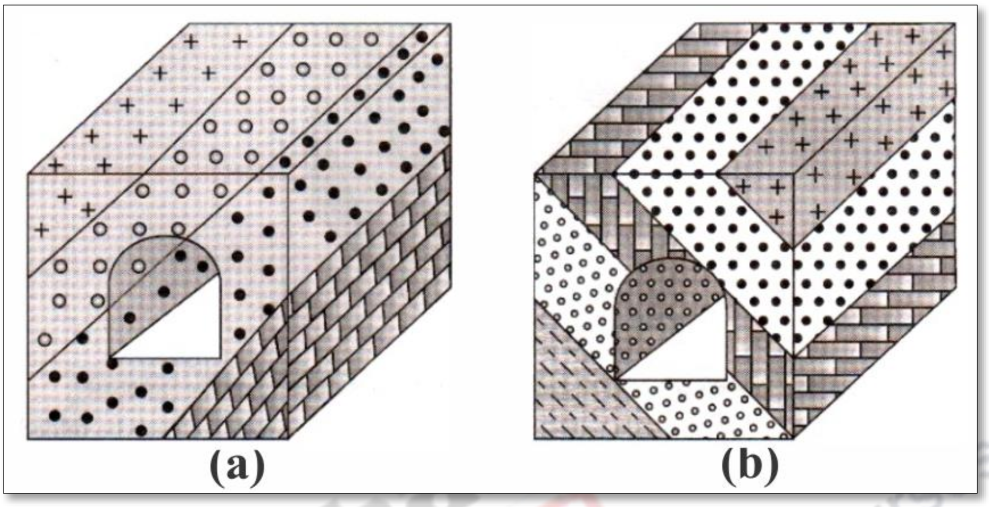

Fig. 16 Tunnel parallel to strike of rocks dipping sideways resulting into loading of left (a) and right flank (b) of tunnels loading the back corner and wall of tunnels.

If the rocks are striking perpendicular to the tunnel length then the rocks will dip either towards or away from the tunnel entry (Fig. 17a). The loading of the tunnel back will be in inclined fashion and will affect the back of the tunnel. Different problems may arise depending up on the excavation of the tunnel with the dip or against the dip (Fig. 17b). The excavation with the dip is easier and safer as compared to against the dip.

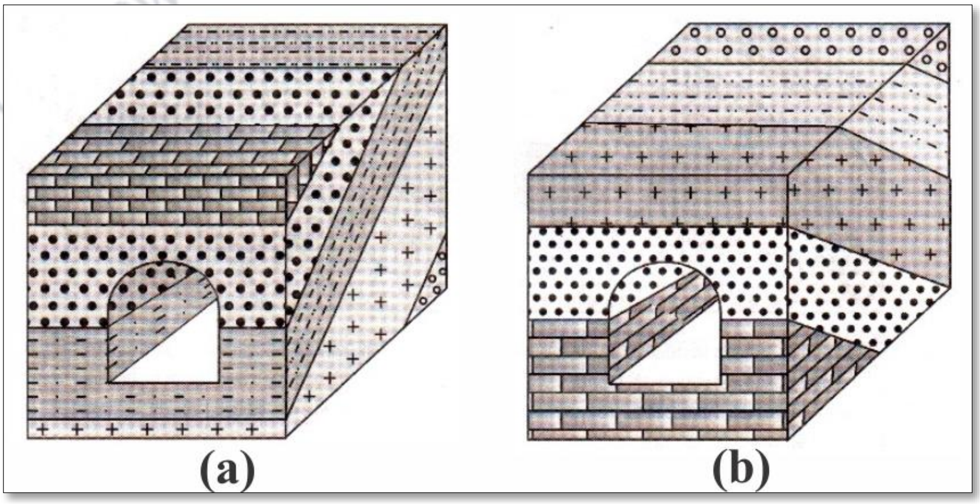

Fig. 17 Rocks with strike perpendicular to tunnel axis and dipping towards

entry or exit point. (a) Excavation against the dip, difficult and problematic (b) Excavation with dip, easy and ideal.

The rocks dipping *obliquely* to the tunnel length as shown in Fig. 18, will not only load the tunnel back but also the tunnel wall. The loading will be eccentric and will vary according to the angle of dip i.e. low angle dip will have lesser effect as compared to high angle dips.

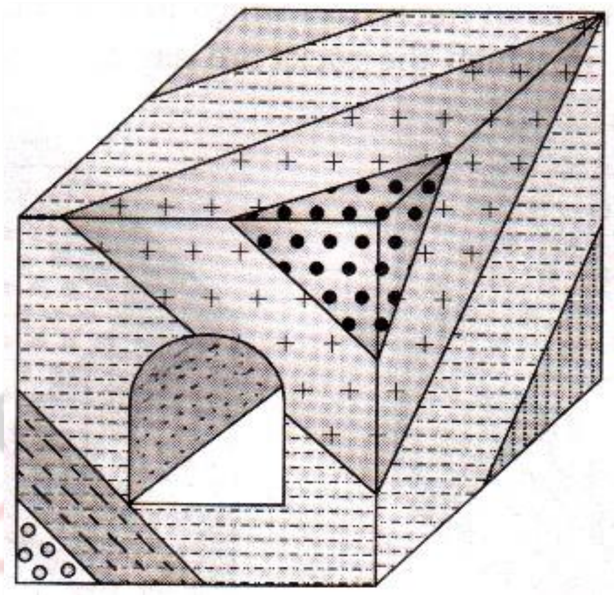

Fig. 18 The rocks with strike direction oblique to the tunnel length.

8.4. Rock Structure: A rock sequence through which tunnel is proposed may be folded, faulted and sheared, not to talk of joints, as they are ubiquitous. The presence of folds or faults or both, will not only result in repetition and omission of rocks but will bring in many other issues and problems.

The construction of tunnels will be effected by attitude of folding with respect to tunnel length and width. Depending upon the thickness of rocks and wavelength of folding repetition of rocks will take place and rocks will be loaded differently across and along the tunnel length. In the case of fold axis running parallel to the tunnel length, the tunnel may run through either anticline or syncline. The anticline will provide natural arching and may not at all load the tunnel back, an ideal condition, provided width of anticline is more than the width of the tunnel. In the case tunnel is going through the syncline the whole load will come on the tunnel back, a non-ideal condition. Apart from this, it has been found that rocks in anticlinal zone are heavily jointed due to presence of tensile stress regime as against synclinal zone, which remains under compressive stress regime. Hence, driving a tunnel will be easier along the anticlinal zone as compared to synclinal zone but support requirement may be more in anticlinal as compared to synclinal zone. Another issue is related to groundwater seepage along the folded layers; the water will move away from the tunnel in case of anticlines and will move into in the case of synclines (Fig. 19). It is suggested that if the rocks involved in folding are thick enough then the best option is to have tunnel in between the anticline and syncline axis i.e. in the limb.

