GUIDELINES
FOR
ROAD TUNNELS

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1 INTRODUCTION

The Road Tunnels Committee (H-7) of the IRC was constituted in August 2006. The Personnel of the H-7 Committee are as under:

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Vidwans, R.M.	Co-Convenor
Mahale, J.G.	Member-Secretary

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Secretary General, IRC	(Indoria, R.P.)

This is the first time that such guidelines are being prepared for Road Tunnels in the country by the IRC. Therefore, the Committee in its first meeting held on 18th Oct, 2006 discussed the scope as suggested by IRC and decided upon various topics to be taken up by the members. The Committee had several meetings and prepared a draft for consideration of Highway Specification and Standards (HSS) Committee. The draft was placed before the Highway Specification and Standards (HSS) Committee on 1st May, 2010, wherein some comments were offered for incorporation.

The revised draft incorporating the comments of the Highway Specification and Standards (HSS) Committee was presented before the Council in its 191st meeting held on 22nd May, 2010 at Munnar (Kerala). The document after discussion was approved by the Council for printing as a publication of IRC. The valuable contributions of the members of the Road Tunnels Committee (H–7) and suggestions of members of Highway Specification and Standards (HSS) Committee and Council members are hereby acknowledged.

1.1 Tunnels are introduced into the road system in mountainous terrain to negotiate mountain ranges and reduce the road length. The tunnels may also be introduced to avoid passage through snow bound areas or pass below sea, creeks and rivers or even to cross thickly populated urban areas etc. A road tunnel may also be considered in open country on environmental grounds to protect areas of ecological interest. The fundamental objective of road tunnel is to ensure safe transit of the road traffic in difficult terrain.

1.2 The decision to introduce a tunnel in a road system largely depends upon the cost benefit ratio, traffic volume, category of road etc. Cost of Tunnelling is much more than that of open excavation. The tunnel cost is mainly dependent on topography, geology and access. For expressways and high density corridors passing through mountain ranges the option of tunnel is generally more economical considering life-cycle cost and overall saving for the traffic using the shorter route.

1.3 The planning, design and construction of a road tunnel is a complex inter-disciplinary task and requires expertise in different fields. The planning and design involves site investigation, physical planning, conceptual design and detailed design with due consideration for construction methods. All these aspects, construction methods, lighting and ventilation, safety and operation and maintenance are dealt with in further sections.

1.4 Terminology: **Annex-A** contains definitions of terms that relate to planning, design, construction and operation and maintenance of road tunnels.

1.5 Classification of Road Tunnels

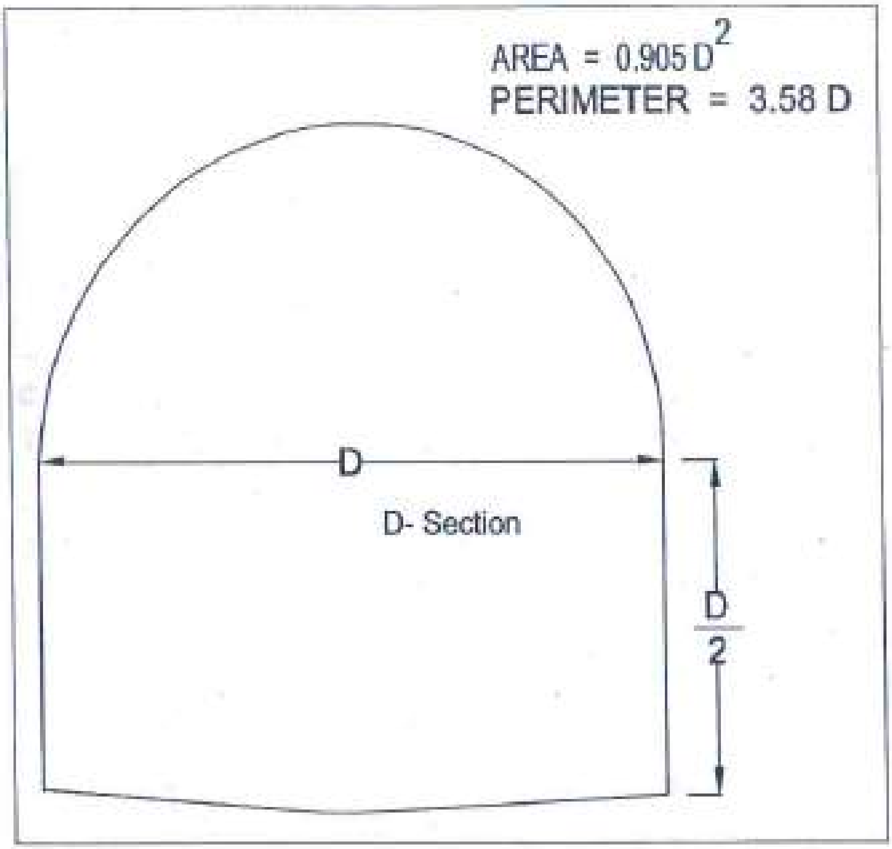
1.5.1 *Location wise*

- Underground Tunnels: These are subterranean structures constructed by Tunnelling methods.
- Underwater Tunnels: These are tunnels constructed by Tunnelling methods below the bed or by placing precast segments/tubes, below water bodies.
- Cut and Cover Tunnels: These are ducts constructed in open pits with the space outside the ducts back-filled to original ground level.

- Over ground Tunnels: Ducts constructed over the ground for protecting roads in landslide/avalanche areas.

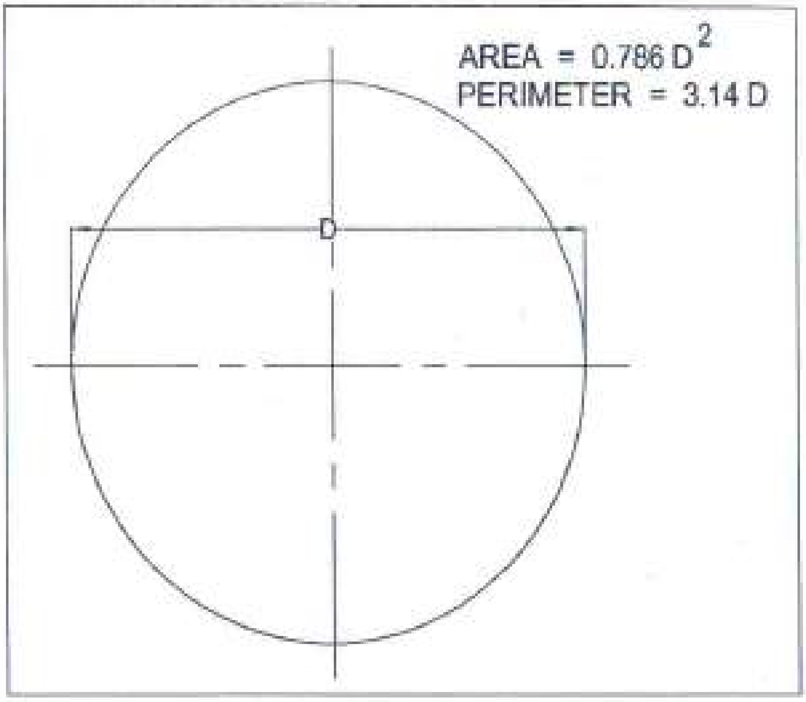
1.5.2 *Shape wise*

- 'D' Section: 'D' sections are most suitable for transportation tunnels. The flat invert of 'D' shape greatly facilitates construction. However, this section is not suitable for tunnels in soft ground.

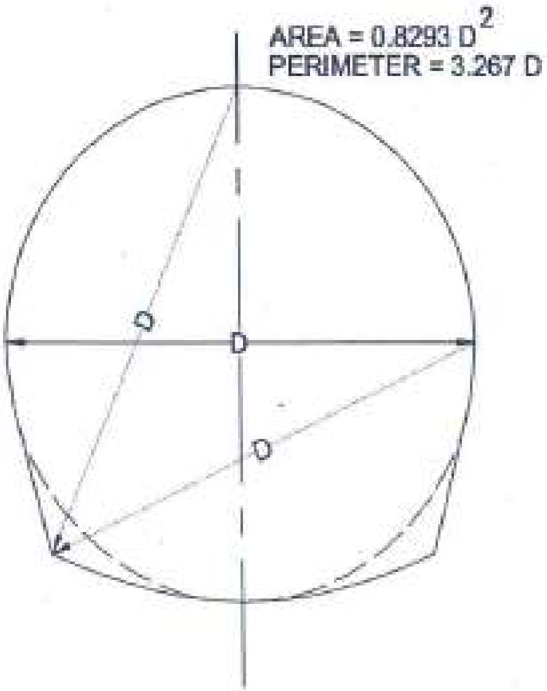


- Circular Section: Circular sections are structurally the best and are commonly used for underwater tunnels, tunnels through soft ground and for tunnels excavated with tunnel boring machines.

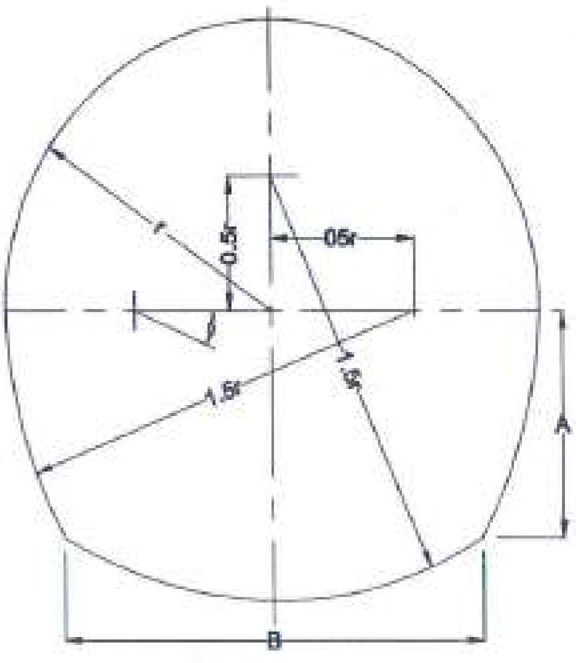
- Horseshoe Section: Horseshoe and Modified Horseshoe sections are a compromise between 'D' Section and Circular Section and have added advantage for accommodation of utility services, better head room, etc.



Circular Section

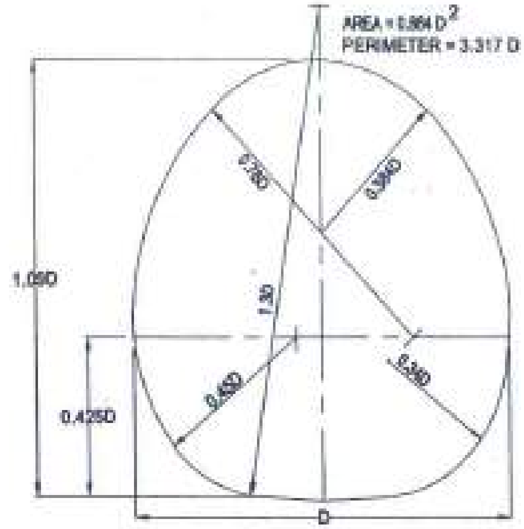


Horseshoe Section

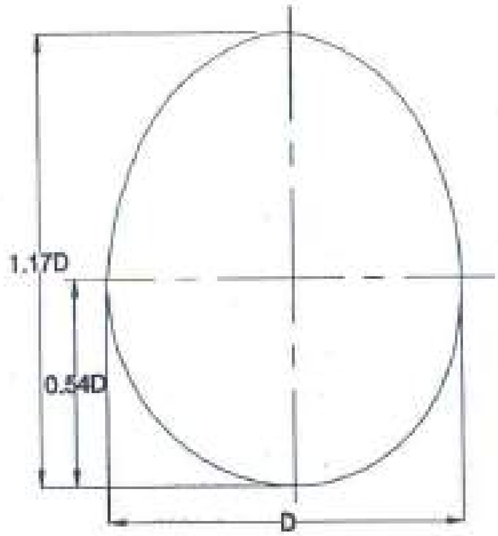


Modified Horseshoe Section

- Egg Shaped Sections: Egg shaped and egglipse sections are best suited for sewerage tunnels because of their hydraulic properties. They are also used for road tunnels with high vertical pressure.



Egg Shaped Section



Egglipse Section

1.5.3 *Construction method wise*

- Drill and Blast Method: This method is suitable in medium and hard strata. It is also adopted where excavation with machines like TBM, Road Headers etc becomes unfeasible due to very high strength of rock.
- No-Blast Excavation: This method mainly envisages the use of Tunnel Shields, Road Headers and Tunnel Boring Machines (TBM). These techniques are suitable for various strata, to avoid vibrations and for faster progress.

1.5.4 *Length wise*

- Short tunnels: Up to 500 m length
- Medium tunnels: Over 500 m to 1500 m length
- Long tunnels: Over more than 1500 m length

(**NOTE:** For classification of tunnels on length basis for Expressways refer para 6.2 of "Guidelines for Expressways VOL II: DESIGN")

1.5.5 *Side coverage wise*

- Full Tunnel: Where side cover is adequate and full section tunnel is possible.
- Half Tunnel: Where side cover is inadequate on valley side for full section.

1.6 Distinctive Features of Tunnelling

Following distinctive features of Tunnelling shall be kept in mind while planning and designing,

- Space inside tunnel is limited and therefore calls for use of specially designed plant and equipment.
- Due to space limitations and linear nature of work, not many operations can be carried out simultaneously, particularly at the tunnel face. Delay caused at any stage gets carried through and can rarely be made up
- Conventional methods of Tunnelling are normally with cyclic drilling and blasting.
- Adequate ventilation and lighting need to be provided during construction.
- Even in the compact and hard rock, possibility of meeting jointed and weak zones, leading to accidental rock falls can not be ruled out. A tunnel can pass through complex geological formations wherein adverse geological occurrences like rock bursting, squeezing, swelling, sudden ingress of water, emission of inflammable, poisonous & noxious gases and high geothermic zones could be encountered.
- Urban tunnels pass below populated areas and built-in structures where surface subsidence and ground vibrations are of paramount consideration.
- Non-urban tunnels could pass below reserved forests containing flora and fauna. It would therefore be necessary to ensure that Tunnelling techniques chosen are such that disturbance and damage to environment is avoided or at least minimized.
- Efficient Tunnelling calls for a good understanding and appreciation of the geological aspects. Modern techniques call for the application of the right amount of appropriate supports applied at the optimum time, based on sound understanding of geology and rock mechanics.
- Tunnelling is essentially a hazardous operation and appropriate Health, Safety and Environmental measures must be implemented.

1.7 Open Cut vis-a-vis Tunnel Option

Tunnelling is an expensive process. Cost of tunnel excavation is several times more than that of open excavation. However, deep open cuts are associated with problems of land acquisition, landslides and impose maintenance problems during operation, whereas properly designed and constructed tunnels do not pose such problems.

In view of these aspects of cost and maintenance, generally for non-urban tunnels, it is preferable to restrict depth of open cuts to about 20 m to 30 m. Beyond this depth the tunnel option is economical. These considerations need to be reviewed on the basis of local ground conditions, geology and cost-benefit analysis.

2 PLANNING OF ROAD TUNNELS

2.1 Planning and design of road tunnels require adequate investigations and studies, as underground structures are always associated with a lot of uncertainties. It is preferable to carry out studies as listed below. Most of these investigations or studies can be parallel activities.

2.2 Assessment of Functional Requirements

The starting point of planning of road tunnels is the Traffic Study which identifies the volume and nature of traffic likely to be generated over the design life of the connecting road network. The study also identifies the complexion of traffic i.e. number and types of vehicles likely to use the tunnel and the design speed of traffic. The number of traffic lanes required to be provided shall be decided, taking into account the outcome of the traffic study. The need for footpaths/walkways and their widths shall also be decided at this stage, particularly for urban tunnels. The minimum vertical clearance shall be decided taking into consideration the local regulations and the height of loaded vehicles likely to pass through the tunnel. Based on the traffic studies, preliminary design of ventilation system and tunnel lighting shall be carried out. The preliminary design of the side drains, which are generally located under the walkways meant for pedestrians/maintenance personnel, shall also be carried out taking into consideration the quantity of rainwater/seepage water likely to pass through the drains.

2.3 Conceptual Planning

The study of topo-sheets and maps of the area shall be carried out. Possible alternative accesses to the tunnels shall be conceived, taking into account natural topography of the area. In populated area, many existing alternative accesses would be available. From various alternative options the access to be considered shall be one which causes the least disturbance to existing structures, infrastructure, etc. The alternative alignments shall be marked on the topo-sheets and maps/drawings. From the contours longitudinal sections along the alignment shall be prepared and grades and levels of tunnels and probable locations of tunnel portals plotted thereon.

2.4 Rough Setting-out of Alternative Layouts at Site and Reconnaissance Survey

The topo-sheets and available maps of the area may not be up-to-date and may not exactly indicate the present position in respect of structures, roads, service lines, etc. For verification of the actual situation at the site, alternative conceptual layouts shall be roughly set out at the site and reconnaissance survey of the area shall be carried out. Salient features of the area and local constraints such as habitation, structures, power transmission lines, pipelines, local roads etc. shall be noted and marked on the topo-sheets/drawings. The feasibility of creating access roads for construction work, if not already existing, shall also be examined. Necessary adjustments and realignments in the layout of the conceptual alternatives shall then be made so as to avoid or minimize disturbance to existing structures, monuments etc.

2.5 Preliminary Assessment of Geo-technical Conditions

As described in detail in a subsequent section entitled "Geo-technical Investigations", data regarding general geology of the area as available with Geological Survey of India and similar organizations of the State Government shall be collected. After setting out of the conceptual alignments of the tunnel on the ground, geological mapping of the area shall be carried out. Taking into account general geology of the area and the data collected during geological mapping, preliminary assessment of geotechnical conditions that are likely to be met with along the conceived alternatives shall be made in the form of a proper report. A detailed geological investigation followed by adequate rock mechanics assessment eliminates surprises and design inaccuracies which could result in cost escalation and time over run.

2.6 Assessment of Impact on Environment

The assessment of impact on environment during construction and subsequent operation of the tunnels shall be carried out for each alternative alignment by availing of services of experts. A typical Environment Management Plan for various issues pertaining to the tunnel project is appended as '**Annex-B**'. Disposal of excavated muck is one of the major environmental issues to be dealt with in Tunnelling project. In order to address this issue adequate and suitable land for dumping muck excavated from the tunnel and open approach cuts shall be identified and acquired.

2.7 Assessment of Socio-Economic Impact

Assessment of socio-economic impact of the tunnels during operational stage shall be carried out beforehand for each alternative alignment availing the services of experts. Factors to be considered in this process would be resettlement, better access, cost saving, effect on the social and economic welfare of the community and connected issues.

2.8 Geometrics of the Tunnel

2.8.1 The geometry of the tunnel is a very important aspect of tunnel design. The main objective of road tunnel design is to ensure safe transit of traffic for which the facility is designed, at least cost. The safety of traffic depends upon the geometrics of tunnel i.e. its cross section, gradients and curvature. Generally a tunnel shall maintain the same geometrical standards as on the adjoining carriageways in the open air outside the tunnel. Where geometry is confined, such restriction shall commence at least 150 m from the entrance of the tunnel along with speed restrictions.

2.8.2 *Cross-section of the tunnel*

The cross section of a tunnel mainly depends upon projected traffic volume, provision of ventilation system (if any), geology of area and provision for pedestrian traffic, particularly in urban areas. Considering the geotechnical conditions likely to be met with, the traffic volume and functional requirements as given in Table 1 below, the most economical section shall be selected. The finished width of a tunnel depends upon the number of traffic lanes required considering future projected traffic and the number and width of the footpaths / walkways, kerbs, crash barriers and drains required to be provided.

2.8.2.1 *Width of the tunnel*

The lane width of 3.5 m (3.75 m for Expressways) shall be kept for highway tunnels. However, for urban areas the lane width may be reduced to 3.2 m and even to 3.0 m for low volume traffic roads. As far as possible the width of traffic lanes and off-carriageways in road tunnels shall be same as that on the adjoining carriageways in the open air. If the width of traffic lanes in tunnels is restricted as compared to the adjoining carriageways in the open air, such restriction shall commence at least 150 m from the entrance of the tunnel along with speed restrictions.

2.8.2.2 *Height of the tunnel*

The finished height of a tunnel would depend upon the minimum vertical clearance, which shall not be less than 5.5 m. However for tunnel on road with low traffic volume it may be reduced as per local regulations and the height of loaded vehicles likely to pass through the tunnel. Such minimum vertical clearance shall be available over the full width of the carriageway as mentioned in para **2.8.2.1** above, irrespective of the shape of tunnel. Space required above the minimum vertical clearance line for accommodating tunnel ventilation and lighting fixtures proposed, if any, shall be provided accordingly, duly considering the shape of tunnel proposed which in turn depends upon strata met with.

Where tunnel cross sections of especially small dimensions are adopted due to various constraints, dimensional templates shall be erected outside the portals at the point of entry so that vehicles larger than the permitted size do not enter and get stuck. Such templates shall be suitably strengthened to resist impact from over-dimensioned vehicles without getting damaged, but at the same time not unduly stiff so as to damage the vehicles excessively.

2.8.2.3 *Shape of the tunnel*

In case of 'D' shaped tunnels, the geometry of the arch could be semi-circular, segmental or multi-radius. The segmental or multi-radius arch is flatter and reduces the quantity of excavation, concrete etc. However, under similar geotechnical conditions, semi-circular arch is structurally more efficient as compared to segmental or multi-radius arch.

2.8.2.4 Bi-directional/uni-directional traffic tunnel

For tunnels on low volume traffic roads, bi-directional two lane cross-section shall be adopted. For roads with projected traffic volume exceeding 10,000 vehicles/day/lane, uni-directional twin tube tunnels each of two-lane, three-lane or at the most four-lane cross section shall be adopted depending upon volume of projected traffic. In case of twin tube tunnels the clear distance between the tubes shall be between 0.5 to 2 times width of tunnel depending on the type of strata, the stresses generated and their effect on stability.

2.8.2.5 Finished section of tunnel

Taking into account all these factors along with functional requirements as given in **Table 1** below and geotechnical conditions likely to be met with, necessary geometry of finished section of the tunnels shall be determined.

* Cross passage as Egress between the two tubes

Table 1 Table Showing Functional Requirements Based on Lengthwise Classification of Tunnels Having Bearing on Geometric Design

Classification of Tunnel	Single Tube Bi-Directional						Double Tube Uni-Directional					
	CP	VN	LG	TE	FS	EG	CP	VN	LG	TE	FS	EG
Short Tunnel Up to 500 m	NA	---	***	---	---	---	---	---	***	---	---	---
Medium Tunnel 500m to 1500 m	NA	Yes	Yes	Yes	Yes	---	Yes	Yes	Yes	Yes	Yes	*
Long Tunnel Above 1500 m	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	*

*** Lighting shall be provided for Urban Tunnels and preferably for tunnels longer than 100 m in Non-urban area.

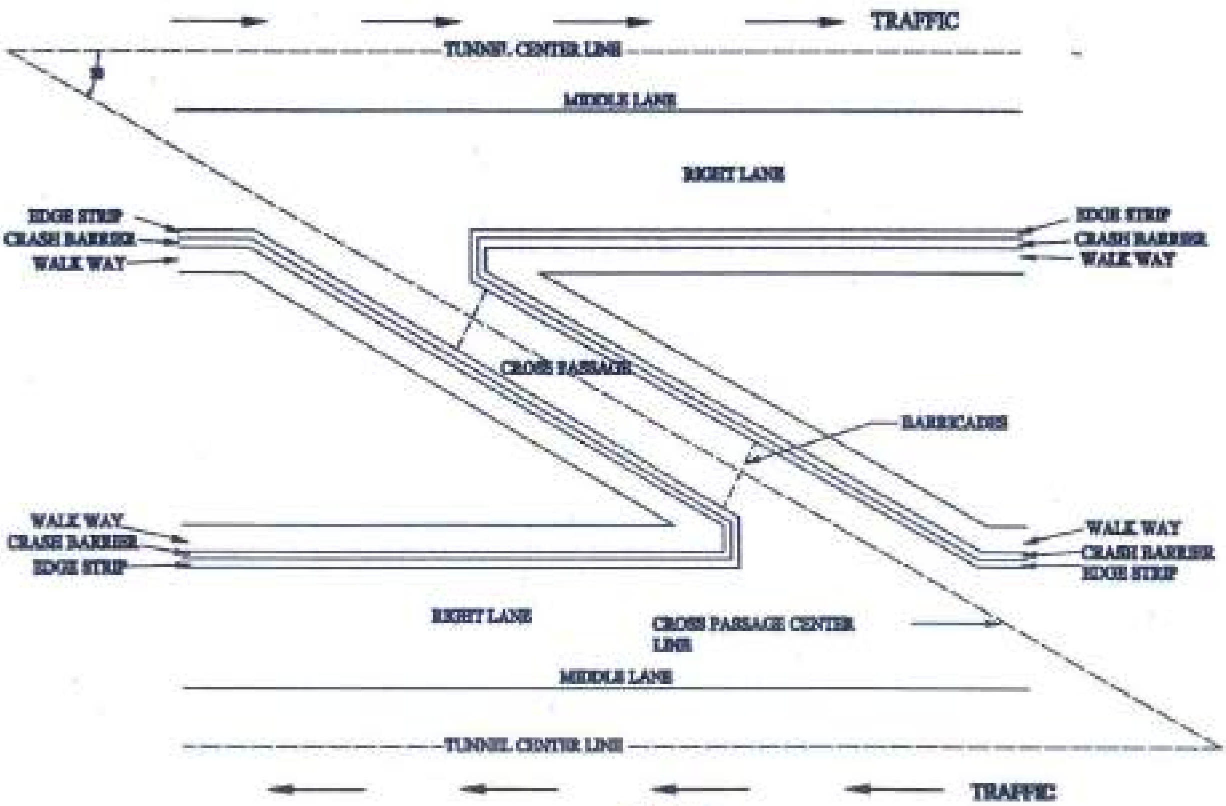
- NA - Not Applicable
- CP - Cross Passage.

- VN - Ventilation.
- LG - Lighting.
- TE - Telephone at spacing of about 200 m
- FS - Fire Safety - Fire extinguisher at spacing of about 50m
- EG Egress (Such egress shall have minimum dimensions of 2 m x 2.5 m height with adequate ventilation & lighting, and isolation from main tunnel through fire proof doors)

Note 1: In case of long tunnels, provision of refuge to park at least 6 vehicles along the length of tunnel with one-lane width, proper informatory signs, transitions and line of sight shall be planned at about 750 m intervals beyond the leftmost lane.

Note 2: In case of twin tube tunnels, each tunnel tube with uni-directional traffic, cross passages connecting the two tubes shall be planned at a spacing of about 300 m. In the event of an incident/accident in one of the tubes, the other tube shall be used as an escape and rescue route by diverting the traffic through cross passages to the extreme right lane of the other tube, so as to clear the tunnel in case of emergencies. The cross passages shall be at an angle of about 300 to the alignment as shown in sketch below and shall have provision for one traffic lane, edge strips, crash barriers/kerbs and walkways on either side. In normal conditions cross passages shall be barricaded.

Note 3: For installation of facilities in expressway tunnels refer Table 6.01 of "Guidelines for Expressways Volume – II:DESIGN"

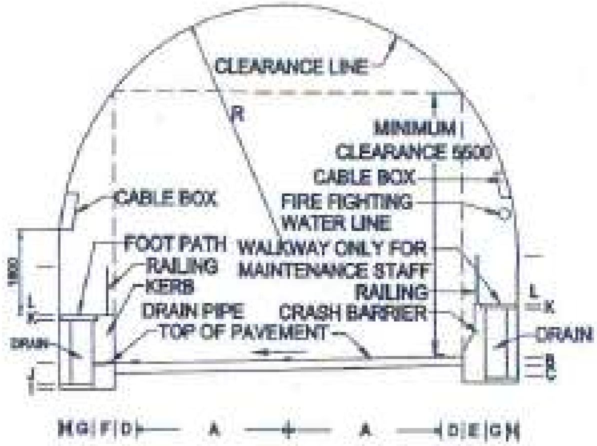


PLAN

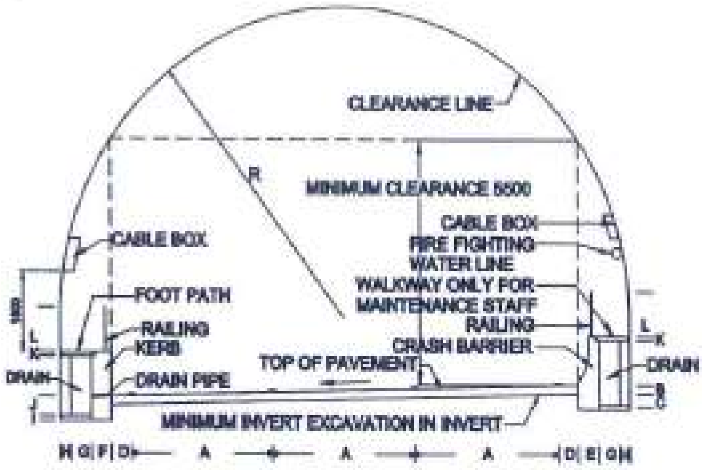
Typical sketches indicating tunnel cross sections for bi-directional and uni-directional traffic conditions are given below.

LEGEND FOR SYMBOLS USED IN SKETCHES			
Symbol	Particulats	Unit	Dimensions
A	Traffic Lane Width	mm.	As per design
B	Pavement Thickness		Type and Thickness as per design requirements
C	Pavement Camber	%	Around 2 percent
D	Edge Strip Width	mm.	Minimum 500 for Running Tunnels and 1000 for Cross Passages
E	Crash Barrier Width	mm.	Type and Dimensions as indicated or as per design
F	Kerb Width	mm.	Minimum 500 thick and 1000 high
G	Drain Waterway Width	mm.	As per design and enough to accommodate the Footpath / Walkway above.
H	Drain Wall Thickness	mm.	As per design
I	Drain Floor Thickness	mm.	As per design
J	Drain Waterway Depth	mm.	As per design
K	Footpath / Walkway Slab Thickness	mm.	As per design
L	Railing height	mm.	As per design
M	Width of Median	mm.	As per design
R	Radius of Roof Arch	mm.	As per design

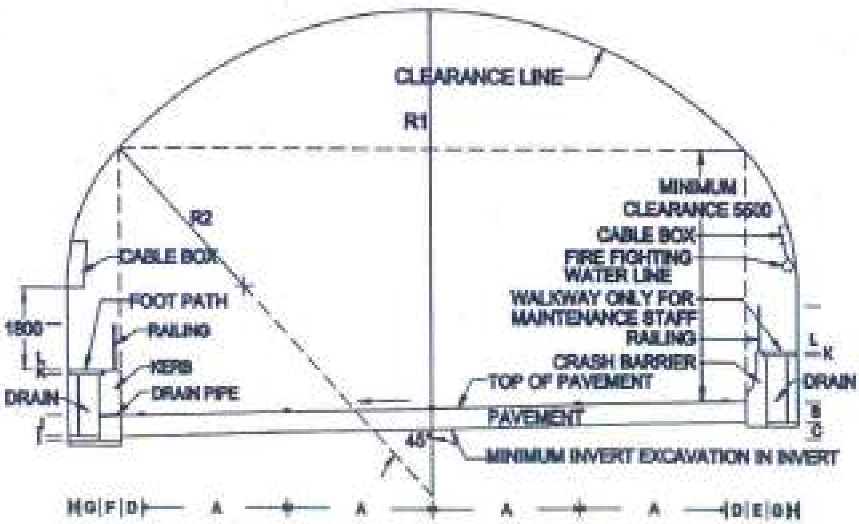
Sketch 1: Section of Two Lane Bi-Directionla Traffic Tunnel



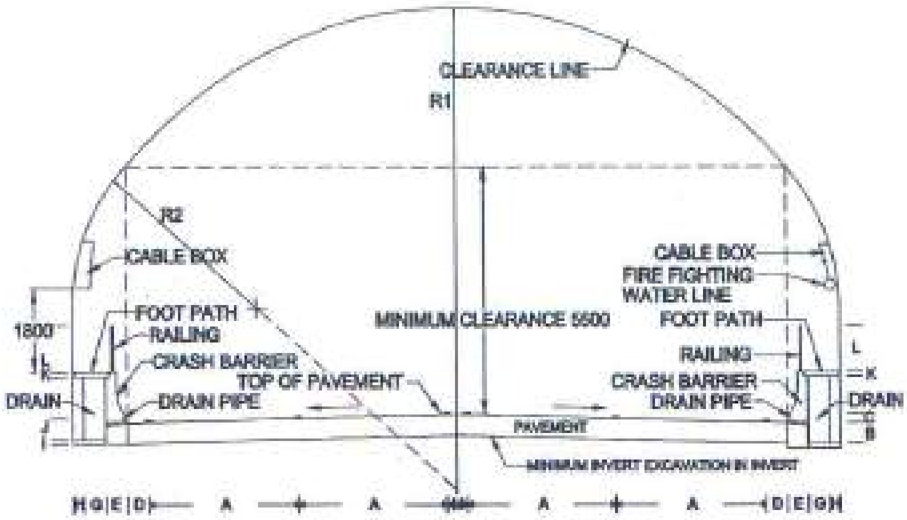
Sketch 2: Section of Two Lane Uni-Directionla Traffic Tunnel



Sketch 3: Section of Three Lane Uni-Directionla Traffic Tunnel



Sketch 4: Section of Four Lane Uni-Directionla Traffic Tunnel



Sketch 5: Section of Four Lane Bi-Directionla Traffic Tunnel

Note: If geotechnical conditions prevent use of above section of 4 lane bi-directional Tunnel, two separate tunnels of two lane unidirectional cross section as per Sketch 2 above shall be adopted.

2.8.3 *Vertical alignment*

The gradient along the tunnel length shall be very gentle. Steep gradient affects traffic capacity, resulting in additional emission by vehicles and makes ventilation more difficult. The tunnel gradients are generally limited to 4-6 percent in short tunnels and to around 3 percent if length exceeds 500 m. Where steeper gradients become necessary, the design of the ventilation system shall be done taking into consideration the effect of steep gradients and possible incidences of fire. Generally a high point somewhere in the tunnel shall be provided for efficient drainage of seepage water.

2.8.4 *Horizontal alignment*

The straight alignment is generally preferred. However the straight stretch shall not be more than 1500 m in case of long tunnels to avoid the effect of monotony and induction of an unconscious increase in speed. For the same reason last few meters of the tunnel shall have gentle curve. The curves if provided shall be gentle and meet the minimum radius requirements for the design speed of the tunnel. Tunnel alignment at the ends and open/approach cuts shall merge smoothly with adjoining road in the open air. In case of twin tube tunnel, crossing of central median shall be planned at suitable locations at approaches of both tunnels so as to allow emergency services gain immediate access to either tube and also to send back diverted traffic to proper traffic lanes.

For long tunnels the distance traversed shall be suitably marked so that motorists are aware of distance covered and remaining distance. This is especially useful in times of emergencies to give people a clear idea of distances involved in both the directions for fast egress.

2.9 Preliminary Assessment of Tunnel Supporting System

Based on the geometry of the finished tunnel section and the anticipated geotechnical conditions along the alignment, a preliminary rough assessment of the need, type and quantum of tunnel supporting systems shall be made. The supporting system shall be in the form of rock-bolts, shotcrete, steel ribs, forepoling, pipe roofing and concrete lining, separately or in combination. This preliminary assessment shall be made on the basis of past experience and supporting systems provided in other tunnels under similar conditions by engaging services of geotechnical experts. A combination of rock bolts and steel fibre reinforced shotcrete [SFRS] with or without lattice girder is the present trend based on cost and time considerations and flexibility in construction.

2.10 Collection of Data on Construction Costs Prevailing in the Area

For rough assessment of cost of different alternatives, data regarding cost of various construction materials and specialized construction manpower shall be collected. Data in respect of construction costs in general and costs of similar projects in the area shall also be collected.

2.11 Preliminary Estimation of Cost

Taking into account data on construction costs, quantum of tunnel excavation and supporting system and appurtenant works etc. preliminary estimate of the cost shall be made.

2.12 Selection of Alternative for Detailed Studies

Technical feasibility of each alternative shall be assessed in the light of physical, environmental and other constraints. Construction costs of different alternatives shall be compared. Considering merits and demerits of each alternative, one of the alternatives shall be selected for further detailed studies.

2.13 Detailed Survey

A detailed survey of the tunnel alignment for the selected alternative shall then be carried out. Drawings showing the longitudinal sections, cross-sections and contour plans along the tunnel alignment shall be prepared.

2.14 Detailed Geotechnical Assessment

For designers and constructors of tunnel, the ground through which the tunnel passes is the construction medium. As described in details, in a subsequent section entitled "Geotechnical Investigations", realistic geotechnical and geophysical assessment of the ground through which the tunnel would pass should be made. A detailed geological mapping shall also be carried out based on the investigations.

2.15 Detailed Design of the Tunnel Supporting System

Geotechnical information and data should be used to assess the loads that are likely to be caused on the periphery of the tunnel. Section of the tunnel shall then be analyzed by empirical and/or numerical methods and need, type and quantum of necessary supports be determined, as described in detail, in a subsequent section entitled "Structural Designs".

2.16 Detailed Design of Permanent Ventilation and Lighting System

Taking into account the length, shape, size, tunnel environs and the complexion of the likely traffic for which the tunnel has been designed, detailed design of the Ventilation and the Lighting System shall be carried out by experts, as described in detail, in a subsequent section entitled "Ventilation and Lighting".