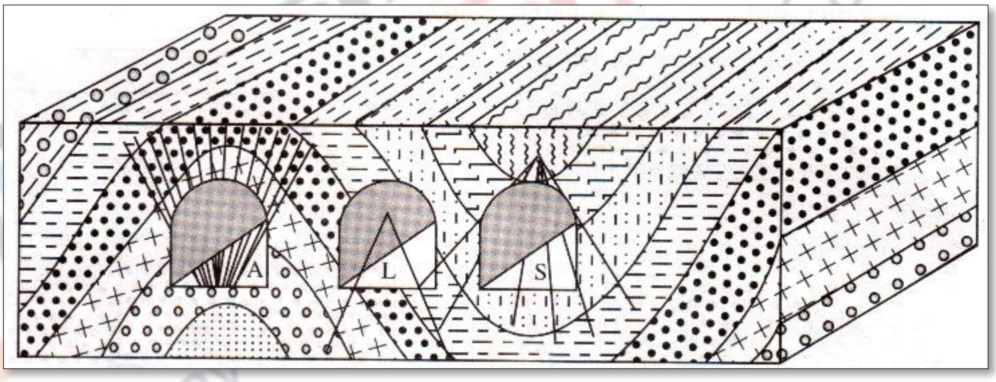

Fig. 19 Different options of tunnels in folded rocks. Through profusely jointed anticline (A), see the fold curve almost following the curvature of tunnel back forming natural arch. Through syncline (S) under loading from top and also compressed from sides, less jointed, tight rocks. Tunnel lying in fold limb (L) i.e. in between anticline and syncline, the most suitable condition.

If the tunnel length is perpendicular to the fold axis then depending upon its wavelength one or more than one, anticline and syncline may come across with varying loading and unloading options (Fig. 20). Fold axis running diagonally to the tunnel length will have different force pattern.

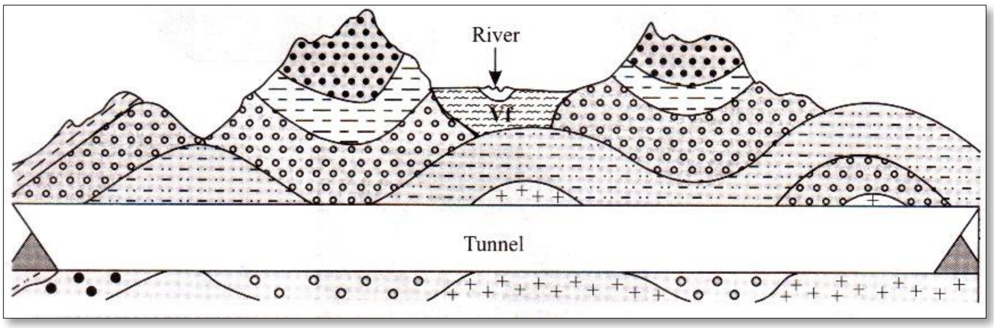

Fig. 20 Tunnel running perpendicular to fold axis, see arching below anticline and loading below syncline. Also, see presence of a valley along anticline, which may create seepage problem.

Faults coming along the tunnel should be identified in terms of its type, disposition with reference to tunnel length and its active or dead nature. The faults along which some movement or any earthquakes have been reported in recorded history of that region will be helpful in discerning its nature. Specialized geological and geophysical studies (radioactive and thermo-luminescence dating), can also be employed to work out the antiquity of a fault. Faults lying in regions of Seismic Zone IV to V, such as Himalayan Mountain System should be seen with caution and tunnel alignment may be changed to avoid if it is going through known active faults. Even if a fault is dead then too, tunnel should cross a fault in perpendicular fashion because fault making lesser angle or becoming parallel to tunnel axis, will result into its run all along the tunnel, thus making it unsafe (Fig. 21a).

The presence of crushed material along the fault or fault zone (gouge/mylonites/breccia), being weak will result in high over break and may need concrete back filling. The crushed zone may also act as medium for groundwater storage or if extended up to the earth surface then rain and surface water may percolate along it resulting into permanent seepage to water gush during excavation leading to flooding of the tunnel. Dewatering prior to excavation, proper sealing and grouting are the options to solve this problem (Fig. 21b). If a tunnel is running near the fault plane then the best option is to have it on foot block (Fig. 21c). There are other issues related to fault such as repetition and omission of rocks resulting into change of lithology across the fault.

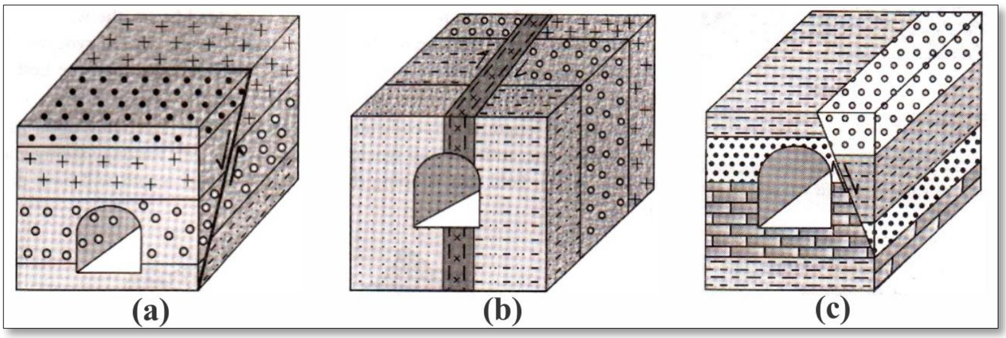

Fig. 21 Fault orientation and position of tunnel. (a) Fault running perpendicular to the tunnel alignment, a tolerable situation. Also, see the fault is very close to entry and portal lies in hanging block, a better option than the fault found in the mid part of the tunnel. (b) Fault zone running parallel to the tunnel length a non-ideal situation, as presence of crushed rocks, groundwater seepage, over break etc. will be found all along the length of the tunnel. (c) Fault is avoided by slightly shifting the alignment, now it runs close to the tunnel. The shift is made towards left of the fault so as tunnel is founded in foot block rather shifting it to the right of fault to avoid founding tunnel in hanging block.