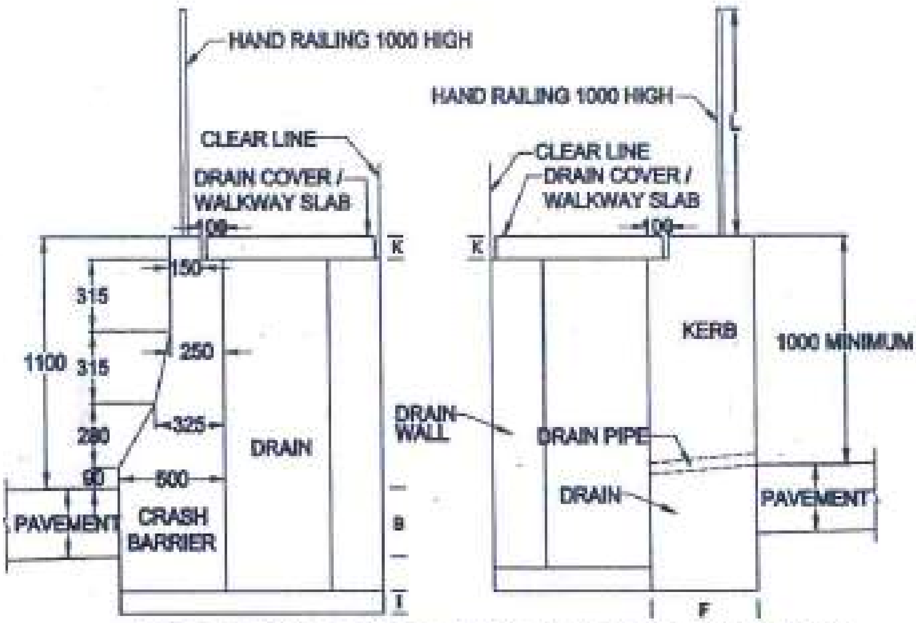
2.17 Design of Drainage System

2.17.1 In order to trap rainwater from hill slopes and prevent it from flowing into the approach cuts and the tunnel, suitable catch water drains shall be provided above the top of sides of the open/approach cuts and above excavated portals.

2.17.2 In the open/approach cuts discontinuous kerbs shall be provided to demarcate the edge of the carriageway. Beyond the kerbs, side drains with adequate waterway shall be provided in the open/approach cuts.

2.17.3 Inside the tunnel, suitable side drains shall be provided behind the kerbs/crash barriers. Suitable drain pipes going through the kerbs/crash barriers shall be provided to lead seepage and wash water to the drains. The drains shall be located below the walkways meant for the pedestrians and maintenance personnel, as shown in the sketches below. The carriageway shall have suitable camber to facilitate drainage into the side drains. In case of bi-directional tunnel, the camber shall be from the centre outwards and in case of uni-directional tunnel from high speed lane towards low speed lane. The vertical profile shall facilitate self draining of tunnel by providing high point somewhere in the tunnel. However, for long tunnels this may not be possible and detailed drainage system shall be designed by providing sumps and combination of self draining and pumping arrangements.

2.17.4 The black topped road surface inside tunnel, generally constructed on rocky subgrade, gets damaged due to seepage water and creates sever problem for surface drainage. Hence the pavement inside the tunnel and in approach cuts shall be of high performance pavement concrete.



Details of Crass Barrier/Kerb with Poothpath Walkway

2.18 Tunnel Furnishings

Provision for installation of tunnel furnishings such as sign boards, fire fighting arrangement, cable trays for telephone and power lines etc. shall be made in consultation with relevant local authorities.

2.19 Aesthetics

The tunnel portals and other components shall be suitably designed with particular care for good aesthetics, pleasing geometry, shapes and proportions, patterns, textures, colours, etc. For important tunnels, particularly in urban areas, specially designed internal paneling may be thought of for all internal surfaces, which would be amenable for easy cleaning, improved acoustics and sound absorption as well as enhanced fire resistance. Muck dumping areas shall be suitably dressed to proper stable slopes, shapes and turfed/landscaped to improve the environment and aesthetics.

2.20 Selection of Suitable Construction Technology

Various Tunnelling technologies have been described in broad details in subsequent section titled "Methodology of Tunnelling". Choice of suitable construction technology would depend on many inter-related aspects. Environmental considerations may dictate the necessity for use of controlled blasting techniques or no-blast techniques. Time constraints also may call for use of faster methods of Tunnelling as described under no-blast techniques. In Tunnelling, stand up time of the strata is an important factor for deciding advance of the tunnel in each cycle. In strata with long stand up time, Tunnelling can go on without constraints with longest possible advances. At the other end of the spectrum, is the ground with stand up time so low, that Tunnelling is required to be carried by dividing and tackling the face in parts. Taking into account the environmental aspect, cost considerations, time aspect and the nature of the ground through which the tunnel would pass, the most appropriate Tunnelling technology shall be selected.

2.21 Statutory Clearances and Approvals

All necessary statutory clearances and approvals shall be obtained before taking up construction. These shall include at minimum;

a) Environmental and Forest (if any) clearances,

b) Permission for blasting in the area,

c) License for storage and handling of explosives,

d) Acquisition of right of way,

e) Approvals from Fire authority in case of urban tunnels

f) Clearance from Pollution Control Board

2.22 Detailed Estimation of Project Costs

Based on the data on cost of required construction materials, ownership and operation cost of plant and equipment, cost of manpower, construction technology required to be used and time required for completion of Tunnelling operations, detailed analysis of cost of all the items of work should be prepared and total cost shall be analyzed.

2.23 Project Implementation

Upon completion of all these activities and steps, the project proposal would be ready for further processing, if any and implementation

3 GEO-TECHNICAL INVESTIGATIONS

3.1 Site specific geological conditions along a tunnel alignment play a prominent role in influencing major decisions regarding planning, designing and construction e.g.

- Alignment and portal locations
- Shape of the tunnel
- Tunnel supporting systems
- Minimum distance to be kept between twd tunnels
- Methodology of construction of tunnel including risk assessment
- Construction method and treatment of open cut/slopes

The starting point of all these designs is knowledge in respect of the behavior of the Tunnelling media-likely to be met with during Tunnelling. It is therefore very important that appropriate geo-technical investigations are conducted early in the planning process. The objective of geological investigations is to understand the history, topography, geology, environmental setting and the engineering properties of the underlying strata. The geotechnical information regarding nature of ground, groundwater conditions, engineering and other scientific parameters is essential for anticipating ground behaviour which is useful to select tunnel shape, size, excavation method & the support system, and other essential parameters for a cost and time effective tunnel design.

3.2 Relevant Strata

For designers and constructors of tunnels, the ground through which the tunnels pass is the construction medium. It is therefore necessary to have fairly realistic geotechnical assessment of the construction media and its environment. The most important consideration is the condition of the ground mass just above crown of the tunnel (generally for a height of 2 times width of tunnel) and at the level of the tunnel

3.3 Geo-technical Investigations

The methods available for carrying out geo-technical investigations are

- Collection of available data regarding Regional and Local Geology of the area
- Detailed mapping of surface geology of the tunnel area
- Geophysical studies along the alignment of the tunnel
- Exploratory boring and/or Drifting: In-situ testing

Besides the above, additional data shall be collected during actual construction as given in para **3.4.**

3.3.1 *Collection of available data regarding regional and local geology of the area*

Data regarding General Geology of the project area shall be collected from

a) Site reconnaissance survey to collect information on geological features.
b) Geological Survey of India and similar organizations of the State Government,
c) Nearby Engineering Institutions and Engineering Projects in the vicinity.

The data collected shall include general idea of in-situ stresses in the ground formations of the region, which is required for assessment of rock mass quality.

3.3.2 *Detailed mapping of surface geology of the tunnel area*

After conceptual alternative alignments of the tunnel have been set out on the ground, geological mapping of the area should be carried out to observe and to make note of geological features such as type of strata, existence of outcrops, dip and strike of strata, discontinuities, folds, faults, ground water regime etc. Taking into account general geology of the area and the data collected during the study of surface geology, a preliminary geological map shall be prepared and preliminary assessment of geo-technical conditions that are likely to be met with, along the alternatives shall be made. These studies along with other preliminary studies would help in arriving at the technical feasibility of each alternative, rough cost of each alternative and selection of preferred alignment for further detailed studies.

3.3.3 *Exploratory boring and drifting*

3.3.3.1 *Determination of locations of bore holes*

Locations of exploratory bore holes shall be decided considering salient features of the ground profile above the tunnel, preliminarily assessed geological conditions and the likely location of the portals conceived on the basis of the preliminary geological map. If the profile of the ground above the tunnel is accessible and formations are likely to be fairly uniform the bores shall be generally taken at an interval of about 200 m. If the formations are likely to be heterogeneous the borehole interval shall be reduced to 100 m. If any specific geological feature is encountered additional bores shall be taken. If the profile of the ground above the tunnel is not easily accessible nearest accessible location shall be chosen. In any case, even for a shorter length tunnel, minimum three bores shall be taken, one at each portal location and third in the middle.

3.3.3.2 Geo-technical assessment by exploratory boring

For realistic geo-technical assessment of the ground, exploratory bores shall be drilled to a depth of about 5 m below the expected level of invert of the tunnel. The cores shall be collected from the relevant strata as defined above in para **3.2** above. Boring shall be carried out using at least NX size coring bits and using double-tube core barrel in normal situations and triple-tube core barrels in weak rocks, fault zones, shear zones, crush zones, folded rocks etc. Use of triple tube core barrel helps preventing mechanical breakage of rock cores due to rough handling.

3.3.3.3 Observations and tests to be made during boring operations

During boring operations, following observations shall be made and tests shall be carried out:

1) Rate of penetration in each 1.5 m drill run:

   The rate of penetration gives a broad idea about toughness of the strata.

2) Locations, if any, where rate of penetration changes suddenly:

   Sudden change in the rate of penetration indicates change in the type of strata. If the drill string suddenly drops, it will indicate presence of hollow joint/cavity or joint with very soft matrix.

3) Quantum of drilling water:

   Flow of drilling water going into the drill hole and water flushing out of a drill hole shall be monitored continuously. Sudden loss of drilling water indicates presence of open dry joints or fractured zone. Increase in the rate of drilling water flushing out of a drill hole indicates intersection of groundwater table. Sudden large increase in the rate of drilling water flushing out of a drill hole would indicate artesian conditions.

4) Colour of drill water/sludge:

   Observing carefully the colour of drill water/sludge coming out from the borehole is important as it gives idea about the type of strata in which bore is passing.

5) Permeability:

Permeability of rock strata is the amount of flow of water through rock mass when it is saturated. Generally one permeability test shall be carried out in each 6 m tier. However, one test shall be carried out in each 3 m length of the borehole in the relevant strata, using Double packers and using falling and constant head methods

The drilling data shall be recorded in the proforma given in the **Annex-C.**

3.3.3.4 *Preservation of cores samples*

As soon as core is removed from the core barrel all pieces of core must be immediately numbered serially, their depths and serial numbers painted on them and their lower ends marked so as to ensure that all pieces are kept in correct order exactly representing the depth from which they have been obtained. Lengths of all pieces of core shall be measured and recorded in the daily drill report. Cores shall be immediately placed in core boxes made according to standard specification, and all the necessary information such as the name of the project, location of drill hole, drill meterage, drill hole number, etc. shall be painted on the box. The cores of some soft and weak rocks disintegrate on exposure to atmosphere. Cores of such rocks when raised to the surface should be covered with a thin layer of wax by immediately immersing it in melted wax for preventing its exposure to atmosphere. Such waxed core remains intact indefinitely and the rocks in their true form as they occur in-situ are seen in the core and not in the misleading disintegrated form. The core boxes shall be preserved till three years after completion of the tunnel and after it is put to use.

3.3.3.5 *Observations to be made on the core samples*

Following observations shall be made by an expert geologist:

1) Lithology

Lithology will be useful to study the origin, formation, mineral composition and classification of rocks. Study of core samples would enable identification of nature and classification of the formations.

2) Nature of joints in the formations

A core would normally break only along pre existing divisional planes. However, due to vibrations during drilling, particularly with a defective machine or defective operation, core may also break even at places where joints do not exist. It is necessary to distinguish between fractures due to jointing and mechanical fractures caused by faulty drilling, by examining the fracture surfaces. Inspection of the core samples would also enable identification of location, orientation, spacing, thickness and physical condition of joints, their tightness or openness and roughness and alteration of joints in the formations and type of infill material.

3) Core recovery and RQD

A core recovery is the percentage of total length of cores obtained as compared to the total section cored including lost cored sections i.e. core run. The RQD – Rock Quality Designation is the percentage of cumulative length of pieces of core longer than 10 cm obtained from a total section cored i.e. core run. RQD is normally assessed and recorded for each meter of the core run. These observations help in assessment of the strata in respect of jointing and other disturbances.

3.3.3.6 Tests on core samples

Following tests shall be carried out in a competent laboratory. At least five samples of each lithological category should be tested. If the lithology indicates that the relevant ground mass is only of one category, at least a total of ten samples from different levels shall be tested.

- Unconfined compressive strength and hardness
- Natural and dry density and specific gravity
- Rate of water absorption and porosity
- Young's modulus of elasticity
- Poisson's ratio
- Tri-axial strength (for structurally disturbed rock formation)
- Petrography – Hand and microscopic petrography
- Tensile strength – (in completely geologically disturbed area)

3.3.3.7 Geo-technical assessment by excavation of exploratory drifts

Sometimes, when a tunnel passes below a high mountain, boring of exploratory holes to cover the relevant strata becomes impracticable due to the excessive depth of boreholes. In such a situation as also to gain information in respect of the hidden geological features along the alignment, geo-technical assessment is carried out by excavation of tunnels of small cross-section called exploratory drifts. These drifts give an idea of the nature of strata likely to be met with.

Such information collected from drifts, which are at shallow depths from the ground surface, shall be used only by a Tunnelling expert in association with an experienced geologist since the behavior of rock masses under small cover in drifts is significantly different than the behavior of the similar rock masses at higher depths actually encountered during tunnelling.

3.3.4 *Geo-technical assessment by geophysical methods*

Initial geophysical assessment followed by a quantitative geological investigation programme often provides reliable information in a short time.

3.3.4.1 Exploratory boring gives detailed information of the geological formations at and around the location of the boreholes. However, when a tunnel passes below a high mountain, boring of exploratory holes to cover the relevant strata becomes impracticable due to necessary excessive depth of boreholes. In such a situation as also to gain information in respect of the hidden geological features along the tunnel alignment, geophysical methods should be resorted to. Geophysical surveys enable in-situ determination of engineering properties of the strata such as profile of the strata, hidden faults, discontinuities and voids, groundwater, elastic moduli and density etc. Most often, these techniques do not directly measure the parameters and the same have to be developed from the known geological data and the measured geophysical contrast. Geophysical methods give qualitative assessment of the engineering properties and do not provide quantitative results as are available from exploratory boring.

3.3.4.2 *Some of the methods of geophysical studies are*

- Seismic Methods
- Electrical Resistivity

3.3.4.3 Seismic methods are the most commonly used methods of geophysical surveys for engineering investigations. These methods are mainly based on application of analogies of optical laws to seismic wave propagation. Seismic refraction and reflection provide engineers and geologists with the most basic geological data via simple procedures with common equipment. Seismic methods of subsurface evaluation involve the generation of pulses of energy, usually at the ground surface, consisting of compression, shear and surface waves that propagate through the ground and are either reflected back toward the surface, or are refracted at and travel along lithological boundaries. The wave energy which returns to the surface is picked up by geophones placed at the ground surface. The geophones convert the wave energy to an electronic signal which is recorded on a seismograph. Refracted waves travel along the interface of lower density material overlying higher density material, for example sediment overlying bedrock. The speed of wave propagation of refracted signals changes along the path, traveling at relatively slow speeds in the sediment, at higher speeds along the bedrock interface, and slow speeds again as they return to the surface. Refracted waves can only be detected at the surface for situations in which higher velocity material underlies low velocity material. Reflected waves travel downward until they meet an interface between layers of differing density. The speed of wave propagation is constant at the speed of the overlying material. In the case of sediment overlying bedrock, the wave will travel at the slower sediment speed. Surface waves are the portion of the seismic energy pulse which travels along the surface of the ground directly to the geophone.

3.3.4.4 Electrical resistivity method generally enables broad mapping of rock surfaces below, up to a depths of about 30 m. Electrical resistivity is a method for assessment of soil and rock mass and vertical and horizontal discontinuities therein, in by observing its resistivity and discontinuities in their electrical properties.

Distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivities and disposition of the surrounding soils and rocks. Grains of soil and rock are essentially nonconductive except those of metallic ores. Therefore the resistivity of soils or rocks primarily depends on the amount of pore water and the arrangements of the pores. Materials with different lithology therefore have different resistivity. Igneous rocks have the highest resistivities while sedimentary rocks tend to be most conductive because of their high water content and metamorphic rocks fall in-between them. Interpretation is carried out by qualitative comparison between the resistivity measurements observed in the field and the hypothetical models or on the basis of empirical methods. The Electrical resistivity method makes use of this principle.

The usual practice in the field is to apply a direct current or alternating current of low frequency through two electrodes implanted in the ground and to measure the difference of potential between two additional electrodes that do not carry current, also implanted in the ground, a few meters away. The difference in the electrical potential i.e. resistivity of the ground between the two types of electrodes as above, is measured.

3.4 Corroboration of Data During Construction

Data collected during planning stage shall be got corroborated by following additional investigations during actual construction. This will help in revalidating the initial design or for making any course corrections required.

3.4.1 *Advance probing hole*

Horizontal bore holes of suitable length shall be drilled at regular intervals at tunnel faces to gather geological information about strata ahead of the face. This information shall be used to plan further Tunnelling operations and changes in design, if required. Adequate advance precautions shall be taken in case large ingress of water is encountered from the probe hole.

3.4.2 Seismic method as described in para **3.3.4.3** above can also be used for advance probing by detonating very small explosive charges on the tunnel face and mapping the reflected/refracted waves to get some idea of the strata ahead.

3.4.3 *Tunnel instrumentation*

In-situ stress measurement is useful in long mountain tunnels. Adequate tunnel instrumentation program shall be adopted for observation and monitoring the behavior of excavated faces/surroundings, especially the state of in-situ stresses. The purpose of instrumentation is to confirm that actual behavior of the Tunnelling media is similar to the one assumed in design. Any variation from the design assumptions shall be considered for correction in design during construction and for improving safety measures. This aspect becomes more important in poor rock masses. The information on Instrumentation is given in **Annex-D**.

3.5 Assessment of RMR & Q

Study of cores and data collected from surface and subsurface observations shall be used to evaluate parameters required for the assessment of RMR and Q described in details in the section titled 'Structural Design'. These indices are useful for assessing the characteristics of various lithological units. These two parameters are also used for assessing method of excavation, support requirements, anticipating tunnel deformations and construction problems.

The collected geological information should be used to prepare a geological L-section of the tunnel. This L-section must cover the lithological units, geological discontinuities with strike and dip direction along the tunnel axis.

3.6 Drawings to be prepared

Lithological Section i.e. longitudinal section along the alignment of the tunnel and its approach/open cuts showing location of the boreholes shall be prepared, incorporating therein all the relevant data collected during the geo-technical investigations. The lithological section would give an idea about the spread of different formations along the tunnel alignment, together with expected Rock Mass Rating/Classification (RMR & Q) to reasonable accuracy. The geophysical information shall be used to supplement wherever necessary, to prepare a geological L – section of a tunnel.

4 STRUCTURAL DESIGN

4.1 Preamble

In tunnelling, Structural Design is required for

- Deciding the geometry of excavated periphery of the tunnel
- Design of tunnel supporting systems
- Deciding on the minimum distance between adjacent tunnels

The basis or the starting point of all these designs is the assessment of applicable loads. For arriving at the quantum of these loads, it is necessary to have sufficient knowledge in respect of the structural properties of the ground likely to be met with during tunnelling. Such knowledge is obtained by carrying out detailed geological and geotechnical studies, as set out in the section dealing with 'Geo-technical Investigations'.

The rock mass through which a tunnel is driven could vary from a strong massive formation to fissured, jointed and weak formation. Depending on the in-situ stresses and other characteristics of the formations, the periphery of an underground opening starts showing signs of deformation. In massive strong formations with low in-situ stresses, the deformations could be insignificant (less than 1 percent of the excavation size) needing no supports as against the fissured, jointed and weak formations needing heavy support.

The tunnel supporting systems are divided into two major categories viz. Immediate supports and Ultimate supports. The rock mass through which a tunnel is driven could vary from a strong massive formation to fissured, jointed and weak formation. Immediate support pressures are small in strong rocks, but high in weak rocks. The ultimate support pressure is 1.7 times the immediate pressure irrespective of the rock type. Rock mass rendered with proper immediate flexible supports allows development of just sufficient deformation and self-adjustment without loosening the rock mass and results in generation of minimum ultimate pressures. In massive strong formations with low in-situ stresses, the deformations could be insignificant needing no supports as against the fissured, jointed and weak formations needing heavy supports. All methods of tunnel excavation and support systems presently used, allow some degree of deformation in the surrounding rock mass. Present-day approach is to reinforce the existing rock mass to the extent possible rather than providing it with stiff ribs with lagging with packing behind. When advanced construction techniques such as NATM are used, the design scheme and the construction scheme go closely hand in hand and both have to be developed in a holistic manner.

This section covers the structural design of immediate as well as ultimate tunnel supports. As per current practice, immediate supports comprise of rock bolts, plain and reinforced shotcrete with or without lattice girders embedded in it and ultimate supports comprise of plain & reinforced shotcrete with or without lattice girders embedded in it. Concrete lining with or without steel ribs embedded therein are generally used in weak rocks, where high pressures are developed

There is a third element of 'time', in addition to pressure and deformations, which particularly affects when the ultimate support should be provided. The element of time is controlled by the rock type. Time element is often considered in terms of face advance. Deformations in strong rocks stabilize early, generally within a distance of 3D where D is the diameter of excavation size.

4.2 Study of Relevant Strata

4.2.1 Structural design of tunnel requires a thorough study of the following.

- Geology of the ground mass
- Effective cover
- Stress-strain characteristics
- Mechanical characteristics of intact ground mass
- Ground water conditions

4.2.2 The design shall be based on the most adverse combination of probable load conditions, but shall include only those loads which have reasonable probability of simultaneous occurrence. The methodology of construction is an important factor in structural design, particularly in case of soft strata and soils. The loading conditions vary from construction stage to operation stage & maintenance stage and the design shall be checked for loading conditions during these stages.

4.2.3 The paras given below in this section pertain to tunnels in rock. The structural design of tunnels in soft strata and soils is not covered in this section.

4.3 Various parameters to be considered

4.3.1 From observations made during exploratory boring

- Location of ground water table

4.3.2 From observations made on core samples

- Core recovery and RQD
- Lithology i.e. type of strata
- Spacing of joints
- Tightness or openness of joints
- Thickness of joints
- Orientation of joints
- Roughness of joints
- Type and thickness of infill material of the joints

4.3.3 From data obtained from testing of core samples

- Dry density and specific gravity
- Unconfined compressive strength
- Natural and dry density
- Rate of water absorption and porosity
- Young's modulus of elasticity
- Poisson's ratio

4.4 Assessment of Rock Mass

4.4.1 Based on the data collected in respect of the parameters enumerated in para 4.3 above, assessment of rock mass shall be carried out in accordance with the following Methods:

- Method based on Rock Mass Rating [RMR] as set out in Indian Standard IS 13365 [Part 1]: 1992
- Method based on Rock Mass Quality [Q] as set out in Indian Standard IS 13365 [Part 2]: 1998

These methods are further elaborated below.

4.4.2 Method based on Rock Mass Rating [RMR] as set out in Indian Standard IS 13365 [Part 1]: 1992 and support design base thereon.

In this method following geo-mechanical properties are assessed and ratings in the form of points are allotted as indicated in detail in **Appendix-I & II:**

I) Strength of intact rock material [MPa]:

This is the same as the Uni-axial compressive strength.

II) Rock Quality Designation [RQD]:

Rock Quality Designation indicates aggregate percentage of intact pieces of core that are more than 100 mm in length when compared to the total length of cores.

III) Spacing of Discontinuities [m]:

Spacing of discontinuities means spacing between joints.

IV) Condition of Joints:

Condition of joints indicates degree of roughness of joints.

V) Ground Water Condition:

Assessment of ground water condition is made on the basis of quantum and pressure of ground water in the joints.

VI) Rating adjustment for joint orientations:

Assessment of orientation of joints vis-à-vis direction of tunnel excavation is made taking into consideration as to how much favourable is the orientation for tunnelling through.

Rock Mass Rating (RMR) Value is the sum of the ratings as per 'I' to 'V' above. Adjusted RMR is total of 'I' to 'V' above plus adjustment as per 'VI' above.

Methodology for arriving at the RMR Values is set out in **Appendix-II.** An example for determination of RMR is given in **Appendix-IV**.

4.4.3 Method based on rock mass quality [Q] as set out in Indian Standard IS 13365 [Part 2]: 1998 and support design based thereon.

In this method following geo-mechanical properties are assessed and rating in the form of points is allotted as indicated in details in **Appendix-III**:

a) Rock Quality Designation [RQD] :

As defined in 4.4.2 (II)

b) Joint Set Number [Jn] :

'Jn' indicates the number of joint sets

c) Joint Roughness Number [Jr] :

'Jr' indicates condition of joints in terms of degree of roughness of joints

d) Joint Alteration Number [Ja] :

'Ja' indicates condition of joints in terms of degree of alteration of walls of joints

e) Joint Water Reduction Factor [Jw] :

'Jw' is a measure of water pressure, which has an adverse effect on shear strength of joints.

f) Stress Reduction Factor [SRF] :

SRF is a measure of

1) Loosening pressure in case of an excavation through shear zone and clay bearing rock masses,

2) Rock stress in a competent rock mass and

3) Squeezing or swelling pressure in incompetent rock masses.

Rock Mass Quality [Q] is arrived at on the basis of the following formula:

$$[Q] = (RQD/Jn) \times (Jr/Ja) \times (Jw/SRF)$$

The 'Q' value combined with tunnel excavation width is used to anticipate rock mass behaviour and degree of safety.

Methodology for arriving at the rock mass quality [Q] is set out in **Appendix-III**. An example for determination of rock mass quality [Q] is given in **Appendix-IV**.

4.5 Methodologies for Design of Tunnel Supports

Three broad methods are available for design:

i) Empirical Methods

ii) Analytical Methods

iii) Numerical Methods

4.5.1 *Empirical methods*

Various empirical rules have been developed over the years for characterization of the rock mass. Terzaghi was the first to formulate a rational empirical method classification for evaluation of rock loads which are used for design of steel supports. Rock mass assessed by Method based on Rock Mass Rating [RMR] and by Method based on tunnel quality index 'Q' are considered as more realistic as these methods take into account various variable parameters related to the conditions of the strata. 'Q' system is more appropriate for tunnels in rock. Both these methods take into account very similar geo-mechanical properties of rock mass, self supporting capacity of the periphery of the opening and the reinforcing effect caused by the supporting system. Since these methods are empirical, they need to be used very carefully and correlated with past experience.

A) Terzaghi's empirical method for assessment of rock load for design of steel ribs:

Terzaghi's rational empirical method classification for evaluating rock load was subsequently modified by Deere et al. [1970] and Rose [1982]. Terzaghi's classification and evaluation of rock loads with subsequent modifications, which is currently in use, is given in the table below:

			Rock Load Hp [ft]	Rock Load Hp [ft]
	Condition of Rock	**RQD**	**After Terzaghi**	**After Rose**
1)	Hard & Intact	95-100	0	Same as Terzaghi [1946]
2)	Hard Stratifies	90-99	[0 to 0.5] B	Same as Terzaghi [1946]
3)	Massive, Moderately Jointed	85-95	[0 to 0.25] B	Same as Terzaghi [1946]
4)	Moderately blocky & seamy	75-85	[0.25 B to 0.35] [B+H]	0.25 B to 0.20 [B+H]
5)	Very blocky & seamy	30-75	[0.35 to 1.10] [B+H]	[0.20 to 0.60] [B+H]
6)	Completely crushed but chemically intact	3-30	1.10 [B+H]	[0.60 to 1.10] [B+H]
6a)	Sand & gravel	0-3	Not given	[1.10 to 0 1.40] [B+H]
7)	Squeezing rock, moderate depth	NA	[1.10 to 2.10] [B+H]	Same as Terzaghi [1946]
8)	Squeezing rock, great depth	NA	[2.10 to 4.50] [B+H]	Same as Terzaghi [1946]
9)	Swelling rock	NA	Upto 250 ft. [80 m] irrespective of Value of B & H	Same as Terzaghi [1946]

Values for type 4, 5 & 6 reduced by Rose by about 50 percent from Tergazhi's values because water table has little effect on load [Terzaghi 1946, Brekke 1968]

Rock load 'Hp' in feet of rock on roof of support in tunnel with width 'B' [ft] and height 'H' [ft] at depth more than 1.5 [B+H] ; NA - Not Applicable.

Terzaghi's values of rock loads are found to be more conservative today, due to improvements in Tunnelling technology.

B) Estimated Support Categories based on Rock Mass Rating [RMR]:

Adjusted Ratings	Original RMR Rating									
	90-100	80-90	70-80	60-70	50-60	40-50	30-40	20-30	10-20	0-10
70-100										
50-60		a	a	a	a					
40-50			b	b	b	b				
30-40				c, d	c, d	c,d, e	d, e			
20-30					g	f, g	f, g, j	f, h, j		
10-20						i	i	h, l, j	h, j	
0-10							k	k	l	l

a) Generally no support, but joint intersections may require local bolting.

b) Patterned, grouted bolts at 1.0 m spacing.

c) Patterned, grouted bolts at 0.75 m spacing.

d) Patterned, grouted bolts at 1.0 m spacing, and shotcrete 100 mm thick.

e) Patterned, grouted bolts at 1.0 m spacing, and massive concrete 300 mm thick; only used if stress changes are not excessive.

f) Patterned, grouted bolts at 0.75 m spacing, and shotcrete 100 mm thick.

g) Patterned, grouted bolts at 0.75 m spacing, and mesh-reinforced shotcrete 100 mm thick.

h) Patterned, grouted bolts at 1.0 m spacing, and massive concrete 450 mm thick; if stress changes are not excessive.

i) Patterned, grouted bolts at 0.75 m spacing, and mesh-reinforced shotcrete 100 mm thick, plus yielding steel arches as repair technique if stress changes are excessive,

j) Stabilize with wire mesh cover support and massive concrete 450 mm thick; if stress changes are not excessive.

k) Stabilize with wire mesh cover support followed by 100-150 mm shotcrete (including face if necessary), plus yielding steel arches where stress changes excessive.

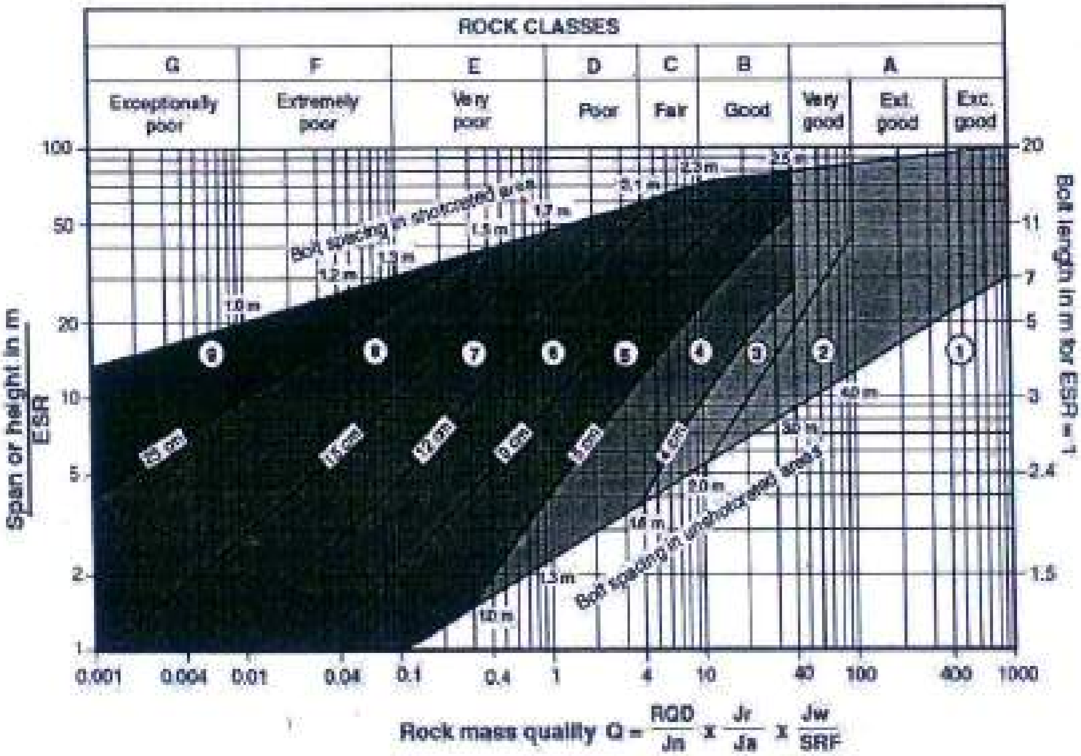
l) Avoid failure development in this ground if possible; otherwise, use support systems j or k.

C) Estimated Support Categories based on Rock Mass Quality 'Q' [After Grimstad and Barton, 1993 reproduced from Palmstorm and Brooch, 2006]

Barton et al [1974] have suggested the following Excavation Support Ratio [ESR] for use in the Estimation of Support [Reinforcement] Categories based on Rock Mass Quality Q

	Excavation Category	ESR
A	Temporary mine openings	3 - 5
B	Permanent mine openings, water tunnels for hydro power [excluding high pressure penstocks], pilot tunnels, drifts and headings for large excavations	1.6
C	Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels	1.3
D	Power stations, major road & railway tunnels, civil defence chambers, portal intersections	1.0
E	Underground nuclear power stations, railway stations, sports and public facilities, factories	0.8

Estimated Support [Reinforcement] Categories based on Rock Mass Quality 'Q' are indicated in the following nomogram:



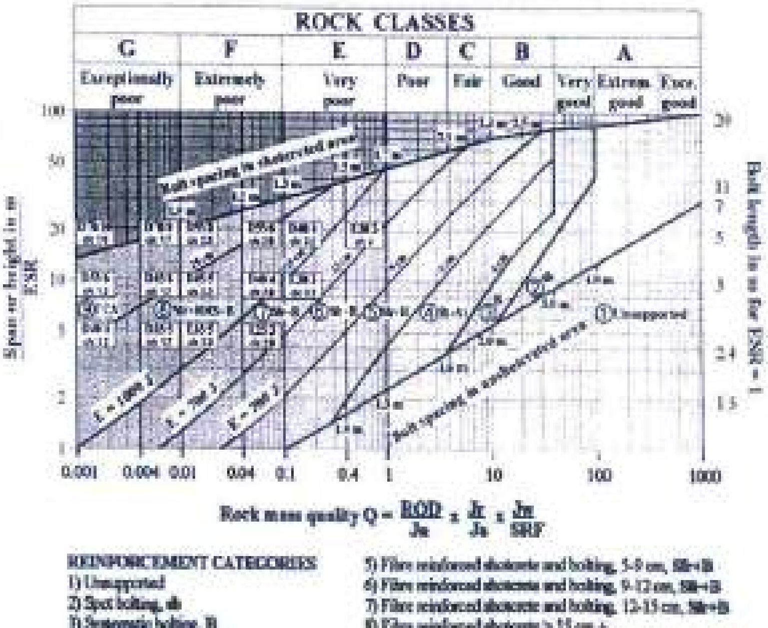
REINFORCEMENT CATEGORIES:

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting, (and unreinforced shotcrete, 4 - 10 cm)
5) Fibre reinforced shotcrete and bolting, 5 - 9 cm
6) Fibre reinforced shotcrete and bolting, 9 - 12 cm
7) Fibre reinforced shotcrete and bolting, 12 - 15 cm
8) Fibre reinforced shotcrete, > 15 cm, reinforced ribs of shotcrete and bolting
9) Cast concrete lining

An example of Estimated Support requirements based on the above nomogram is attached as **Appendix-V.**

An abstract of the recent updating of the Q-charts has been quoted below for the benefit of the users, especially considering its utility to replace the conventional cast concrete tunnel lining even in very poor to exceptionally poor rock masses (Q=1-0.001). The charts are backed by deformation measurements and numerical analysis based on static analysis of the support using STAAD software.

A second updating of the Q system for rock mass classification [1st updating by Grimstad and Barton, 1993] is in progress. In this updating, emphasis has been placed on the wide application of fibre reinforced sprayed concrete [Sfr], even in the lowest rock mass qualities and the recent changes in rock support practice and material properties. In extremely poor rock, where some deformations may be expected, the toughness and the energy absorption of the sprayed concrete has been taken into considered in the improved Q-support chart. A substantial amount of data from recent projects has been gathered and analyzed. Analytical research has been carried out with respect to the thickness, spacing and reinforcement of reinforced ribs of sprayed concrete [RRS] as a function of the load from the rock and the rock mass quality. The basis of the RRS design is the calculated deformation and bending moment. The analytical calculations are compared with numerical analysis and deformation measurements in the tunnel. Modem practice



REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting, sb
3) Systematic bolting, B
4) Systematic bolting, (and unreinforced shotcrete, 4-10 cm), B(+S)
5) Fibre reinforced shotcrete and bolting, 5-9 cm, Sfr+B
6) Fibre reinforced shotcrete and bolting, 9-12 cm, Sfr+B
7) Fibre reinforced shotcrete and bolting, 12-15 cm, Sfr+B
8) Fibre reinforced shotcrete > 15 cm + reinforced ribs of shotcrete and bolting, Sfr+RRS+B
9) Cast concrete lining, CCA

E) Energy absorption in fibre reinforced shotcrete at 25 mm bending during plate testing

– RRS with 6 reinforcement bars in double layer in 45 cm thick ribs with centre to centre (c/c) spacing 1.7 m. Each box corresponds to Q-values on the left hand side of the box. (See text for explanation) indicates that RRS may replace traditional cast concrete lining in extremely poor rock. RRS in shape and support capacity is similar to lattice girders, but are more flexible in application because RRS is not prefabricated. An improved Q-support chart that gives derails of RRS in very poor to exceptionally poor rock mass is given below:

D) Estimation of the Length of Rock Bolts:

Barton et al [1980] have suggested the following formula for estimation of the length of rock bolts:

$$L = 2 + \frac{0.15\,B}{ESR}$$

where,

L = Length of Rock Bolt in m.
B = Width of Excavation in m.
ESR = Excavation Support Ratio as per foregoing para **4.5.1.3**

E) Estimated Maximum Unsupported Span:

Barton et al [1980] have suggested the following formula for estimation of the Maximum Unsupported Span:

Maximum Unsupported Span = 2 ESR $Q^{0.4}$

where ESR = Excavation Support Ratio as per foregoing para **4.5.1.3**
Q = Rock Mass Quality Value

4.5.1.2 Shortcomings in the empirical methods

Though the empirical methods described in the foregoing para **A to C** give guidelines in the form of provision and spacing of rock bolts, many of them are silent about the diameter and length of the bolts, grade of shotcrete and size and spacing of rib supports etc. and have to be decided based on the experience of the designers.