The joints in rock mass through which tunnel is to be bored are going to play the most important role as their presence is assured. The number of joint sets per unit area and their attitude controlling block size and shape, their length and depth persistence, opening and asperities of the joint plane as well as alteration along them etc. are going to be the most important factor which will not only control the engineering behavior of the rock mass but also decide the approach to tunneling operation. Based on strength of rocks, joint incidence and their nature Rock Mass Quality or "Q" System classification, of rock mass can be used to predict rock mass behavior and required support (Table 1).

Table 1: RMR and 'Q' System of rock mass classes, stand-up time and support requirement.

ROCK MASS CLASS	**I** Very Good Rock	**II** Good Rock	**III** Fair Rock	**IV** Poor Rock	**V** Very Poor Rock
RMR System	81 – 100	61 – 80	41 – 60	21 – 40	< 20
'Q' System	> 40	10 – 40	4 – 10	1 – 4	< 1
Average Stand-up Time	20 yrs for 15 m Span	1 yr for 10 m Span	1 weak for 5 m Span	10 hrs for 2.5 m Span	30 min for 1 m Span
Tunnel Support System	None	Spot Bolts	Pattern Bolts	Bolts + Shotcrete	Steel Ribs

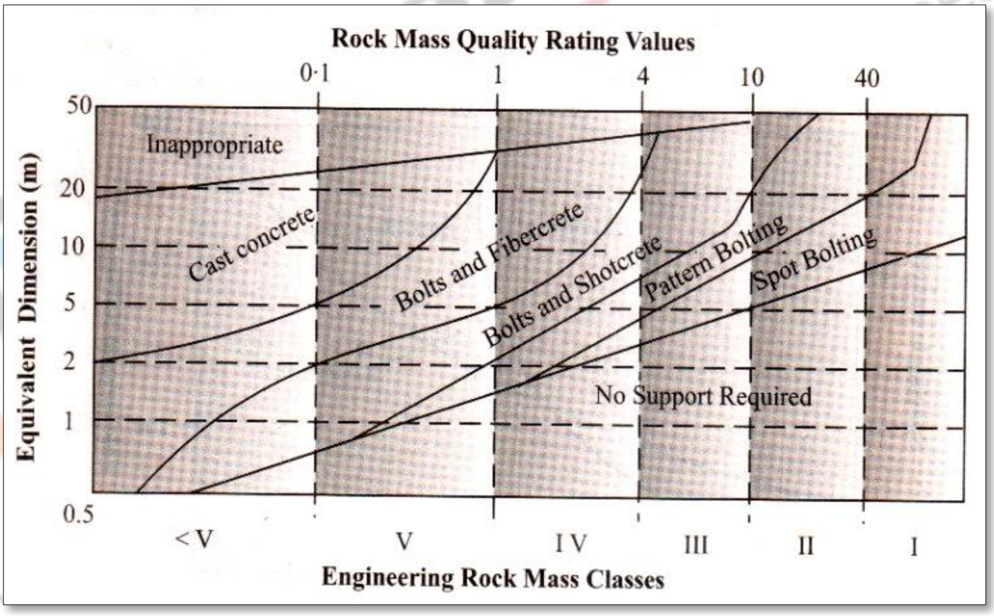

Fig. 22 shows the requirement of rock bolting, shotcreting and installation of steel ribs in different rock mass classes based on Rock mass Quality System or 'Q' rating values (Waltham, 2000).

Another way of working out the requirement of support system is to identify a parameter termed as *Equivalent Dimension* which take into consideration span of opening and purpose of excavation by a quantity called as *Excavation Support Ratio* (ESR), which reflects the safety considerations for an opening (Table 2, Fig. 23).

$$\text{Equivalent Dimension} = \frac{\text{Span}}{\text{ESR}}$$

Table 2: Excavation Support Ratio of different kinds of openings.

Excavation Category	ESR	Excavation Category	ESR
Temporary Mine Opening	3.0 – 5.0	Storage Caverns, Minor Road and Rail Tunnels, Access Tunnels	1.3 – 1.5
Vertical Circular Shaft Vertical Rectangular Shaft	3.0 – 5.0 2.0 – 3.0	Power Stations, Major Highway and Rail Tunnels, Portals, Civil Defense Chambers	1.0 – 1.2
Permanent Mine Openings, Water Pressure tunnels, Pilot Tunnels, Drifts	1.6 – 2.0	Tunnel Intersections, Railway Stations, Factories, Nuclear Power Stations,	0.8 – 1.0

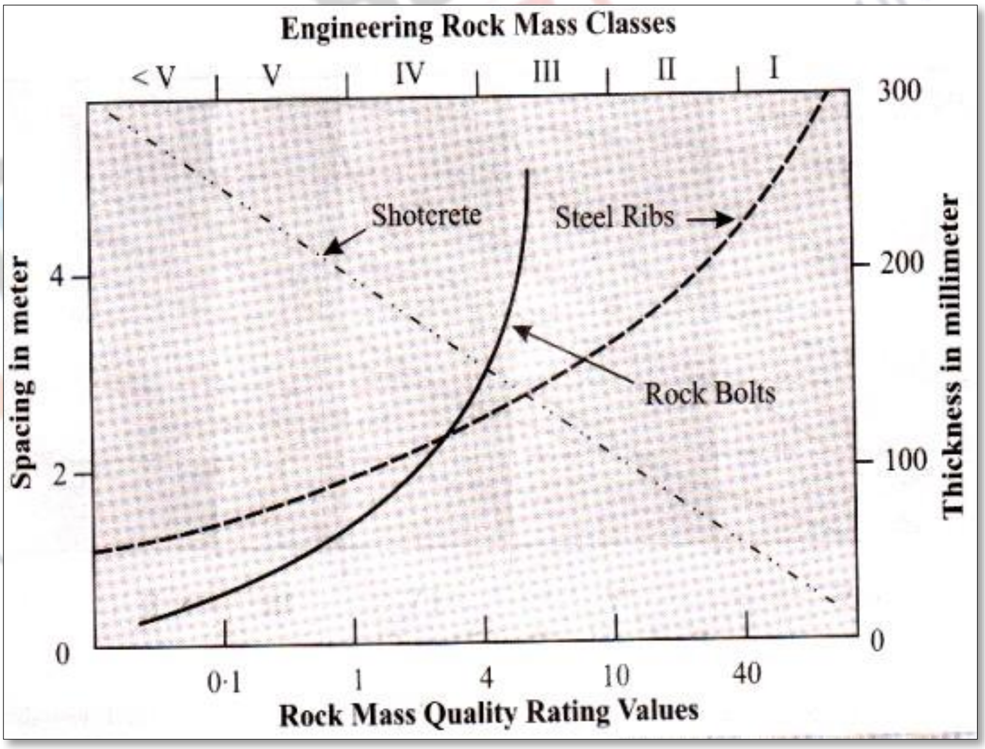

Fig. 23 A graph showing different support mechanism based on equivalent dimension in different rock mass classes based on ‘Q’ System (Waltham, 2000).