4.5.1.3 Stand up time

4.5.1.3.1 The stand-up time is the time duration for which periphery of a tunnel excavation line is able to stand without 'tunnel supports'. The stand-up time is directly related to the quality of rock mass. Poorer the rock mass, shorter will be the stand-up time. Stand-up time is also inversely proportional to 'unsupported span'. It explains the necessity of resorting to multiple heading in case of wide tunnels.

In the direction of tunnel advance, unsupported span is the distance of tunnel face from the support line. In the transverse direction, unsupported span is the width of the tunnel opening. Good rock masses permit larger unsupported span whereas poorer rock mass permit only smaller unsupported span. In other words, a wider tunnel opening can be left unsupported in good rock mass. The unsupported span is defined as the shorter of the two distances between,

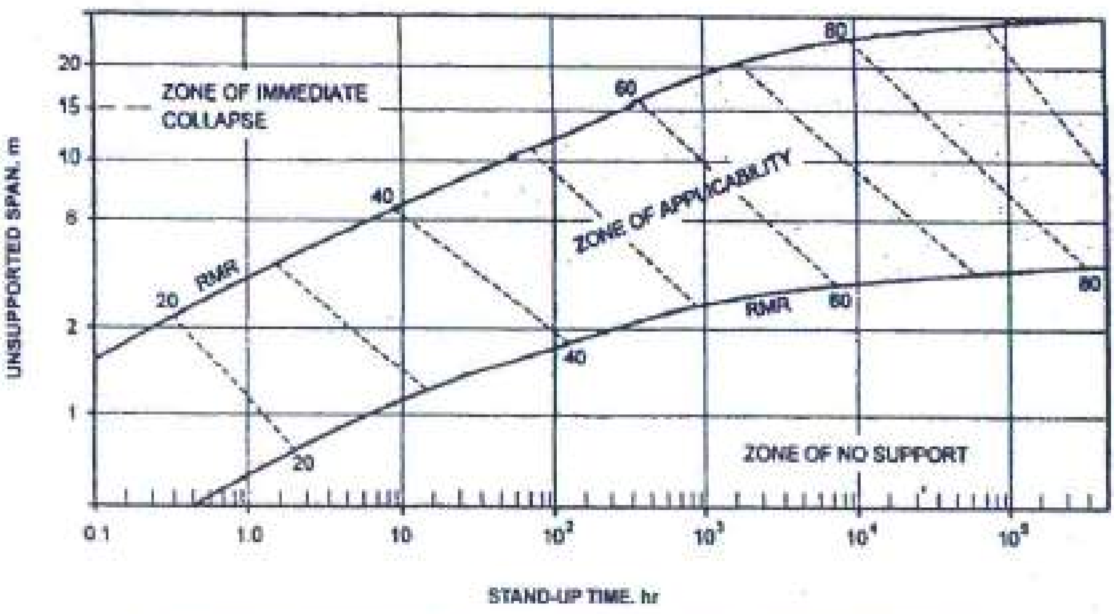
i) the tunnel face and the line of support nearest to the face and

ii) the excavation width.

In poor rock mass, the distance of the tunnel face from the line of support would be the unsupported span. In a good rock mass, however, the excavation width will be the unsupported span.

4.5.1.4 Relation between rock mass rating, stand-up time and unsupported span

This basic inter-relation between the rock mass rating, the stand-up time and the unsupported span is given by Bieniawski as shown below.



Stand up Time v/s Unsupported Span as per Rock Mass Rating

4.5.1.5 Inter-relation between 'Q' and 'RMR'

'RMR' is used for estimating 'unsupported span' and 'stand-up time', whereas 'Q' is used for estimating support pressure and for selecting supporting details as shown in the nomogram presented at the end of para **4.5.1- C.** Thus an inter-relation between

'Q' and 'RMR' is used when only 'RMR' and not 'Q' are assessed during geological investigations. Various inter-relations are shown in the following chart.

Conversion of 'Q' to 'RMR' by Different Correlations

	Barton [1995]	NGI [1994]	NGI [2001]	Bieniawsky [1989]
Q	RMR = 15logQ+ 50	RMR = 6.28lnQ+52.48	RMR = 15logQ+ 56	RMR = 9lnQ+ 44
100	80	81	86	85
40	74	76	80	77
20	70	71	76	71
10	65	67	71	65
4	59	61	65	75
1	50	52	56	44
0.1	35	38	41	23
0.01	20	23	26	3

4.5.2 *Analytical methods*

Analytical solutions assess support stiffness and maximum support pressure for concrete/shotcrete, steel ribs, and rock bolts etc. The stresses caused on the supporting system by the rock mass can be calculated from analytical elastic closed form solutions. Kirsch's elastic closed form solution is one of the commonly used analytical solutions. The closed form solution is restricted to simple geometries and models, and therefore often of limited practical value. However, it serves as a good check for the results obtained from numerical analysis.

4.5.3 *Numerical methods*

Various numerical methods are available for stress analysis such as two dimensional Plane Frame Method, Finite Difference Method, 2D/3D Finite Element Method or other similar computational/numerical methods for;

- Deciding the geometry of excavated periphery of the tunnel
- Deciding on the minimum distance between adjacent tunnels
- Tunnel support design comprising of shotcrete, lattice girders,steel ribs and concrete lining based on incremental needs of an advancing face

There are a number of commercial software available in the market.

4.5.4 *Observational approach*

Apart from methodologies mentioned above, the Observational approach is used when the tunnel behaviour is not known with confidence. This is also called build-as-you-go approach. The tunnel deformations and support pressures are monitored to develop a stable support system to stabilize the tunnel. The NATM and the NTM both depend on this approach with a purpose of ensuring adequacy of support and identifying time for providing a rigid final support called lining.

The design of steel rib supports aims at estimating bending moment, shear forces and axial load, which are compared with safe capacities of support system. The design ignores a very vital factor called 'rock-support interaction'. Without rock-support interaction, the support is akin to hang in air. This assumption leads to an over-design. This explains why this empirical tunnel support design has gained popularity the world over.

The use of steel arch support as primary/immediate support should therefore be avoided. Its use as a part of ultimate support in very poor ground conditions be made till lattice girders/shotcrete reinforced ribs get popular.

The use of steel arch support as primary/immediate support should therefore be avoided. Its use as a part of ultimate support in very poor ground conditions be made till lattice girders/shotcrete reinforced ribs get popular.

4.6 Loads to be Considered for Design of Ultimate Supports

IS 13365 (Part 2) : 1192 lays down the procedure and methodology for estimation of Immediate [Short-term] Support Pressures and Ultimate [Long-term] Support Pressures.

Assessment of what pressures to consider for design of the permanent lining of a tunnel in rock depends on the following aspects:

- If initial supports are installed early and correctly, they may not deteriorate within the design life of the structure, and if the opening is stable, then a structural final lining may not be required.
- If initial support(s) are installed early and correctly, the opening is stable but it cannot be guaranteed that the initial supports will remain completely effective for the design life of the structure, then the loads on the final lining may be essentially equal to those of the initial support.
- If initial supports are providing a seemingly stable opening but it is considered that additional support is required for long term stability then that support must be provided by the final lining.

4.7 Concrete Lining

As a structural system tunnel linings differ from other structural systems in that their interaction with the surrounding ground is an integral aspect of their behavior, stability and overall load carrying capacity. The flexibility of the lining to deform under load also depends on the surrounding ground. This flexibility allows the lining to deform to match with the surrounding ground, allowing the surrounding ground to mobilize strength and stabilize. The tunnel lining deformation allows redistribution of the moments by creation of "hinges" at points of high moment that relieve the moments in the tunnel lining.

The purpose of cast-in-situ concrete linings is to support the ground, provide base for installation of furnishings and control seepage of ground water. Cast-in-situ concrete linings are in plain or reinforced concrete, installed some time after the initial ground support. Cast-in-place concrete linings can take on any desired geometric shape.

5 TUNNEL CONSTRUCTION METHODOLOGY

5.1 General

5.1.1 Construction of a tunnel involves various activities which are to be planned depending upon the type of strata, available technology and construction period. Methodology of construction of tunnels in hard rock and stable ground is quite different from that for tunnels in poor rocks and soft ground. In case of very small isolated Tunnelling job in rocky strata the drilling work may be carried out with pneumatically operated Jack Hammers mounted on either pusher legs or specially designed multi platform 'Drill Carriage'. For bigger Tunnelling jobs Mobile Drilling Jumbos comprising of hydraulic rock drills mounted on hydraulic booms which can cover full face of a tunnel and which are much faster and capable of drilling bigger diameter holes may be deployed.

5.1.2 Construction activities inside a tunnel are required to be carried out in restricted space. Due to space restrictions and for working underground, specially designed plant and equipment are required along with adequate artificial ventilation and lighting arrangements. The construction operations are therefore required to be carried out in 'work cycles'. In general a 'work cycle' consist of following activities;

- Surveying and Profile marking
- Advancing the face by appropriate excavation methods
- Defuming (after blasting) and Scaling
- Mucking including disposal
- Plotting of excavated profile and geological mapping
- Support Installation - temporary and/or permanent

While tunnel size and stand up time of the strata dictates the choice between full face or multiple drift excavation, the standup time of strata dictates support installation activities. The work cycle time involving various activities of construction shall be monitored as documented in 'Method Statement'.

5.2 Stages in Tunnel Construction

5.2.1 *Surveying and profile marking*

5.2.1.1 Proper Surveying is very essential for efficient tunnelling. Skilled and experienced surveyors, appropriate techniques and instruments shall be used. Otherwise serious consequences, such as deviations in alignment and levels, excessive or inadequate excavation of the cross-section, reduction in safety due to adjacent tunnels straying towards each other, excavations of same tunnel from the two end faces not meeting properly, etc. may result. Contractual problems may also arise because of poor surveying.

5.2.1.2 Surveying equipments range from the common Level instruments through Theodolites and Total Stations to advanced Lasers and Profilers. Proper Bench Marks duly transferred from existing GTS or Project Bench Marks shall be established outside the tunnel at either end. All traverses shall always be closed and any resulting closing error should be negligible and be properly distributed. Construction Bench marks shall also be established at intermediate locations for long tunnels to speed up the surveying. Such Bench marks shall always be got cross checked independently to ensure maximum accuracy. Tunnel grade line shall be drawn on excavated side surfaces using indelible markings or embedded fixtures to facilitate quick ready checks. Check surveys shall be carried out at regular time/ progress intervals using an independent agency and with independent instruments and methods. Generally cross sections shall be generated immediately after excavation using post-survey data and cross-checked with required sectional area to monitor over-breaks or undercuts, as both these defects are expensive and difficult to rectify. Such comparisons also enable corrections to be applied to excavation techniques to minimize further erroneous excavation and also to avoid dangerous over-excavations. Such comparisons shall also be made contractually mandatory. All field observations and plots shall be preserved at least till the completion of the tunnel excavation and lining work. Any corrections required in the alignment due to wrong excavation shall always be made up gradually and as per approved plans.

5.2.2 *Excavation of open/approach cuts and location of portals*

Almost all the tunnels have an Open/Approach Cut at each of its ends. The length of open/approach cut depends upon cost of open excavation vs. cost of underground excavation and cost of protective work involved which depends upon type of strata met with. In case the cost of protective work becomes very high the option of cut and cover shall be studied which may be economical in such circumstances. However the excavation of these approach cuts in any case shall be carried out to stable side slope and continued till a near vertical stable ground mass, suitable for forming of excavated portal of the tunnel gets exposed. The locations of portals shall be decided with reference to rock cover in rocky strata. The minimum cover above tunnel crest depends upon the type and structure of rock mass, the size and shape of tunnel. The portals and approaches shall be designed with great care with regard to safety. If need be, the ground mass in which the excavated portal is to be formed shall be stabilized by installation of rock bolts, grouting, shotcreting etc. Thereafter, Tunnelling shall commence carefully by using techniques for advancement of tunnel face, described in the subsequent paragraphs. In case of mountainous region having very steep vertical cliffs with valley on other side, the approach to tunnel or sometimes road alignment itself may have to be planned along cliffs. In such case the option of half tunnel by partial excavation on hillside with one side remaining uncovered and exposed to valley side, can be considered if geological formations are favorable. The details about 'Half Tunnel' are dealt with at the end of this chapter in para **5.6.**

5.2.3 *Advancement of tunnel face by excavation*

Various types of equipment required to tackle different types of strata envisaged shall be planned for right from the beginning. The tunnel face shall be advanced by carrying out excavation using techniques and methods suitable for type of strata, stand up time of the strata, type of machinery available and with due regards to size and shape of tunnel. The tunnel face can be advanced by two techniques as follows:

- No-Blast Techniques.
- Conventional Technique of Drilling and Blasting.

Most common technique used for advancement of tunnel face, except in soft strata is by 'Drilling and Blasting' and same is dealt with in detail separately in para **5.3** below.

5.2.3.1 No-blast techniques

In many a situation, where surface subsidence is not desirable or where blasting vibrations cannot be permitted and where speedy Tunnelling operations are desired, No-Blast Techniques are employed with advantage. Various machines are available for such work:

Tunnelling Shields

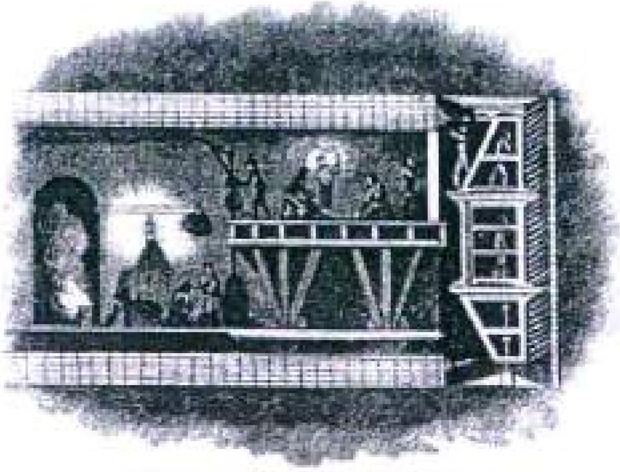


Photo of Tunnelling Shield

Tunnelling Shields are used for constructing circular or ovular tunnels through different types of soft ground. Shield is a rigid steel cylinder. The front end is in the form of a cutting edge and fitted with excavation facilities and the rear end has facilities for removal of excavation spoils and for installation of supports inside the tail of the shield. In shield tunnelling, periphery of excavation is not visible as it is either supported by the shield itself or by tunnel supports. As the excavation at the face progresses, the shield is pushed forward with the help of hydraulic jacks which take thrust from the supports at the rear end of the shield. During forward movement of the shield, the tail end slides past the supports already erected inside the tail transferring the load of the excavated periphery from the shield to the supports. Various types of shields such as Compressed Air Shield, Slurry Shield and Earth Pressure Balancing Shield etc. are available to deal with different soil conditions.

Roadheaders

Another type of machine that can excavate tunnels of any shape is the Roadheader. It has a hydraulic boom with a rotary cutting head at its front end, a loading device usually involving a conveyor and a crawler traveling track to move the entire machine. The boom can be moved up or down and right or left to cover the whole face. The boom presses the rotating cutting head into the rock face, cuts the rock into small fragments which drop down to the invert of the tunnel. Collector arms of the machine pull the muck onto an apron which transfers the muck onto a trailing conveyor for depositing the muck into muck disposal vehicles. In case of soft soil tunnels, the roadheaders operate under the protection of and inside the shields. Apart from rotating cutting head, various types of special function heads are available. For tunnels having height more than about 5 m excavation using roadheader may have to carried out in multiple stages in view of boom limitations, even in competent rocks.

Photo of Roadheader

Tunnel Boring Machines

One type of machine which can excavate only circular sections through a variety of strata from hard rock to soft strata and at a considerable speed is the Tunnel Boring Machine (TBM), which comprises a rotating circular head with several cutters mounted on its face. As the cutter head rotates, it presses the cutters into the tunnel face, cuts rock into small fragments, picks up the dislodged rock fragments with its muck collectors and drops the fragments onto the head of a trailing conveyor for depositing them into muck disposal vehicles. The TBM train is scores of meters long and has arrangements and equipment for drilling of probe holes and grout holes, erection of precast lining segments and grouting, as well as service equipment such as dewatering pumps, transformers, hydraulic power units, containers for materials, rest rooms etc.

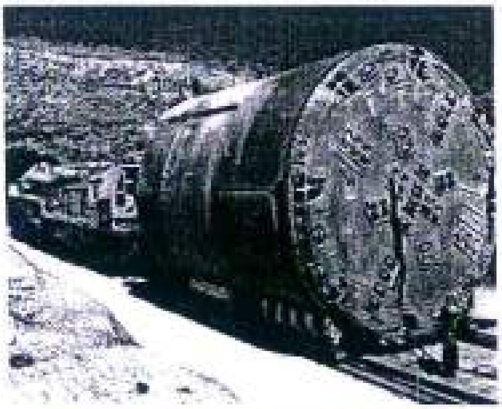


Photo of Tunnel Boring Machine

TBM can be steered in vertical and horizontal direction along smooth curves. TBM have advantage of not disturbing surrounding strata which makes them suitable for use in built up area. However main disadvantage is cost as they are expensive to construct, difficult to transport and require significant infrastructure. Various types of TBMs such as Open, Shielded and Earth Pressure Balancing Machine are available to deal with different soil conditions with certain limitations.

Splitting Techniques

Where rock cannot be blasted for various reasons such as avoiding noise, vibrations and surface subsidence, the rock can be split along planes of weaknesses and fissures. Then the pieces can be separately picked up and removed. There are various methods available for splitting the rock. Some of them are listed below:

a) Conventional wedging and splitting:

Wedges and feathers are inserted into natural fissures or predrilled holes and the rock induced to split along the line of wedges, for subsequent removal.

b) Hydraulic Splitters:

Hydraulic splitters can be inserted in holes pre-drilled in a pattern and the rock induced to split along the line of holes quickly and noiselessly, of subsequent removal.

c) Splitting rock using expansive chemicals:

When such chemicals are poured into holes/fissures, they expand and split the rock in predetermined patterns, for subsequent removal.

d) Other splitting agents such as Cardox, Nonex and Penetrating Cone Fracture (PCF):

The Cardox system is based on liquid Carbon dioxide being converted to high pressure carbon dioxide gas with ignition. The gas spreads through fissures and microcracks in the rock and breaks it in tension, rather than compression as with explosives. It is this tension breaking mechanism that results in the reduced noise, vibration, flyrock characteristics and much less energy required to break the rock in this way.

Both the Nonex and PCF products are based on the burning of a propellant, releasing many gases at high pressures, again breaking the rock along existing fractures to break in tension.

The Nonex system consists of a cartridge which contains a propellant which when ignited produces high volumes of harmless gases such as nitrogen and carbon dioxide are released, providing a pressure increase when the cartridge is sealed in a drillhole. Nonex is particularly suited in situations where the rock is not required to be fractured, but rather, split as it does not cause the rock to shatter.

The PCF tube is a hollow plastic tube, open at one end which can then be filled with the powdered smokeless propellant and then closed with a small cap. The other end is machined into a wedge to lock into the stemming, and to seal the hole when inserted for ignition. In the cap there is an entry port for insertion of an electric match, which is the means of detonation. This heat ignites the propellant. As there are not the crushing effects of compressive breakage as with explosives, dust and fines are significantly reduced. As the rock requires less energy to break in tension than compression, a much smaller energy input is required.

These methods are slow and are preferred where use of other techniques is not feasible.

Immersed Tube/Sunken Tube Tunnels

An Immersed/Sunken Tube is an underwater tunnel made up of prefabricated elements in the form of a tube. The elements are cast on the shore, floated to the tunnel site, sunk in to place (often into an excavated trench, connected to the elements already in place, finished and covered up. Immersed/Sunken Tube normally takes off from and ends into a cut and cover tunnel or bored tunnel constructed up to the edge of water.

An Immersed/Sunken Tube works out to be a cost effective solution when a cost of a bridge turns out to be quite high due to high depth of water, difficult ground conditions for foundations etc. and cost of a bored tunnel turns out to be high due to ground conditions.

Immersed/Sunken Tubes cause least disturbance to marine traffic and are more resistant to seismic vibrations.

Cut-and-cover Tunnels

Cut-and-cover is a simple method of construction for shallow tunnels.

Two basic forms of cut-and-cover Tunnelling are available:

In the Bottom-up method, a trench is excavated with the help of ground support in the form of diaphragm walls, sheet piles or intersecting piles etc. and the tunnel is constructed within. The tunnel may be of in situ concrete, precast concrete, precast arches, corrugated steel arches etc. The trench is then backfilled with compacted fill material and the surface is reinstated.

In the Top-down method, initially, a trench is excavated with the help of ground support in the form of diaphragm walls, sheet piles or intersecting piles etc A shallow excavation is then made to allow the tunnel roof to be constructed using precast beams or in situ concrete. The surface is then reinstated except for access openings. This allows early reinstatement of roadways, services and other surface features. Excavation machinery is then lowered into the access openings, and the main excavation is carried out under the permanent tunnel roof, followed by constructing the base slab.

5.2.3.2 *Conventional technique of drilling and blasting*

(A) In the conventional technique of drilling and blasting, holes of requisite diameter, length and direction, as determined from the blast design, are drilled into the tunnel face at designated locations. The profile of the drilling holes is marked on the face of the tunnel with the help of surveying. The job of correct profile marking has to be emphasized to the surveyor and the marker. The direction of holes with respect to the face cannot be marked at site and therefore that aspect has to be explained to the operator of the drilling machine. Before profile marking, the study of the last executed and plotted profile must be made and then required changes, if any, may be made.


Photo of Drilling Jumbo

The time cycle of the activity may be noted and variation with the planned time may be studied for modifying the blasting pattern. The drilling at face according to profile marking is carried out with the help of drilling jumbos, which operate electrically/hydraulically. In advanced machines, the three dimensional drilling pattern can be fed into the program of the drilling jumbo. In such cases the activity of profile marking on tunnel face is not required. The water pressure for flushing the drill holes must be controlled so as to avoid the weakening of surrounding rock mass in case of Tunnelling in jointed and weak rock mass. The 'look out' of the drill holes may be kept as low as possible, depending upon the deployment of the drilling machine. At the end of drilling activity, the details of the holes including their number, depth, diameter, and angle with the face along with the time taken for the activity may be recorded and analyzed vis-à-vis the provision in the Method Statement.

(B) Based on the planning contained in the Method Statement and the experience gained from the previous cycles the charging of the face shall be carried out with the explosives. Due consideration shall be paid to the charge per series of detonators and the location of the holes being charged in the face for minimizing the vibrations and damage to the surrounding rock mass. Charge comprising of designed quantity of suitable explosives together with a delay detonator of designated delay shall be inserted into each drill hole. Leading wires of the detonators shall then be connected to form a circuit and ends of the circuit connected to an electric exploder through hook up wires. Due safety precautions at the time of charging the face shall be taken. The face shall be cleared and service lines, equipments withdrawn from the face and shall be parked at a safe distance of about 70 m from the tunnel face. The other necessary precautions as prescribed for blasting shall be observed. The exploder shall then be charged and the circuit fired to blast the explosives. To overlap the activity of 'charging the holes' and the 'drilling of holes', the use of non-electrical detonators (NONEL) can also be resorted to. By doing so, the overall cycle time can be reduced at some extra cost. NONEL is also suitable for safe working in periods of lightening incidence.

(C) For facilitating drilling, charging of blast holes and scaling etc. mobile access platforms with intermediate deck can be used. Mobile Drilling Jumbos comprising of hydraulic rock drills mounted on hydraulic booms which can cover full face of a tunnel are available. A basket mounted on a telescopic hydraulic boom is also provided with the jumbos for facilitating scaling, charging of blast holes etc.

(D) Where for aesthetic or any other considerations, it becomes necessary to create a smooth line of breakage at the periphery of excavation, closely spaced holes are drilled along the periphery. These holes are treated as dummy holes and are left uncharged during blasting. Outermost ring of the blast holes are drilled about 200 mm inside the tunnel periphery depending upon the properties of the rock. Line joining these peripheral holes creates a weak line of breakage. The drilling patterns and blasting technique are dealt in detail at the end of this sub-section.

(E) Ventilation: The tunnel face is a dead end and at the same time it is an area of maximum activity. It therefore becomes necessary to see that the face is properly ventilated by means of artificial ventilation. Where the excavation is carried out by the No-blast Techniques, operation of heavy equipment generates a lot of heat, diesel equipment fumes and increased humidity. Where excavation is carried out by Drilling and Blasting technique, heat and fumes caused by the blast need to be exhausted out from the face.

Artificial ventilation is effected by means of by axial flow type fan(s) operating on a ventilation duct. In tunnels where reversible type axial flow fans are used, immediately after the blast, the fans are operated in the exhausting mode so as to suck out blasting fumes from the face. Thereafter the fans are reversed to operate in supply mode so as to supply fresh air at the face

5.2.4 *Methods of driving the tunnel*

Methods of driving the tunnels by attacking the face depends upon the size and shape of tunnel, equipments available, the condition of formation, the stand up time of the strata through which tunnel is passing, the extent to which supports are necessary and overall economics. Tunnels can be driven by the following methods:

- Full Face Method
- Heading and Benching Method
- Multi-drift Method
- Multi section Method

5.2.4.1 Full face bethod

This method is used when the tunnel is being excavated through stable formations. Limitation of full face method depends upon the size of the tunnel and capacity of equipment being used for the job.

5.2.4.2 *Heading and benching method*

Heading and Benching method is used when height is more than about 8 m and area of the face is large and/or when the tunnel is being excavated through not very stable formations, to enable installation of supports within the available stand-up time.

5.2.4.3 *Multi-drift method*

In this method, the heading and the bench are divided into smaller parts. This method becomes necessary when the tunnel is being excavated through very poor and unstable formations, to enable installation of supports within the available short stand-up time.

5.2.4.4 *Multi section method*

For wider tunnels in stable formation pilot heading followed by side slashing has to be resorted to.

5.2.4.5 *Advance probing & treatment*

Even in the so called compact and hard rock formations, possibility of meeting jointed and weak and water charged zones can not be totally ruled out. Though the geotechnical explorations help to gain adequate knowledge of the strata, knowledge about the condition of the strata immediately ahead becomes absolutely necessary for safe and efficient Tunnelling through heterogeneous strata. Assessment of the strata immediately ahead is carried out by drilling probe holes of suitable diameter through the tunnel face itself. If water starts gushing out through a probe hole, it indicates presence of ground water ahead and sufficient care shall be exercised. Sudden increase or decrease in the rate of drilling would give indication of the thickness and condition of joints and weak zones. This information enables to carry out advance grouting to seal passages of water and loose joints and be prepared to deal with the difficulties before actually entering the ground ahead.

It is therefore preferable that assessment of the strata immediately ahead is carried out by drilling probe holes, on regular basis. In locations where the geological investigations indicate likely presence of highly jointed and fissured formations such assessment with advance probing and treatment shall be made mandatory.

5.2.5 *Scaling*

Immediately after blasting, defuming activity at the face shall be taken up using the ventilation fans and the ducting system provided. The defuming time will depend upon the type of explosive, quantity of explosive and the ventilation system, etc. Thereafter the face shall be approached and inspection shall be carried out to see the efficacy of the blast. The service lines shall then be extended/reinstalled. If found necessary, water shall be sprinkled on the muck pile created at the face to contain the blasting fumes. The scaling, which is an operation for knocking down all loose rock fragments hanging on to the periphery of the Tunnel, shall then be started mechanically or manually immediately after the blasting fumes are exhausted from the face.

Routine inspection of the periphery of already excavated tunnel shall also be carried out and loose scales that may have developed because of spalling shall be knocked down.

5.2.6 *Disposal of excavated muck*

The blasting crushes the rock of the tunnel face into small fragments and forms a muck pile in front of the face. After scaling of the sides and face, the activity of removing the muck shall be undertaken provided the excavated sides and the face retain themselves till the muck from the face is removed. Otherwise, the muck pile shall be spread near the face and temporary support measures be adopted to increase the stand up time. The muck coming out of excavation at the face shall be removed from the face with the help of loaders and muck haulage units and led to and disposed off into the areas designated for muck disposal. In case of long tunnels, deployment of diesel operated excavators/loaders and dumpers for muck removal be avoided and in their place electrically/pneumatically operated loaders and battery operated haulage cars or belt conveyers shall be preferred. For long tunnels rail mounted equipment as against tyre mounted equipments and conveyers are preferred.

A suitable area in one or more locations, of adequate size to hold the total quantity of muck expected to be removed from the tunnel with a reasonable height of the pile, shall be identified and earmarked as Muck Disposal Area. This Area shall be well accessible from the Tunnel portal(s), connected by a road of appropriate quality. The muck haulage units carrying the disposal muck from the tunnel shall dump the muck only within this Area and dozers shall be deployed for spreading the muck uniformly in layers to permit muck to be stacked safely up to the design height of the pile. In the process of building up the pile up to the maximum specified height, temporary roads shall be formed by the dozer(s) to enable the dumpers to reach various locations of the Muck Disposal Area to spread the muck uniformly. In all the temporary stages the pile shall be carefully heaped and leveled to avoid unintended and unsafe slides or collapses of the slopes. Once a particular stack reaches its deigned height, muck dumping shall be immediately diverted to the next designated pile. The stable slopes of the stack shall be pitched with excavated stones to prevent mud from oozing out and the slopes shall be finally turfed to make them more stable and prevent erosion due to run-off water.

5.2.7 *Installation of temporary and permanent support*

Provision of Tunnel Supports becomes necessary when exposed periphery of a tunnel is not capable of standing on its own as time passes. The temporary and permanent rock support may consist of one or the combination of following measures;

- Providing plain shotcrete on the excavated surface with or without wire mesh.
- Providing steel fibre reinforced shotcrete on the rock surface.
- Providing tor steel/high tensile steel rock anchors.
- Providing tor steel/high tensile steel pretensioned rock bolts.
- Providing structural steel/lattice girder ribs with backfill concrete/ shotcrete.
- Providing plain/reinforced concrete lining.
- Providing forepoling

It shall be realised that for efficient and safe tunnelling, supports shall be installed as soon as possible after exposing the face and well within the stand up time.

- Plain or Steel Fiber Reinforced Shotcrete, as the name suggests, is concrete shot over exposed periphery of a tunnel. In case of Tunnelling through highly weathered and very highly jointed rocks, immediately after completion of defuming, a layer of Steel Fiber Reinforced Shotcrete [SFRS] shall be placed on the exposed periphery, to give it an immediate support and to prevent dilation of the exposed surface and to extend it's stand up time. This will also make the area safe for further operations. Even in very stable rock formations, a layer of shotcrete is provided over exposed periphery to prevent weathering and dilation of joints.
- Rockbolts are provided to stitch together layers of jointed and blocky formations. Different types of rockbolts such as split-wedge type, expansion shell type and those grouted with resin or mortar capsules etc. are available. The choice depends on the type of strata in which the rockbolts are to be placed. For facilitating installation of rockbolts, Mobile Access Platforms can be used. Rockbolters comprising of a

hydraulic rock drill mounted on hydraulic boom for drilling and a basket mounted on a telescopic hydraulic boom for installation are also available for rockbolting.

- Provision of ribs made of joists or lattice girders is made where exposed periphery of a tunnel is not capable of standing on its own and needs active external support. To form a continuous roof, lagging in the form of steel plates or concrete planks shall be placed over the extrados of the rib supports and the annular gap between the tunnel periphery and the lagging shall be tightly packed with backfill concrete. In case of Lattice Girder Supports, girders shall be embedded in plain concrete lining or SFR Shotcrete.
- Where excavation of the heading is carried out by multi-drift method i.e. by initially advancing the central drift & followed by widening to full section of the heading. Arch of the Central Drift shall be supported using segments of the arch rib and held in place by rock bolts or by installation of temporary verticals and bottom struts. After completion of excavation & supporting of the central drift, widening of the central drift shall be carried on in stages. At this stage, the segments of the arch ribs already erected in the central drift shall be extended in the widened section. These extension segments can be held in place by rock bolts or the other end of these extension pieces shall be made to rest and fixed onto a wall beam laid on each side of the heading. In case of Supports fabricated out of steel joists, concrete lagging planks shall be placed over the extrados of the supports and the annular gap between the tunnel periphery and the lagging shall be packed with backfill concrete. In case of Lattice Girder Supports, the girders shall be embedded in SFR Shotcrete/concrete lining.
- Plain or Reinforced Concrete Lining of appropriate thickness shall be used where exposed periphery of a tunnel is not capable of standing on its own and needs active external support. The Concrete Lining can be built from pre-cast segments or can be cast-in-situ. Cast-in-situ lining in sides and overt of tunnels can be cast together using mobile telescopic shutters or in separate operations. Invert concrete can be placed thereafter. Mixed Concrete shall be brought to the placement point in transit mixers and placed in position with Concrete Pumps. Depending upon the development of the stresses in the tunnel, suitable time gap shall be allowed between excavation and lining so as to gain stability of the excavated section of rock and thus avoid transfer of load to lining.

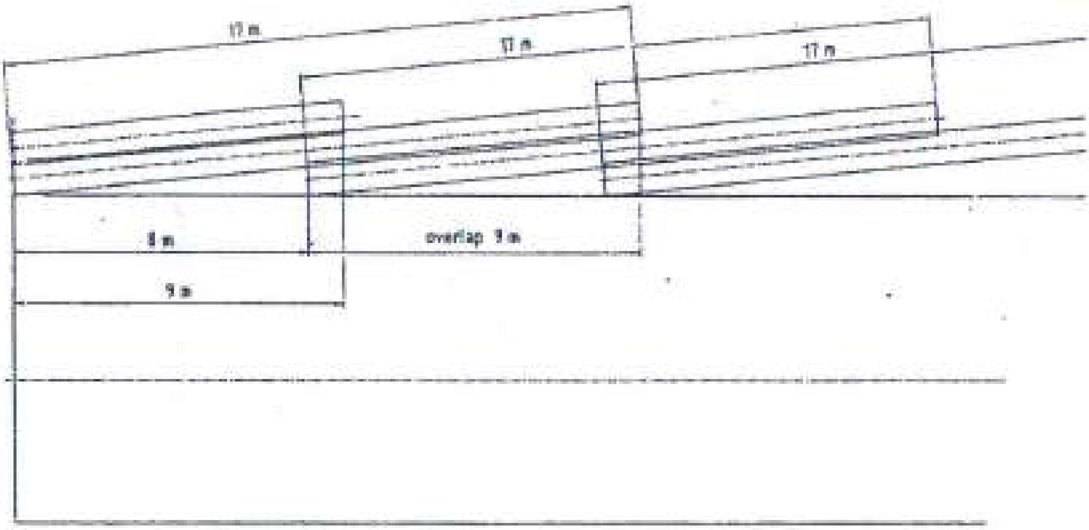
- Where excavated tunnels require concrete lining, cast in-situ concrete lining is commonly adopted. However, lining using precast concrete segments and installed soon after excavation is adopted where speed is critical. Typically, the assembly of precast segments is always in the shape of a circle and the elements form segments of the circle, typically with 4 to 8 segments per cross-section. These interlocking segments are connected in the transverse and longitudinal directions using bolts and compressible seals or only with interlocking of special keying shapes formed while casting. As such, great care is necessary to ensure the correct geometry while precasting these segments. Rigid steel moulds are normally used to ensure correct geometry and to minimise progressive damage/warping after many repetitions of the mould. Such moulds shall be properly designed and fabricated using specialized expert agencies. Good care shall be exercised while using and handling these moulds to avoid damages. Concrete for precasting shall be with approved appropriate mix design and shall be of sufficient high strength to be able to safely bear the handling and stacking stresses apart from the permanent stresses. Curing shall be carried out for adequate time period before the segments are sent inside the tunnel so that adequate strength is developed. Often steam curing is used in conjunction with precasting to ensure early development of strength to permit handling and stacking. The precast segments shall always be identified with engraved/permanent-painted markings to ensure that they fit into the right place during assembly at site. The segments shall be stacked as per designed methods to ensure that no damage is caused, particularly to the edges and corners so that the permanent joints are not impaired. The ground in the stacking yard shall have adequate strength to bear the stacked segments without any undesirable deformations. Any segments having warping of the sections or chipping of the edges and corners shall not be sent inside the tunnel unless proper rectifications are carried out (wherever such rectifications are feasible only), using approved techniques. Usually vacuum grips using rubber pads are used for lifting the segments. Such equipment shall be regularly checked to ensure proper and safe working to ensure that there is no damage to the segments and also to ensure good safety during construction. Wherever precast segmental lining is used, it is preferable to have a mock-up done prior to use in the regular Tunnelling operations to ensure that the correct geometry is attained and to check up on the interlocking of the joints and efficient functioning of the assembly. The space behind the lining and excavated periphery of rock is generally filled up with pea gravel, injected with cement grout and adequate contact for stress transfer from the rock strata to the lining is ensured.

- In poor rock with limited standup time, forepoling technique is used to improve/strengthen the strata ahead above the tunnel roof before advancing the face. Basically an arch-like shell is created ahead of the tunnel face prior to its excavation, enabling tunnel excavation to be carried out safely and speedily under a protective arch. Forepoles are also installed to treat cavity formation and extremely weak geological material like highly sheared rock mass and even overburden material like colluvium and river deposits. Forepoling is also useful in situations where tunnels have to be excavated at shallow depths, or where minimum disturbance is to be caused to the surface structures, i.e. ground surface settlements have to be restricted, as for instance in urban areas. Three different methods of forepoling are commonly used:

i) Roofing Method: Forepoling is carried out by installing steel bars of required diameter (generally 25 mm, 32 mm and 36 mm). Steel sections, plates or pipes can also be used instead of rods in poorer strata. Length of fore poles may vary from 5 m to 12 m. Spacing is generally 300 to 500 mm depending upon the geological material to be treated. Forepoles can be used with or without grouting. Forepoles are installed outside the tunnel periphery at an angle (with the longitudinal horizontal centerline of the tunnel) ranging from 5 to 7 degrees up. For Pipe roofing heavy duty seamless steel pipes are used with or without perforations to allow grouting to be done through the perforations. Pipe diameter varies from 89 mm to 100 mm and length may vary from 10 m to 20 m depending upon the site conditions. Pipe jacking or micro Tunnelling methods can also be used for installing the pipes.

ii) Spiling Method: The Spiling method is a ground improvement technique where the support structure of a tunnel top sector is installed ahead of the excavation of the face. Such support mechanism provided by forepoling technique stabilizes the tunnel face area in both longitudinal and transverse directions by means of an arch-like reinforced zone formed primarily by injection. This method can also be used in conjunction with standard drill-and-blast Tunnelling when severe fault zones are encountered or wherever extra support structures are required.

iii) Horizontal Jet Grouting Method: Horizontal Jet Grouting is a technique used for Tunnelling through soft ground especially with difficult conditions where both weak soils and thin overburden occur and in sandy or gravel formations. The technique is used for creating a protective fan-shaped canopy ahead of the face, as a temporary support for advancing the face under its protection comprising of near horizontal columns, of a diameter of 0.5 to 0.9 m usually at an angle of about 15° with the centerline/axis of the tunnel. The process of jet grouting uses a high speed jet with nozzle pressure of up to 50 MPa. The jet fractures the soil around and mixes the soil with the cement/chemical grout and forms a near horizontal column upon setting. As the face is advanced, the canopy is also progressively advanced.