9. Problem of Over Break

The cross sectional shape and diameter of a tunnel are decided on the basis of its use and accordingly the contractor responsible for excavation is asked to proceed. The payment for excavation and concrete lining depends upon the breakage pattern. The minimum requirement of tunnel diameter as per its use and design is called as A Line or minimum concrete line. While the maximum diameter to which excavation can go is called as pay line or B Line. If breakage during excavation goes beyond B line, it is termed as Over Break and if it is less, then it is called as Under Break. The contractor is paid for B line, in case of over break he has to get it backfilled by concrete and if there is any under break then further excavation is to be done without any extra payment. After "A" line lies, the reinforcement and finished line termed as neat concrete line (Fig. 24). The thickness of concrete, between neat concrete and "B" line is usually 10 cm for every 1 m of tunnel diameter. In soft ground tunnel line "A" and "B" coincides while in hard ground it may depart from each other. If excavation is very close to proposed "B" line, it is said to have optimum break, the most economical. The over break is usually more in weak rocks, along the bedding/lamination or foliation plane, along closely spaced joints, shear and fault zones etc.

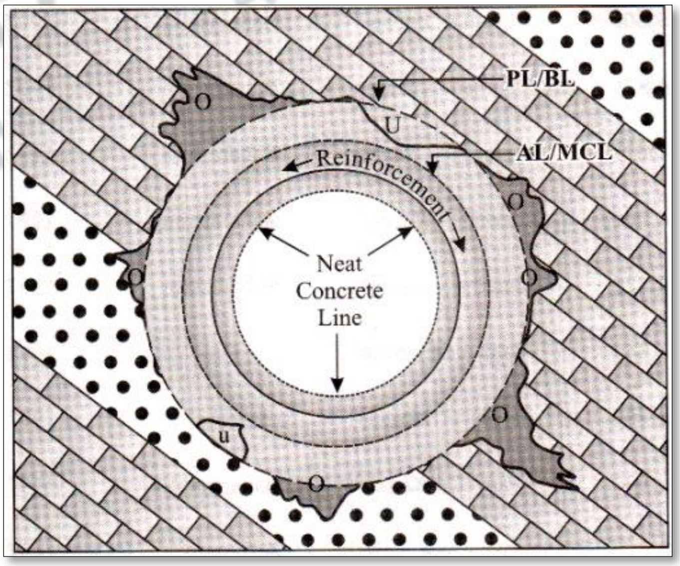

Fig. 24 The breakage pattern around a circular tunnel, over break (O), under break (U). Identify the pay line (PL / BL), PL or B line, minimum concrete line (MCL / AL) and final neat concrete line.

10. The Construction Management Aspects of Tunneling

Depending upon the tunnel length, terrain and ground condition, excavation method the whole gamut of work needs proper management of resources and time for accomplishing the task in time. Selection of proper excavation method and timely identification and installation of support plays a very important role in successful completion of tunnels. World over two main strategies are being adopted for tunnel construction known as New Austrian Tunneling Method (NATM) and Norwegian Tunneling Method (NTM) in terms of excavation, support type and time.

10.1. New Austrian Tunneling Method: In this method deformation-taking place due to excavation as "dead zone" is allowed to take place for releasing the stored and imposed stresses. However, if spalling is heavy, then temporary support in form of shotcreting and rock bolting is given to help in redistribution of stresses. This is taking into concept an idea"

"Not too stiff nor too flexible and not too early, nor too late"

10.2. Norwegian Tunneling Method: This method is based on the identification of correct behavior of rock mass and prediction of support measures. The support is installed as and when needed without allowing deformation. It monitors different section of tunnels using instruments and may install further support if required. The supports used are mainly rock bolting shotcreting, fibercreting and usage of steel ribs.

The measure of progress is termed as Rate of Tunneling, which is a function of following parameters:

(i) Selection of site and alignment, (ii) Selection of machine and men for operation and maintenance (iii) Persons with expertise and training of newly appointed personals, (iv)supervision of operation, (v) Coordination and communication amongst different units, (vi) punctuality and dedication for work, (vii) Incentives to workers and facility for their treatment in case of emergency etc. The proper working condition and management will get maximum benefit out of actual working time (AWT) on daily basis, will reduce the break down time (BDT) and will improve the tunnel advance per round (APR).

11. Some Important Tunnels of India

Name	Length (m)	Between Stations	State	Year of Commissioning	Transport Tunnel
Pir Panjal	11000	Cheril – Munda	J & K	2012	Rail
Karbude	6,506	Ukshi – Bhoke	Maharashtra	1997	Rail
Nathuwadi	4,389	Karanjadi – Diwan	Maharashtra	1997	Rail
Tike	4,077	Ratngiri – Nivasar	Maharashtra	1997	Rail
Berdewadi	4,000	Adawali – Widavali	Maharashtra	1997	Rail
Savarde	3,429	Kamathe – Savarde	Maharashtra	1997	Rail
Barcem	3,343	Balli – Canacona	Goa	1997	Rail
Karwar	2,950	Karwar – Harwada	Karnataka	1997	Rail
Chowk	2,830	Panvel – Karjat	Maharashtra	1997	Rail
Parchuri	2,628	Sangameshwa – Ukshi	Maharashtra	1997	Rail
Jawahar	2,500	Banihal – Qazigund	J & K	1956	Road
Khowai	2,472	Mungiabari – Teliamura	Tripura	2008	Rail
Sangar	2,445	Sangar – Manwal	J & K	2005	Rail
Monkey Hill	2,156	Karjat – Khandla	Maharashtra	1982	Rail
Aravali	2,100	Aravali – Sangmeshwar	Maharashtra	1997	Rail
Chiplun	2,033	Chiplun – Kamathe	Maharashtra	1997	Rail

12. Summary

Tunnels are linear opening below the ground or through natural obstacles for easy and faster transport. It can also be used as penstocks and for transporting water from reservoir to power generating unit. Drift as advance opening with much less diameter and length, Adit for underground advance exploration and to carry men and machine in to the tunnel. The vertical variants of tunnel is shaft used for ventilation in tunnels and also for transporting workers and machine to underground opening, mines etc. Underground power stations, railway stations, waste disposal sites (nuclear waste), bunkers and other strategic storage structures, involving excavation of rectangular openings termed as caverns, also require techniques of tunneling.

The alignment of a tunnel, probable support system, method of excavation, type of explosives, problem of groundwater, workability and disposal of rock waste, all need detailed geological investigation before starting the tunnel excavation or construction. The cross sectional and linear dimensions of tunnels will depend upon natural obstacles they have to go through and purpose of the tunnel and accordingly will be subjected to different kinds of geological problems.

The typical cross sections and parts are shown in figure. Most of the transport tunnels in soil have square sections and in rocks arch or horseshoe shaped sections. Water carrying tunnels are invariably circular in shape. Mostly tunnels run as single tube but twin tubes tunnels are not uncommon. The important parts of the tunnel include top most portal, while ceiling is termed as roof or back. The tunnel walls connect floor also known as invert, incorporating spring line.

The purpose of underground tunnel in soil is to ease out traffic congestion on the surface, for example Calcutta Metro, is termed as soft ground tunneling made by cut and cover method. For this a trench like opening is created of required dimension, ground foundation is laid for rail or bus roads followed by erection of wall to be covered by roof slab, followed by backfilling by the excavated soil. The cross section of such tunnels is usually square shaped. The removal of soil during excavation can pose different problems such as raveling, running, squeezing, swelling and flowing ground conditions. Groundwater incursion is a common problem especially if tunnel is excavated below the groundwater table leading to flooding of opening and stoppage of work.

Tunneling in rocks are termed as hard ground tunneling and involve different kind of mining methods. Tunnels can be excavated by mining method or by employing machines. Mining method involves drilling and blasting while machines are used for ripping and boring in rocks. The old and conventional method of making tunnel by drilling horizontal holes and blasting it with explosives either as full face in good rocks, top heading and benching in moderate strength rocks or as top heading and bench drilling in weak rocks. The stages include, marking, drilling, charging, blasting, ventilating, mucking, recuperating, supporting as one cycle of operation.

Nowadays Jumbo Machines with 2 to 5 arms are used to drill holes on the rock face as per blasting plan. A circular cut or very closely spaced drill holes are made in the center of the face so that during blasting rocks should find ready space to collapse into. Otherwise, the perimeter of the tunnel will face the brunt of blasting and will not only result into over break but also weakening of rock mass around the tunnel opening. Drilling and blasting can create noise, vibrations and may damage the rock structure depending upon the blasting power and rick mass properties leading to litigations, delay and cost escalations.

Mechanized tunneling involves machines with large sized drill bits. The important ones are Raise Borers for boring in upward direction, Shaft Borers for boring in downward direction, Road Headers and Tunnel Boring Machine (TBM) for boring in horizontal direction. The important issues are rate of tunneling, debris clearance, tunneling cost, mechanical breakdowns, wear and tear of bore heads. Road headers with rotary milling head is the best choice for small tunnels in weak to moderate strength rocks (<60 MPa UCS).The costliest of all these are TBM which are being used successfully in all kinds of rocks. However, it is economical only if tunnel length is more than a km. The rate of tunneling may vary from 10m per day in hard rocks and 30m per day in soft rocks. The rotating head may come of diameters to give 7 to 9m opening with tightest possible curve of 300m radius. The machine has inbuilt provision of providing circular concrete support made of readymade circular segments.

During excavations depending upon soft or hard ground tunneling various measures can be taken to avoid collapses. Depending upon the soil type and its texture it can be stabilized by spraying chemicals. To solve the problem of groundwater incursion pumping of water is the most viable option to lower the groundwater table well below the tunnel floor in some extreme cases soil freezing can also be applied. The most common method is to install support instantaneously during the excavation. The traditional support method include timber frame sets comprising of accessories such as cap, post, sill, lagging, breasting soldier, raker etc. Wooden support system are being replaced by steel ribs, struts and posts, for circular water pressure and arched and semi-circular cross sections of vehicular tunnels. The spacings of these support elements will depend upon soil and rock mass conditions.

Roof bolting is also a common method to stabilize and hold the dead zone of loosened rocks in to some firm strata lying above the back. For local spalling individual bolts and for supporting large section of tunnel pattern bolting is provided. The bolting can be done by drilling holes and by placing bolts with a wedge at far end by hammering. Different types of bolts are in use and the size, numbers and spacings will depend upon the rock mass conditions. Most of the bolts are 2-5 m long drive in 35-45 mm holes and can take load up to 100 kN. The Expansion Shell bolt is the most used, takes immediate load and is cheap. The Grouted bolt is fixed with the help of resin or cement and is strongest. Swellex bolts are made of deformable steel tube which can be expanded in hole by applying 30 MPa water pressure. The advantages of roof bolting include supporting of roof immediately adjacent to working face, prevent rock slippage, provide much needed arch action, remain firm during vehicular movement allows proper ventilation and better clearance in the opening as compared to steel support. It is also used as advance ground improvement by installing rock bolts by 100 in spilling fashion from the tunnel perimeter.

Sometimes, for giving immediate support to loosened rocks due to blasting or to prevent spalling of jointed rocks Shotcrete and Fibercrete are applied. Depending upon the thickness of weak zones concrete 20 to 200 mm thick is sprayed under pressure at the rate of 5 to 15 m3/h onto the back and wall of tunnel. It can also be applied with reinforcement comprising welded steel mesh. For weaker and heavily jointed rocks, 50 to 80 kg of steel fibres with lengths 40 to 50 mm is added to per cubic meter of concrete. After providing initial support precast concrete segments called, Cast-in-Place concrete are installed as final lining and support. Apart from correcting irregularities of excavation, it provides sound foundation for tunnel finishing. A water proofing system between the initial support and cast in place concrete is invariably provided to protect it from corroding water. TBMs also have provision of installing these precast concrete segments.

The excavated material is called as muck and its removal is called as mucking. Rocks too offer different tunneling conditions starting from intact ground with sound rocks, not requiring any support to stratified, jointed, blocky, crushed, swelling and squeezing rocks, requiring different kinds of tunneling operations and support mechanism based on the dead load. The tunneling operation in rocks have their own set of problems, termed as spalling, popping, blowouts, bumping, squeezing and swelling ground conditions. Many of the above mentioned problems are due to pressure relief phenomena, related to stresses stored in the rocks due to overburden and tectonic stresses present in that region. Groundwater seepage is common in rocks also, which may delay the work. During excavation under and over break with respect to pay line is also an issue, which leads to litigation.