Driving of pipes for Horizontal Jet Grouting in Tunnels

Biggest advantage of the technique is that it can be used in varying ground conditions and for tunnels of all shapes and reduces surface settlement and is therefore most suitable for urban Tunnelling through soft ground. However, as the process of jet-grouting is a high energy process, in shallow tunnels the jet-grouting process may induce surface settlements that exceed the design requirements.

Ground Freezing technique is used for Tunnelling through water-bearing soft ground. Ground freezing is achieved by circulation of a freezing mixture such as brine or liquid nitrogen etc. through a suitable pipe system, so as to cool the soil and convert the soil water to ice. On freezing the wet soil gets converted into a hard mass resembling concrete which is watertight and has load carrying capability. Ground freezing can be applied in all types of soil and groundwater conditions, such as running sand, clay and gravel.

5.2.8 *New Austrian Tunnelling Method (NATM)*

For tunnelling in soft grounds, an approach called 'The New Austrian Tunnelling Method' (NATM) can be adopted. It was developed between 1957 and 1965 in Austria and was given its name to distinguish it from the old Austrian tunnelling approach. The main idea is to use the geological properties of the surrounding rock mass to stabilize the tunnel itself.

The main idea is to use the geological properties of the surrounding rock mass to stabilize the tunnel itself. The NATM integrates the principles of the behaviour of rock masses under the influence of the excavation method and the support system and monitoring the performance of underground construction during construction. The NATM is not a set of specific excavation and support techniques. The NATM is a philosophy where properties of the surrounding rock or soil formations of a tunnel and the support systems are integrated into an overall ring-like support structure. Thus the supports and the formations will themselves be part of this supporting structure.

The NATM has since been adopted the world over for a large variety of ground conditions including rock tunnelling. Based on experience, the philosophy has been renamed as Norwegian Method of Tunnelling [NMT].

NATM/NMT are based on following features:

- *Mobilization of the strength of ground mass* - The method relies on the inherent strength of the surrounding ground mass being conserved as the main component of tunnel support. Primary support is provided to enable the ground to support itself.
- *Shotcrete protection* - Loosening and excessive ground deformation must be minimised. This is achieved by applying a thin layer of shotcrete immediately after face advance.
- *Measurements* - Every deformation of the excavation must be measured. NATM/NMT requires installation of sophisticated measurement instrumentation. It is embedded in lining, ground, and boreholes.
- *Flexible support* - The primary lining is thin and reflects recent strata conditions. Active rather than passive support is used and the tunnel is strengthened not by a thicker concrete lining but by a flexible combination of rock bolts, wire mesh and steel ribs.
- *Closing of invert* - Quickly closing the invert and creating a load-bearing ring is important. It is crucial in soft ground tunnels where no section of the tunnel should be left open even temporarily.

- *Contractual arrangements* - Since the NATM/NMT is based on monitoring measurements, changes in support and construction method are possible. This is possible only if the contractual system enables those changes.
- *Rock mass classification determines support measures* - There are several main rock classes for tunnels and corresponding support systems for each. These serve as the guidelines for tunnel reinforcement.

Based on the computation of the optimal cross-section, just a thin shotcrete protection could be adequate. It is applied immediately behind the face, to create a natural load-bearing ring and therefore to minimize the ground deformation. Additionally, geo-technical instruments are installed to measure the later deformation of excavation. Therefore a monitoring of the stress distribution within the ground mass is possible. This monitoring makes the method very flexible, even at surprising changes of the geo-mechanical ground mass consistency during the Tunnelling work. Such problems are not solved only by thick shotcrete, but by using mesh reinforcement/SFRS which can be combined with steel supports or rock bolts.

The measured rock properties lead to the appropriate tools for tunnel strengthening. Therefore NATM/NMT is also applied to soft ground excavations and to tunnels in porous sediments. The flexible NATM/NMT technique enables immediate adjustments in the construction details, but this requires a flexible contractual system too.

The key features of the design philosophy refer to:

- The strength of the ground around a tunnel is preserved and deliberately mobilised to the maximum extent possible.
- Mobilisation of ground strength is achieved by allowing controlled deformation of the ground.
- Initial primary support is installed having load-deformation characteristics appropriate to the ground conditions, and installation is timed with respect to ground deformations.
- Instrumentation is installed to monitor deformations in the initial support system, as well as to form the basis of varying the initial support design and the sequence of excavation.
- If necessary, additional layers of shotcrete are sprayed which, in combination with the earlier support, function as the final support/ lining.

For the construction method, the key features are:

- The tunnel is sequentially excavated and supported, and the excavation sequences can be varied.
- The initial ground support is provided by shotcrete in combination with fibre or welded-wire fabric reinforcement, steel arches (usually lattice girders), and sometimes ground reinforcement (e.g. soil nails).
- The permanent support is usually (but not always) a cast-in-place concrete lining.
- Additional layers of shotcrete are sprayed which, in combination with the earlier support, provide the final support / lining.

5.2.9 *Grouting*

5.2.9.1 Where tunnel excavation is to be carried out in poor ground conditions arising from various reasons such as poor quality rock (low strength rock, sheared rock), excessive ground water, poor behavior due to very high stresses (high cover and residual stresses), very low cover area, etc, pre-grouting is a useful technique. Different types of grouting techniques used in Tunnelling are;

- *Consolidation grouting* - carried out to consolidate poor rock mass,
- *Water control grouting* - carried out mainly to reduce excessive ground water flows. Curtain grouting is one example of the Water control grouting,
- *Contact grouting* - carried out after the installation of a lining (either cast in-situ or precast concrete lining) to fill up the gaps between the outer surface of the lining and the excavated periphery.

5.2.9.2 Consolidation grouting is carried out to consolidate poor ground mass. The grout pumped into weak mass gets filled inside the fissures and other openings and consolidates the ground mass or overburden resulting in a cohesive mass with increased strength due to mixing of grout and geological material. It also controls any seepage to some extent. Consolidation grouting is done generally through holes drilled from the working face longitudinally (with an outward slope) to cover zones yet to be excavated and also through transverse holes to stabilize the ground mass around the already excavated tunnel.

5.2.9.3 Water control grouting (pregrouting) is done through holes drilled to cover the zones ahead of the excavated area to arrest seepage of water into the excavated tunnel. Holes are drilled at an angle to the longitudinal centerline of the tunnel, from all round the periphery of the cross-section. The number of holes and spacing depend on the circumstances involved. In areas of low seepage, Tunnelling can proceed ahead of the seepage zone and arresting the seepage can be carried out with suitable lag behind the excavation face. Length of holes varies from 3 m to 15 m. For arresting large seepages, careful planning is necessary. It is preferable to carry out such grouting ahead of excavation i.e. before tunnel face enters such zone. The locations and extent of grout holes as well as the type of grout and its composition have to be designed duly considering the various parameters such as exact location of seepage, presence of porous seams, origin of seepage water, amount of seepage and its pressure, etc. Such grouting is best done using specialized agencies.

5.2.9.4 Contact grouting is done using transverse drilled holes for cast in-situ lining to fill up the voids caused by shrinkage of concrete or where lining concrete has not penetrated all excavated areas. Contact grouting is essential where cast in-situ concrete plugs are required for a tunnel. In the case of precast and installed concrete lining the cavity behind is normally filled up with pea gravel and grout is injected inside to consolidate the gravel into concrete. Grouting is also done in conjunction with pipe roofing to treat cavity formations and as part of forepoling operations.

5.2.9.5 Grout used for these applications is generally neat cement grout. The water-cement ratio varies from case to case but generally ranges from 1:5 to 0.6. Similarly, grout pressure will range from less than 1 bar to 15 bars depending on the material to be grouted and the ground conditions. Care shall be taken to limit the pressures in areas where possible fracturing of existing strata is dangerous. Pressures are higher where fracture grouting is required/permissible or for jet grouting. Fine sand is added to the grout where large cavities have to be filled up. Special grouts are used for treating seepages, using admixtures such as sodium silicate. Polyurethane Foam (PUF) is also used often to arrest large seepages. Reference to relevant provisions of standards covering River Valley Grouting may also be made.

5.2.10 *Plotting of excavated profiles and geological mapping*

At the end of each excavation cycle, the geo-logging and profile plotting of the excavated tunnel is very important along with evaluation of the efficiency parameters. After analyzing this activity, next cycle may be modified to the required extent.

5.2.11 *Monitoring*

Depending upon the geology of the rock mass during tunnelling, convergence measurements at the excavated crown and sides may be taken up with the help of multi-point bore hole extensometers or studs and tape extensometers. The cycle of taking readings will depend upon the convergence observed.

5.3 Drilling and Blasting

5.3.1 The blasting operation shall be so designed to get desired fragmentation with requisite advance per cycle of operations and the blast induced ground vibration level within permissible limits in accordance with IS 5676.

5.3.1.1 The drills used for tunnelling are either pneumatically or hydraulically powered and having either air pusher legs and/or mounted on drilling jumbos. With air pusher legs it is always advisable to use templates for guiding the direction of drilling. The drilling jumbos have varying specifications. They can have a simple mounting arrangement on truck or rail. In most sophisticated type of computerized jumbos drilling programme is fed in for the total drilling cycle. The choice of drilling system will depend upon the size, shape and length of tunnelling work at hand as these are the main factors deciding total economy of the project.

5.3.1.2 For a successful blast, it is most important to initially create a free face that is required to accommodate the requisite advance of subsequent serial blasts. For creating a free face (barring the burn cut pattern) it is absolutely necessary to drill the blast holes in the following manners.

- *Cut Holes:*

  These holes are located around the middle of the cut and are drilled at an inclination of about 60° and are to be blasted first to create free face for next set of blast holes termed as Cut Spreaders.

- *Cut Spreaders:*

  These are the next set of blast holes having lesser inclination and are in two or more rings. They are meant to widen the free face created by blasting of Cut Holes. They are usually 15 to 30 cm deeper than other holes.

- *Cut Easers:*

  They are drilled almost parallel to the tunnel alignment and are mainly responsible for the scheduled advance of the face. Number of rings of these holes depends upon the size of the tunnel.

- *Trimmers:*

  These blast holes are drilled near the periphery to shape up the tunnel periphery to the requisite section as per the designs and with lighter charge to avoid excessive over breaking.

Where drilling is carried out by hand-held rock drills the diameter of hole is minimum about 28 mm. In case of drilling carried out by mechanical Jumbo the diameter of holes are large to suit the rock drills. The diameter of holes at deepest point shall be about 3 mm more than the diameter of cartridge being used.

5.3.1.3 The drilling pattern to be adopted shall ensure minimum over breaks and shall consume least quantity of explosive per unit volume of excavation. The drilling pattern depends upon texture and formation of rock, size and shape of tunnel, strength of explosives and fragmentation required suitable for handling. The following are the drilling patterns most commonly used for tunnel drivage.

1) *Wedge Cut or "V" cut Drilling Pattern:* In this pattern horizontal cut holes are driven around the middle of the face, in an inclined angle of around 60^0 to the face towards the centre. Maximum explosive charge concentration is required at the apex end of the blast holes as they are to be blasted at the first instant for creation of the free face.
2) *Cone/Pyramid/Diamond Cut:* This kind of cut is suitable for laminated rock type which is of sedimentary in nature. It also helps in drivage of smaller cross-sectional area tunnels so as to break the rock along the cleavage planes.
3) *Burn (Parallel) Cut Holes:* The burn cut holes are drilled parallel to the tunnel advance and perpendicular to the face of the tunnel. Some of the drilled holes (mostly in the middle section of the face) are holes of large diameter [say 100 m,m.] or a set of closely spaced holes of conventional diameter [46 to 56 mm] and are left as dummy holes without any explosive charge, so that they act as free face for the heavily charged blast holes around. Specific Geometrical relationship in between the diameter of dummy holes and spacing in between dummy holes and charged blast holes is required to be maintained for the given rock in order to create the free face.

With Burn or Parallel holes cut possible advance per round is longer as compared to than that with angular cut holes. Success of Burn or Parallel Hole Cut depends upon accuracy in keeping the holes parallel. This requirement and requirement of holes of large diameter or a set of closely spaced holes of conventional diameter calls for use of drilling Jumbos.

5.3.2 *Blasting*

5.3.2.1 Charging of blast holes

The explosive cartridges shall be inserted in to the blast holes with great care so that the detonator leads are not rubbed or damaged in the process. The wooden tamping rod of sufficient and requisite length shall be used for the purpose. The stemming material ideally could be of mud cakes or preferably pneumatic charge locks.

5.3.2.2 *Choice of explosives*

The best choices for the blasting operations are the emulsion explosives produced by intimate and homogeneous mixer of oxidizer and fuel. Basically emulsion explosives consist of micro droplets of super saturated oxidizer solution in oil matrix. They are in the form of water-in-oil emulsion. The various advantages associated with use of emulsion explosives are as below;

- Emulsion explosives are much better water resistant than water gel slurry or ANFO. This is because the oil-phase envelops the water phase.
- They are safer to handle, store and use because of their relative insensitivity to detonation by friction, impact or fire.
- Due to the oxidizer drop-let size (0.2 to 10 micron) they have higher value of Velocity of Detonation (VOD) which can tackle the toughest rock conditions very effectively and that too with out compromising on safety standards.
- Since emulsion explosives are more oxygen balanced they generate minimum noxious fumes and very less smoke. This in turn can reduce the ventilation time after the blasts and further can shorten the cycle time of operations. Liquid emulsion explosives are pumpable and charging time can be cut down.

5.3.2.3 *Requirement of explosive*

Normally, the consumption of explosives in tunnel blasting is much more than that required for open cut, basically because in case of open cut blasting, existing free face is available whereas in tunnel blasting it has to be created. For road tunnels, the Specific Charge or the Powder Factor is normally around 1.2 kg/cum of in-situ rock on an average. However, this requirement of explosives may vary from site to site depending on the geological strata involved and the cross section of the opening.

5.3.2.4 *Choice of initiation system and selection of delay sequence*

Selection of delays in initiation system and timings shall be such as to create a free face effectively by moving out the broken rock mass so much that the rock volume after swell from subsequent blasts must be accommodated. For this the fracturing and breaking time of the rock and time required for spreading out cracks in the rocks is to be studied. It, basically, all depends on condition of rock. In hard and brittle rocks the speed of developing cracks is faster than that in softer rocks. This rock breaking speed can vary from 1-3 millisecond time per meter. But the ejection speed of rock after the blast may vary from 20-30 m per second i.e.20-30 mm per milli-seconds. So it can be understood that for a 4 m long blast holes the broken rock takes about 300-400 milli-seconds for complete removal from the face. Precisely, for this reason long delays (half-second, 300 to 500 milli-seconds) are preferred for tunnel blasting. The short (about 50 milli-second) delays can be used in baby-cut and cut holes as they can provide the requisite initial shattering effect for rock breaking and forming a free face for easer and trimmers. The advantages of delay detonators are;

- Better fragmentation,
- Reduced secondary blasting,
- More uniformity in size of fragmentation,
- Important advantage is more holes can be fired in a single blast with less vibrations, concussion and noise.

5.3.2.5 Type of initiation systems

The available initiation systems are either Shock Tube system or Combination of Millisecond and Half second electric delays. In shock tube system precise calculation of the requisite delay intervals is possible whereas, in case of electric delays there are always short comings in respect to the delay timings because of permitted tolerance. These days, Electronic Detonators ("E"Dets) are available for precision timings.

5.3.2.6 Misfires

Misfire can be defined as a blast hole that has not fired during designated blasting operation owing to following causes.

- Due to manufacturing defects.
- Due to desensitization of explosives.
- Due to faulty connections or faulty blast designs.
- Due to negligence in following laid down rules & regulations.
- Due to prevailing Geological conditions.
- Due to circumstantial conditions like water bearing strata

For dealing with misfires relevant IS codes and explosive rules shall be followed.

5.3.2.7 *Controlled blasting*

The concept of controlled blasting as applied to tunnel blasting is for minimizing over breaks and has many advantages like:

1) Less damage to peripheral rock,
2) Reduced requirement of support system,
3) Safer tunnel operation in general ,
4) Reduced requirement of scaling,
5) Reduction in over breaks.

Controlled blasting generally involves a closer spacing of contour (perimeter) blast holes which are also called as trimmers. They are charged with less explosive than that of the production blast holes. The spacing thumb rule is about 10-12 times of blast hole diameter in hard rocks and about 5-6 times of blast hole diameter in soft rocks.

5.3.2.8 *Air column method to reduce blast induced ground vibrations*

In order to reduce the cracking or damage to the strata at the periphery it is advisable to use "Air-Column Method" which can minimize the redial vector component of blast induced ground vibrations. This method consists of inserting in to the blast hole an inert spacing device of a length about four times of the diameter of the blast hole prior to charging of first explosive cartridge. This leaves requisite air gap in between the explosive cartridge and the end of the blast hole. With this method a plain straight tunnel face can be secured for next drilling cycle with out any cracks.

5.3.2.9 *Efficiency of blasting*

Efficiency of blasting shall be routinely assessed by tabulating Pull, Specific Charge, Specific Drilling, Detonator or Hole Factor, Blast-induced damage and Overbreak/ Underbreak against the values assumed during planning.

5.4 Non-Structural Works in the Tunnel

Non-structural works inside road tunnels involve construction of Side Drains, Walkways, Crash Barriers, Kerbs and Road Carriageway, which can be taken up simultaneously with the other works.

5.5 Tunnel Furnishings

Tunnel Furnishings generally comprise of Installation of Fire Fighting Water Lines, Walkway, Cable Racks, Cable Boxes, Tunnel Lighting, Tunnel Ventilation System, Telephone Stations, Signage and Centralised Monitoring System such as CCTV etc. Furnishings can be conveniently installed after completion of the Road Carriageway work.

5.6 Half Tunnels

5.6.1 *Feasibility*

For construction of roads in precipitous mountains, half tunnels can be built-in the difficult terrains, like vertical hills/cliffs to minimize the excavation quantity as well as time and cost. Half tunnels shall be constructed in selected patches of roads if rock formation is suitable. A comparative techno-economic study between half tunnel and a full face road tunnel shall be made.

There is not much similarity between half tunnels and tunnels. While tunnels are possible to be constructed in any kind of strata, half tunnels may be possible only with

the following geological conditions.

i) Fresh and less weathering prone and competent hard rock.

ii) Massive or blocky formation.

iii) Joint planes i.e. bedding shall be horizontal to sub-horizontal and shall be favorable for half tunnelling.

iv) Fresh and less weathering prone and competent hard rock.

v) Massive or blocky formation.

vi) Joint planes i.e. bedding shall be horizontal to sub-horizontal and shall be favorable for half tunnelling.

vii) Joint spacing shall be more than 3 m.

viii) Joint planes should be undulating rough and tight.

ix) Joints should be free from clay filling, shearing or fault.

Half Tunnelling is feasible even in sedimentary strata such as sandstone; limestone etc. provided joints are widely spaced and free from filling/sheared material.