As tunnels are made either below the ground or through the hills. In both the cases, it will be loaded by overlying rocks depending upon the topography running over them. Presence of inter mountain valleys with stream or with groundwater will have added problem of water seepage. The tunnel through the mid of the hill will have maximum length as compared to tunnels passing close to the slope. However, tunnels close to the sloping surface will face problems related to weathered rock mass. The problem of mass movements and landslides may also cause problem.

The important geological factors to be taken into consideration are related to rocks, structure, groundwater etc. For this, preliminary surveys are made to make geological profile along the central line of the tunnel. Most of these surveys are carried out on the ground surface and are projected downward at tunnel level. The accuracy of geological survey and geological intricacies of a particular area will decide how correct the projections are. Drilling may be used to check these projections and also to know the ground water conditions. But still during excavations many unforeseen situations may crop up and take one by surprise and appropriate decision be taken then and there.

Igneous rocks will be the best bet as for as construction of safe tunnel is concerned. As they are very large rock bodies in three dimension, a tunnel may remain in single rock i.e. granites especially if they are not profusely jointed. Volcanic rocks showing flowage plains, cavities, vesicles and interbedded volcanic ash should be thoroughly investigated and proper measures should be taken. Non-foliated metamorphic rocks will show behavior similar to massive igneous rocks. Foliated metamorphic and sedimentary rocks are comparatively weak and need proper attention in terms of their treatment and requirement of support.

The weathering state of rocks will depend upon its age and climatic setup of the area. Usually rocks of Archaean and Proterozoic ages are highly weathered as they have been subjected to multi-phase deformation, repetitive and long-term exposure to varying weather and climate through time. The rocks exposed in regions of temperate and humid tropical climate will show high degree of weathering. The effect of weathering will be more near the outer surface of the slope and will diminish with depth. Hence, tunnel closer to the topographic surface will face problems related to water seepage and of mass movements, especially in layered rocks. Even, massive and strong rocks may have thin weathered mantle, which may fall as scree and may also have problem of water seepage. In this case, tunnel portals are to be protected and should be lined. In the case of stratified rocks the orientation and thickness of rocks in relation to the tunnel alignment plays a very important role especially in redistributing the stresses created during excavation. The horizontal rocks or rocks dipping by less than 100 with thickness more than the height of the tunnel then the whole tunnel will remain in same rock and will fair good due to 'roof effect', as loading of tunnel back will also remain same all through its width and length. In the case, rock thickness is less than the tunnel height then more than one rock will run through the tunnel. In such cases, the tunnel should be placed or designed to have its back in the strongest rock. The vertical rocks may get disposed in three different fashion with respect to tunnel alignment. First case, strike parallel to tunnel length, second case, perpendicular to tunnel length and third case some angular relationship of strike with tunnel length. The most important fact about all above cases is that rocks are going to load back of the tunnel heavily, a non-ideal situation essentially requiring proper strengthening and support. The thickness again will play an important role especially in the first case where thickness may be more than the width of the tunnel. In second case, the chances of having more than one rock bed will be high, wherein the rock thickness is more than the length of the tunnel. The third case will have rock disposition in between the two extreme cases.

The inclined rocks will show varied nature of disposition depending upon its strike and dip with respect to tunnel alignment. The rocks may strike parallel to tunnel length and may dip towards right or left flank of the tunnel. The load concentration due to in coming rocks will be either in right or left side of the tunnel which need to be taken into account in tunnel design especially the tunnel wall in which the rocks are day lighting.

If the rocks are striking perpendicular to the tunnel length then the rocks will dip either towards or away from the tunnel entry. The loading of the tunnel back will be in inclined fashion and will affect the back of the tunnel. Different problems may arise depending up on the excavation of the tunnel with the dip or against the dip. The excavation with the dip is easier and safer as compared to against the dip. The rocks dipping obliquely to the tunnel length will not only load the tunnel back but also the tunnel wall. The loading will be eccentric and will vary according to the angle of dip i.e. low angle dip will have lesser effect as compared to high angle dips.

A rock sequence through which tunnel is proposed may be folded, faulted and sheared, not to talk of joints, as they are ubiquitous. The presence of folds or faults or both, will not only result in repetition and omission of rocks but will bring in many other issues and problems.

The construction of tunnels will be effected by attitude of folding with respect to tunnel length and width. Depending upon the thickness of rocks and wavelength of folding repetition of rocks will take place and rocks will be loaded differently across and along the tunnel length. In the case of fold axis running parallel to the tunnel length, the tunnel may run through either anticline or syncline. The anticline will provide natural arching and may not at all load the tunnel back, an ideal condition, provided width of anticline is more than the width of the tunnel. In the case tunnel is going through the syncline the whole load will come on the tunnel back, a non-ideal condition. Apart from this, it has been found that rocks in anticlinal zone are heavily jointed due to presence of tensile stress regime as against synclinal zone, which remains under compressive stress regime. Hence, driving a tunnel will be easier along the anticlinal zone as compared to synclinal zone but support requirement may be more in anticlinal as compared to synclinal zone. Another issue is related to groundwater seepage along the folded layers; the water will move away from the tunnel in case of anticlines and will move into in the case of synclines. It is suggested that if the rocks involved in folding are thick enough then the best option is to have tunnel in a limb between the anticline and syncline. If the tunnel length is perpendicular to the fold axis then depending upon its wavelength one or more than one, anticline and syncline may come across with varying loading and unloading options. Fold axis running diagonally to the tunnel length will have different force pattern.

Faults coming along the tunnel should be identified in terms of its type, disposition with reference to tunnel length and its active or dead nature. The faults along which some movement or any earthquakes have been reported in recorded history of that region will be helpful in discerning its nature. Specialized geological and geophysical studies (radioactive and thermo-luminescence dating), can also be employed to work out the antiquity of a fault. Faults lying in regions of Seismic Zone IV to V, such as Himalayan Mountain System should be seen with caution and tunnel alignment may be changed to avoid if it is going through known active faults. Even if a fault is dead then too, tunnel should cross a fault in perpendicular fashion because fault making lesser angle or becoming parallel to tunnel axis, will result into its run all along the tunnel, thus making it unsafe. The presence of crushed material along the fault or fault zone (gouge/mylonites/breccia), being weak will result in high over break and may need concrete back filling. The crushed zone may also act as medium for groundwater storage or if extended up to the earth surface then rain and surface water may percolate along it resulting into permanent seepage to water gush during excavation leading to flooding of the tunnel. Dewatering prior to excavation, proper sealing and grouting are the options to solve this problem. If a tunnel is running near the fault plane then the best option is to have it on foot block.

The joints in rock mass through which tunnel is to be bored are going to play the most important role as their presence is assured. The number of joint sets per unit area and their attitude controlling block size and shape, their length and depth persistence, opening and asperities of the joint plane as well as alteration along them etc. are going to be the most important factor which will not only control the engineering behavior of the rock mass but also decide the approach to tunneling operation. Based on strength of rocks, joint incidence and their nature Rock Mass Quality or "Q" System classification, of rock mass can be used to predict rock mass behaviour and required support.

Depending upon the tunnel length, terrain and ground condition, excavation method the whole gamut of work needs proper management of resources and time for accomplishing the task in time. The measure of progress is termed as Rate of Tunneling which is a function of following parameters:(i) Selection of site and alignment, (ii) Selection of machine and men for operation and maintenance (iii) Persons with expertise and training of newly appointed personals, (iv) supervision of operation, (v) Coordination and communication amongst different units, (vi) punctuality and dedication for work, (vii) Incentives to workers and facility for their treatment in case of emergency etc. The proper working condition and management will get maximum benefit out of actual working time (AWT) on daily basis, will reduce the break down time (BDT) and will improve the tunnel advance per round (APR).

Frequently Asked Questions-

Q1. List different underground structures and their purpose?

Ans. The underground structures can be classed as linear and rectangular openings as part of infrastructure. Of these tunnels are element of transport below the ground to ease out traffic congestion or to make route shorten through natural obstacles. The other horizontal variants of tunnels include water pressure tunnel, used for carrying water from reservoir to power generating unit, adit or drift for underground exploration or as half tunnel to act as underground by pass, Chunnel or subaqueous tunnel or bridge. Its vertical variants such as shaft and raise are used for taking men and machine in underground mines and also to provide ventilation for all kinds of underground openings. Underground mining also requires tunneling technology and many times tunnels and shafts are an important parts of it. Underground power stations, railway stations, nuclear waste disposal sites, bunkers and other strategic storage structures, involving excavation of rectangular openings termed as caverns etc. are also underground structures and require through geological and geotechnical explorations similar to tunnels.

Q2. What are the different types and parts of traffic tunnels?

Ans. The traffic tunnels are made for roads, rails through natural obstacles and also as underground passage for rails to ease out traffic congestions. Some of these tunnels are one-way tunnels i.e. having paired tubes. The traffic tunnels usually have simple arch and horseshoe shape cross sections. The tunnels made in unconsolidated medium usually have square cross section. The top most mast of the tunnel is called as portal, as seen from inside the ceiling is called as roof or back of the tunnel. The tunnel sides are its walls and the bottom ground is termed as floor or invert. The line where arch meets the wall is called as spring line.

Q3. Write a short account of different methods of tunneling and problems associated with them?

Ans. The tunnels are made in soil as mostly through rocks. The tunnel in soil is made by *cut and covers* method, and is termed as *soft ground tunneling*. For this a trench like opening is created of required dimension, ground foundation is laid for rail or bus roads followed by erection of wall to be covered by roof slab and finally the sides and top is filled back by the soil. The cross section of such tunnels is usually square shaped. Tunnels in rocks, as subsurface tube or through natural obstacles are termed as hard ground tunneling and involve different kind of mining methods. The excavated material is called as muck and its removal is called as mucking. The typical cross sections of tunnels through rocks have arch or horseshoe shaped. Water carrying tunnels are invariably *circular* in shape.

The problems encountered during soft ground tunneling are as follows:

Ravelling Ground –falling of chunks or pieces of materials from top and sides.

Running Ground–slippage of dry and less compacted gravel and coarse sand from sides.

Squeezing Ground -Moist soil slowly moving into opening as plastic material from sides and top.

Swelling Ground - Soil moving in due to swelling of clays when they absorb water without getting detached to main mass.

Flowing Ground - Wet saturated soil flowing as slurry in excavated opening.

Groundwater Incursion - If tunnel is excavated below the groundwater table then groundwater may start seeping.

Similarly, there are problems in rock tunneling such as:

Spalling Ground - Falling of rock pieces and chunks from the exposed back and walls.

Popping Ground - Sudden projection of rocks into opening.

Blowouts – sudden detachment of rocks and forceful flying rocks in the tunnel opening.

Bumping Ground - Also termed as rock bursts resulting into local tremors with sound.

Squeezing Ground - Movement of rock mass as creep and heaving.

Swelling Ground - Volume expansion in opening of moist rocks rich in clay.

Groundwater Incursion - Seepage of surface water or groundwater.

Under and Over break – Breakage of rocks less or more than what is required.

Many of the above-mentioned problems are due to *Pressure Relief Phenomena*, which is related to stresses stored in the rocks caused by overburden rocks, and/or current tectonic stresses present in that area. These stresses, as such are not capable of inflicting any deformation but when an opening is created the residual or stored stresses tend to realign and get released by popping, blowouts, bumping and squeezing phenomenon.

Q4. What are the different geological conditions affecting construction of tunnels?

Ans. For tunnels along road or railways, the geology along the route alignment plays an important role. The important geological factors to be taken into consideration are related to rock type, structure, groundwater etc. For this, preliminary surveys are made to make geological profile along the central line of the tunnel. Drilling cores can then be used to verify conditions.

Igneous rocks are best bet as for as construction of safe tunnel is concerned. As they are three dimensionally large rock bodies, hence the chance is that a tunnel may remain in single rock. Volcanic rocks showing flowage plains, cavities, vesicles and interbedded volcanic ash etc., should be thoroughly investigated. Non-foliated metamorphic rocks will show behaviour similar to massive igneous rocks. Foliated metamorphic and sedimentary rocks are comparatively weak and need proper attention in terms of their treatment and requirement of support. The weathering state of these rocks will also play an important role in excavation and also controlling the mass movement around the tunnel. The severity of weathering will be more near the outer surface of the slope and will diminish with depth.

In the case of stratified rocks the orientation and thickness of rocks in relation to the tunnel alignment plays a very important role especially in redistributing the stresses created during excavation. The *horizontal* rocks or rocks dipping by less than 10^0stresses created during the excavation. If the rocks are horizontal, with thickness more than the height of the tunnel then the whole tunnel will remain in same rock and will fair good due to '*roof effect*', as loading of tunnel back will also remain same all through its width and length. In the case, rock thickness is less than the tunnel height then more than one rock will run through the tunnel. The *vertical* rocks may be found in three different fashion with respect to tunnel alignment. First case, striking parallel to tunnel length, second case, perpendicular to tunnel length and third case some angular relationship of strike with tunnel length. The most important fact in vertical rocks in all the three conditions is that rocks will load back of the tunnel heavily, a non-ideal situation essentially requiring proper strengthening and support. The thickness again will play an important role especially in the first case where thickness may be more than the width of the tunnel. In second case, the chances of having more than one rock bed will be high because it is common to have rock thickness less than the tunnel length. The third case will have rock disposition in between the two extreme cases.

The *inclined* rocks will show varied nature of disposition depending upon its strike and dip with respect to tunnel alignment. The rocks may strike parallel to tunnel length and may dip towards right or left flank of the tunnel (Fig. 16 a, b). The load concentration due to in coming rocks will be either in right or left side of the tunnel which need to be taken into account in tunnel design especially the tunnel wall in which the rocks are day lighting.

If the rocks are striking perpendicular to the tunnel length then the rocks will dip either towards or away from the tunnel entry. The loading of the tunnel back will be in inclined fashion and will affect the back of the tunnel. Different problems may arise depending up on the excavation of the tunnel with the dip or against the dip. The excavation with the dip is easier and safer as compared to against the dip. The rocks dipping *obliquely* to the tunnel length, will not only load the tunnel back but also the tunnel wall. The loading will be eccentric and will vary according to the angle of dip i.e. low angle dip will have lesser effect as compared to high angle dips.

A rock sequence through which tunnel is proposed may be folded, faulted and sheared, and jointed. The presence of folds or faults or both, will not only result in repetition and omission of rocks but will bring in many other issues and problems. The construction of tunnels will be effected by attitude of folding with respect to tunnel length and width. Depending upon the thickness of rocks and wavelength of folding repetition of rocks will take place and rocks will be loaded differently across and along the tunnel length. If the tunnel length is perpendicular to the fold axis then depending upon its wavelength one or more than one, anticline and syncline may come across with varying loading and unloading options. Fold axis running diagonally to the tunnel length will have different force pattern. Faults coming along the tunnel should be identified in terms of its type, disposition with reference to tunnel length and its active or dead nature. The faults along which some movement or any earthquakes have been reported in recorded history of that region will be helpful in discerning its nature. Faults lying in regions of Seismic Zone IV to V, such as Himalayan Mountain System should be seen with caution and tunnel alignment may be changed to avoid if it is going through known active faults. Even if a fault is dead then too, tunnel should cross a fault in perpendicular fashion because fault making lesser angle or becoming parallel to tunnel axis, will result into its run all along the tunnel, thus making it unsafe.

The presence of crushed material along the fault or fault zone (gouge/mylonites/breccia), being weak will result in high over break and may need concrete back filling. The crushed zone may also act as medium for groundwater storage or if extended up to the earth surface then rain and surface water may percolate along it resulting into permanent seepage to water gush during excavation leading to flooding of the tunnel.

The joints in rock mass through which tunnel is to be bored are going to play the most important role as their presence is assured. The number of joint sets per unit area and their attitude controlling block size and shape, their length and depth persistence, opening and asperities of the joint plane as well as alteration along them etc. are going to be the most important factor which will not only control the engineering behaviour of the rock mass but also decide the approach to tunneling operation. Based on strength of rocks, joint incidence and their nature Rock Mass Quality or “Q” System classification, of rock mass can be used to predict rock mass behaviour and required support.

Q5. What are the different types of support measures?

Ans. During excavations depending upon soft or hard ground tunneling various measures can be taken to avoid collapses. Depending upon the soil type and its texture it can be stabilized by spraying chemicals. The most common method is to install support instantaneously during the excavation. The traditional support method include *timber frame sets* comprising of accessories such as *cap*, *post*, *sill*, *lagging*, *breasting soldier*, *raker* etc.

Wooden support system was then taken over by steel *ribs*, *struts* and *posts* for circular water pressure and arched and semi-circular cross sections of vehicular tunnels. The spacings of these support elements will depend upon soil and rock mass conditions.

Roof bolting is also a common method to stabilize and hold the dead zone of loosened rocks in to some firm strata lying above the back. For local spalling individual bolts and for supporting large section of tunnel pattern bolting is provided. The bolting can be done by drilling holes and by placing bolts with a wedge at far end by hammering. Different types of bolts are in use and the size, numbers and spacings will depend upon the rock mass conditions. Most of the bolts are 2-5 m long drive in 35-45 mm holes and can take load up to 100 kN. The *Expansion Shell* bolt is the most used, takes immediate load and is cheap. The *Grouted* bolt is fixed with the help of resin or cement and is strongest. *Swellex* bolts are made of deformable steel tube which can be expanded in hole by applying 30 MPa water pressure.

The advantages of roof bolting include supporting of roof immediately adjacent to working face, prevent rock slippage, provide much needed arch action, remain firm during vehicular movement allows proper ventilation and better clearance in the opening as compared to steel support. It is also used as advance ground improvement by installing rock bolts by 10^0 in spilling fashion from the tunnel perimeter.

Sometimes, for giving immediate support to loosened rocks due to blasting or to prevent spalling of jointed rocks *Shotcrete* and *Fibercrete* are applied. Depending upon the thickness of weak zones concrete 20 to 200 mm thick is sprayed (*shot*) under pressure at the rate of 5 to 15 m^3/h onto the back and wall of tunnel. It can also be applied with reinforcement comprising welded steel mesh. For weaker and heavily jointed rocks, 50 to 80 kg of steel fibres with lengths 40 to 50 mm is added to per cubic meter of concrete.

After providing initial support precast concrete segments called, *Cast-in-Place* concrete is installed as final lining and support. Apart from correcting irregularities of excavation, it provides sound foundation for tunnel finishing. A water proofing system between the initial support and cast in place concrete is invariably provided to protect it from corroding water. TBMs also have provision of installing these precast concrete segments.

Multiple Choice Questions-

1. The vertical irregular underground opening is called as

(a) Shaft
(b) Raise
(c) Stopes
(d) Adit

2. The free fall of loose soil material during excavation is termed as

(a) Squeezing
(b) Ravelling
(c) Running
(d) Flowing

3. The breakage of rocks with tremors in hard ground tunneling is known as

(a) Blowouts
(b) Spalling
(c) Bumping
(d) Popping

4. The best part of a fold to make tunnel is

(a) Limbs
(b) Synclinal Axis
(c) Anticlinal Axis
(d) Hinge

5. The concept of "Dead Zone" has come from

(a) "Q" System
(b) Rock Load Theory
(c) NATM
(d) NTM

Suggested Readings:

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