5.6.2 *Design of half tunnels*

There seems to be no standard procedure for construction of half tunnels. It appears that benefits of available geology and terrain have been derived by construction engineers to build such half tunnels in very critical locations with the help of experienced blasting expert. For better appreciation, geological mapping shall be done and joint sets properly recorded and data made available for the design of the half-tunnel.

5.6.3 *Construction methodology for half tunnels*

Having decided about the location of a half tunnel, the sequence of construction shall be as under:

1) The formation level between the two points of the road shall be marked to asses required height of cut.

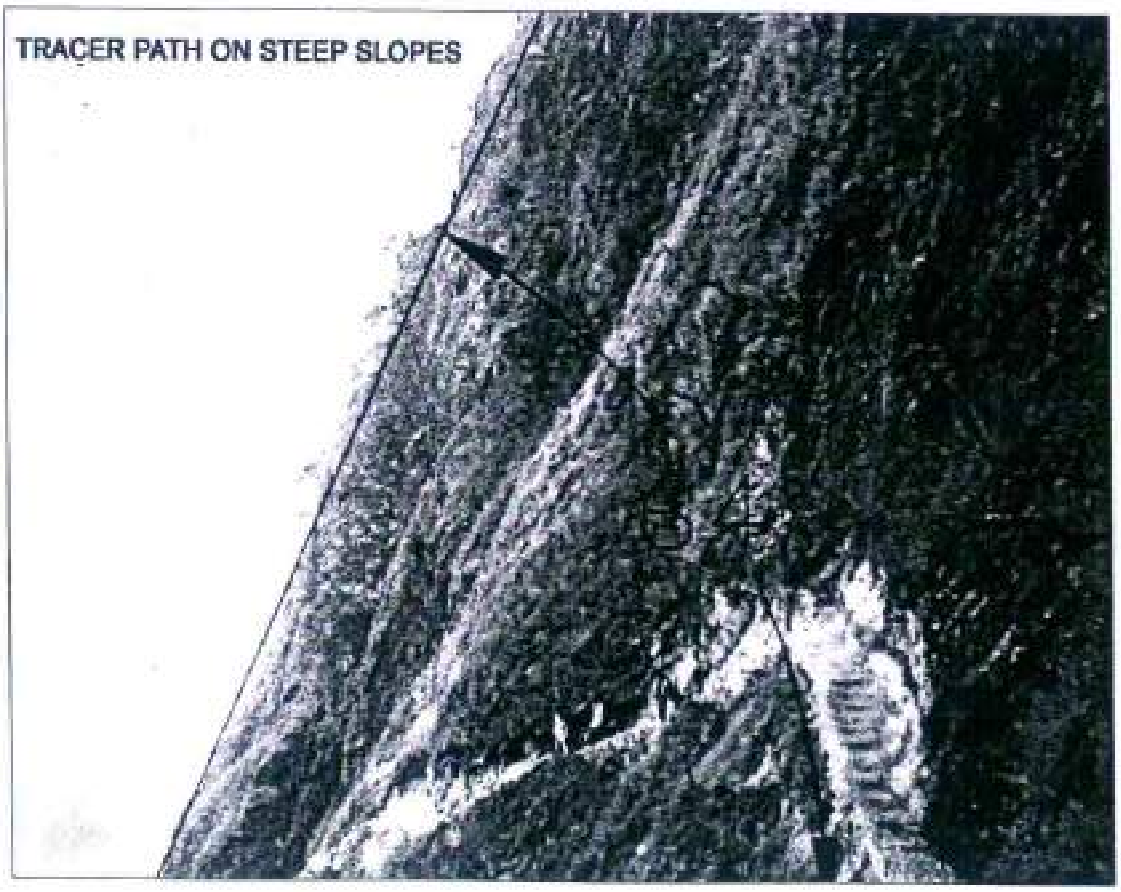
2) Then a tracer path shall be constructed by deploying labour with manual light tools, rock breakers etc. as seen in Photographs below. The size of tracer path can be about 1 m wide and 1.5 m high.

3) After construction of tracer path, 2nd operation shall be of lowering the first bench which also has to be done manually because of space constraints

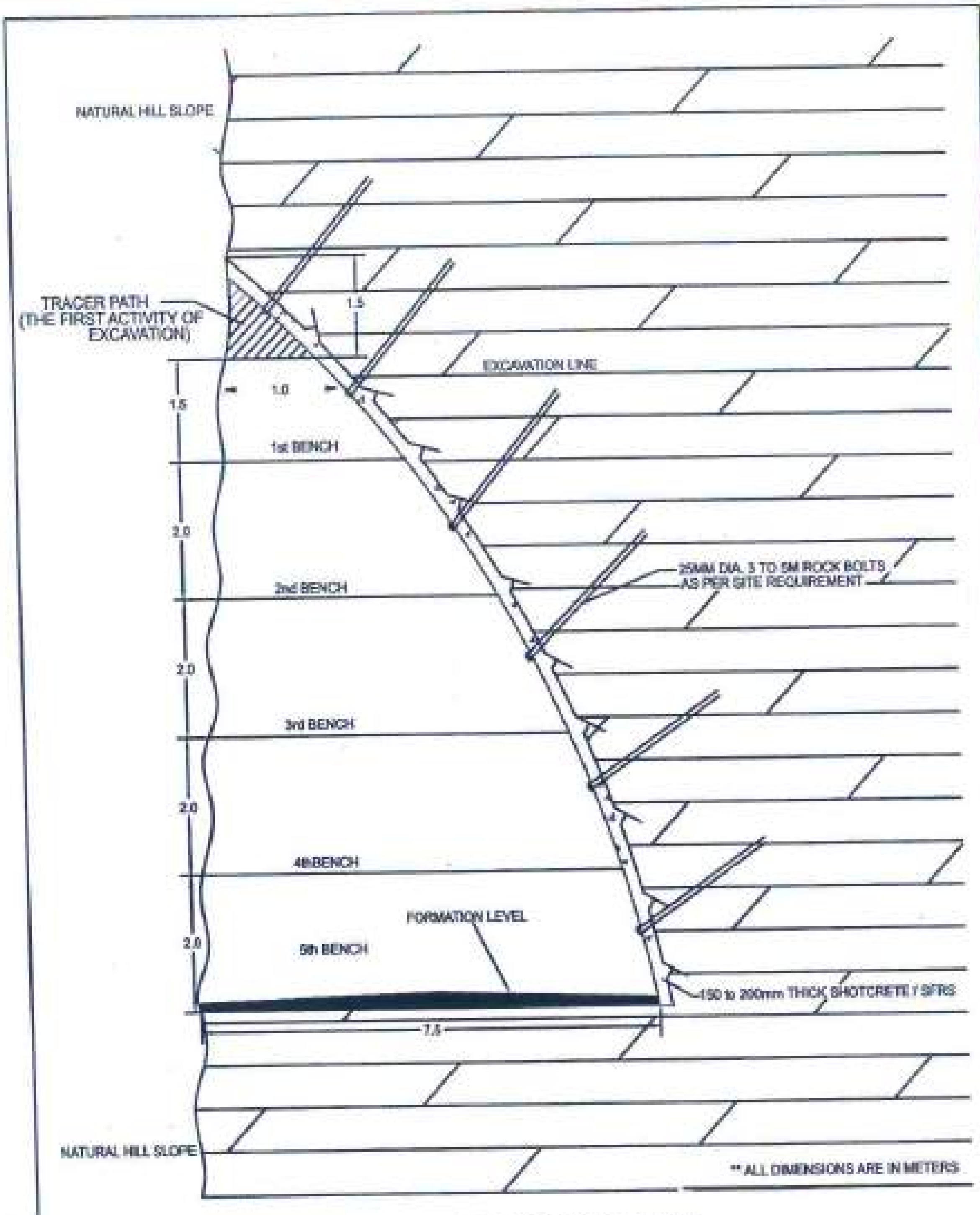
4) During the excavation sides of the trace cut and first bench shall be shotcreted or stitched by rock bolts depending upon the geology of the rock mass. Repeat operation of lowering to the next bench shall be continued till required formation level is achieved.

5) Machinery shall be used for drilling and blasting, mucking and rock supports as and when sufficient working space is created. The blast shall be properly designed to keep the shattering of the rock to minimum.

6) The process shall be continued till full width of Half Tunnel at the formation level is achieved.


TRACER PATH ON STEEP SLOPES

The whole process of construction stages is depicted in the sketch below:



X-SECTION OF HALF TUNNEL

5.7 Quality Assurance and Quality Control

5.7.1 To ensure that the Tunnel is so constructed as to serve the intended purpose satisfactorily, adoption of appropriate Quality Assurance (QA) and Quality Control (QC) measures is essential. The Design and Construction works shall be taken up only after an approved Quality Assurance programme and an approved Quality Control Programme are in place for each activity. While the QA system ensures the establishment of appropriate procedures and systems for ensuring the necessary quality, the QC system ensures that the establish Systems are duly adhered to.

5.7.2 In the Design stage the QA/QC systems shall cover, at minimum, proper establishment of the required objectives, laying down of proper procedures for the design, following established methods, deployment of competent and capable people, the setting up of a suitable monitoring and supervision system, etc for the design activities.

5.7.3 In the Construction stage, the QA/QC systems shall cover, at minimum, the laying down of appropriate construction procedures, checks on the qualities of the personnel, machines and the materials deployed in the works and suitable tests on the completed structure. All processes involved in the construction on and off the site shall be duly covered. Preparation of detailed Construction Method Statement in advance and strict adherence to the same are essential to ensure good Quality Practice.

5.7.4 The Project Quality Plan covering the above at various stages shall be prepared by the concerned agencies and got approved by competent authority. Such systems shall be duly followed by all concern during the Design and the Construction stages.

5.7.5 Wherever relevant, existing National Standards and where they are deficient, the relevant international Standards or Good Engineering Practices shall be adopted while drafting the QA/ QC systems. The Reference Numbers of such standards referred shall be duly listed in the relevant Manuals for ready reference.

6 SAFETY DURING CONSTRUCTION OF TUNNELS

6.1 General

6.1.1 *Background*

Working in underground structures such as tunnels is an inherently risk-prone activity and the risk element increases with longer lengths of the tunnels, poor rock conditions, etc. In view of this there is a responsibility on all stakeholders –owner, consultant and constructor - in tunnel projects to ensure absolute safety during construction. There is increasing awareness nowadays of the importance of Safety, as well as the broader Safety, Health & Environment (SHE), aspects of construction. Respect for human lives is the fundamental criterion and there are many side benefits of ensuring absolute safety such as increased morale, improved productivity, enhanced prestige, etc.

6.1.2 *Applicable regulations*

The various activities involved in tunnel construction are generally covered by a number of codes, acts and regulations. Some of them are:

- Indian Explosive Act –1884
- Mines act - 1952
- The Explosive Rules - 1983
- Mines Rules – 1955
- IS 4081 – 1986 Safety Code for Blasting & Related Drilling Operations
- IS 4756 – 1978 Safety Code for Tunnelling Works

All the agencies involved in the construction of tunnels shall ensure that all applicable rules and regulations are duly complied with in strict conformity with the spirit and body of such regulations.

6.1.3 *Project safety plan (PSP)*

Since each underground project has its own peculiarities and special features in view of topography, rock features, etc, it is very essential for each tunnel project to carry out a comprehensive Risk Analysis of the particular project and evolve a Project Safety Plan (PSP). While the agencies concerned may adopt the standard provisions of their respective organisations, it is essential to have a project-specific safety plan, which is fully relevant to the particular site. The PSP shall be prepared by the concerned construction agency and got approved from the competent authority. The PSP shall address all site-specific issues and tackle all the risk elements identified.

6.2 Basic Aspects

6.2.1 *Basic philosophy*

For Underground construction in rock a fundamental safety measure would be to assess the type and category of rock and establish its stand-up characteristics. It is common practice to divide the classes of rock from Class I to Class VI with the higher numbers denoting weaker rocks. It is essential to provide adequate rock supporting measures before the expiry of the permissible stand-up time for the class of rock involved. Supports should be installed speedily and effectively. The commonly adopted supporting measures in increasing order of complexity are rock bolts, shotcrete (with or without wire mesh, with or without steel fibre inclusions), steel ribs with concrete lagging and back-packing / grouting and permanent concrete lining. The most complex supports are the provision of umbrella tubes used along with forepoling and grouting techniques. The size and shape of the underground installations shall be conducive to safe and smooth operations.

Apart from this all operations connected with the construction of tunnels shall be analysed and appropriate safety precautions taken through the implementation of the PSP.

6.2.2 *Personal protective equipment*

All personnel entering the tunnel during construction shall wear all applicable Personal Protective Equipment (PPE). The PPE shall comprise, at minimum, Safety Helmet, safety (hard) shoes, tight clothing with no loose ends and jackets/clothing with reflective stripes. Additional PPE such as goggles, gloves, dust masks, helmet lamps, etc shall also be adopted wherever conditions so warrant.

6.2.3 *Access control systems*

A proper access control system should be in place to have a clear idea at all times on the identity of all personnel who are inside the underground installations in case any accident take place and rescue operations are to be launched. It is also essential to keep track of all equipment inside the tunnel. It is common to issue token to all concerned personnel and make them deposit the tokens while entering the tunnel and retrieving the same on exiting.

6.2.4 *Signage*

Well-illuminated sign boards shall be placed at required locations to inform people of safety hazards inside the tunnel and the precautions to be taken. Some of them would include warning regarding blasting, rock falls, requirement for wearing helmets, prohibition of unauthorised entry, etc.

6.2.5 *Safety systems*

The contractor's personnel shall practise all standard safety systems. These would include at minimum, safety induction (initial training in basics of Safety) and training (routine training) exercises, medical screening of personnel for working inside tunnels, system of permits for simultaneous operations in various locations, pep talks (regular talks to workmen before they commence work on importance of safety and how necessary it is for them to observe safety regulations for their own welfare) and tool box talks (specific safety instructions at the site in the specific area of work for the workmen), talks on specific operations to be carried out on the day, safety walkabouts(general safety observance checks carried out by safety stewards by going around the site and checking observance of the various safety regulations,etc), safety audits, safety reviews and mock drills.

6.3 Drilling and Blasting

6.3.1 *Drilling operations*

Only wet drilling shall be permitted. Drilling shall not be resumed after blasts have been fired until a thorough examination has been made by blasting foreman (head blaster) to make sure that there are no misfired charges, which the drill may strike. All holes shall be of slightly greater diameter than the diameter of cartridges of explosives used. A drill, pick or bore shall not be inserted in butts of old holes even if examination fails to disclose explosives. Separate holes shall be so drilled as to be nowhere less than 30 cm clear distance away from the previous hole. Charging of drilled holes and drilling shall not be carried out simultaneously in the same area, unless Nonel type of detonators are used and adequate precautions have been taken.

6.3.2 *Blasting operations*

Where blasting operations are to be conducted, sufficient warning shall be given to all staff and workmen prior to blasting. Cell phones are usually prohibited in areas where blasting operations are conducted. Sufficient protective bulkheads, etc. shall be provided to enable personnel to take shelter behind during blasting.

All explosives shall be handled and used with care either by or under the direction of competent persons and following the Indian Explosive Act, 1884, Explosive Rules, 1983, and IS 4081 - I967 Safety code for blasting and related drilling operations. Explosives and detonators shall be placed in separate insulated carriers whether carried by persons or conveyed mechanically and an attendant shall ride with the explosives being conveyed mechanically on slopes in shafts or in underground work areas. For carrying explosives mechanically, prior permission of Chief Inspector of Explosives shall be obtained. Insulated containers, used for carrying explosives or detonators shall be of approved manufacturer and shall be provided with suitable non-conductive carrying device, such as rubber, leather or canvas handle or a strap. Explosives and detonators shall be brought to the working places in separate, tight, well insulated containers, and kept in the containers until removed for placement in drill holes. If drill holes are not ready, they shall be stored in locked box type magazines located at a safe distance of at least 170 m from the working space. No person other than a shot firer shall carry any priming cartridges into a shaft, in which the sinking is in progress. No such cartridge shall be so carried except in a thick felt bag or other container sufficient to protect it from shock.

Electric firing shall be done by an approved method. All drilling equipment and personnel not engaged on loading shall be removed from the site before loading of holes starts. Loading of a round shall be completed by the crew starting the work of loading. Firing of round shall be the responsibility of the blasting foreman. Only clay sticks or pneumatic air locks shall be used for separation of charge/stemming of the holes.

Before use each and every electric detonator shall be tested for a positive test with the help of an ohmmeter. Before shot firing, the circuit shall be tested for insulation and for continuity. Before a shot is fired in an underground working place due warning shall be given to persons within 330 m in all directions and every entrance to the place where a shot is about to be fired shall be guarded so as to prevent any person, not having received warning from placing himself in dangerous proximity to the shot.

In case an exploder is used the revolving handle of the exploder shall be in the custody of the blasting foreman to prevent anybody else firing the shot when the blasting foreman and other persons are inside. Stray currents may cause accidents while loading and utmost care shall he taken in removing all faults from electrical circuits. Electric power, light and other circuits in the vicinity within 70 m of the loading points shall be switched off after charging the explosive and before the blasting operation starts. Power supply is to be switched on only after the blasted area has been properly inspected by the blasting foreman for misfires. All tracks, airlines and vent pipes shall be kept properly grounded. The heading shall be properly lighted with the electric floodlights before and after blasting.

6.3.3 *Inspection after blasting*

Immediately after a blast has been fired, the firing line shall be disconnected from the blasting machine or other source of power. When at least 5 minutes have passed after the blast was fired, a careful inspection of the face shall be made by the blaster to determine if all charges have been exploded, Electric blasting misfires shall not be examined for at least 15 minutes after failure to explode. Other persons shall not be allowed to return to the area of blast until an ALL CLEAR' signal is given by the blasting foreman.

All wires shall be carefully traced and search made for any exploded cartridge by the man-in-charge of the blasting operation. Sufficient time shall be given for the fumes to clear before permitting the labour to work for mucking operations.

6.3.4 *Misfires*

Misfired holes shall be dealt with by the blaster preferably by the same person who had done the charging operations. If broken wires, faulty connections, or short-circuits are determined as the cause of a misfire, the proper repairs shall be made, the firing line reconnected and the charge fired. This shall be done, however, only after a careful inspection has been made of burdens remaining in such holes and no hole shall be fired when the burden has been dangerously weakened by other shots. The charge of explosives from a misfired hole shall not be drilled, bored or picked out. Misfired charges, tamped with solid material, shall be detonated by a safe approved method.

The stemming shall be floated out by the use of water or air jet from hose until the hole has been opened to within 60 cm off the charge, and the water shall be pumped out or siphoned off and the new charge placed and detonated. Whenever this method is not practicable, a new hole shall be drilled 30 cm deep and spaced not nearer than 60 cm, shall be loaded and detonated. A careful search shall be made of the unexploded material in the debris of the second charge.

6.3.5 *Scaling and mucking*

It is essential to carry out proper scaling operations after each blast to remove all the loose rock pieces and guard against rock falls. Many accidents in tunnelling result from rock falls than any other cause. Careful and frequent inspection of walls and roofs as well as of tunnel supports shall be carried out. Thorough scaling of loose rocks at all weak spots is the best preventive against rock falls. Periodic inspection of unsupported sections of the tunnel from a travelling scaling platform shall be carried out for locating weak spots. Supported sections shall also be inspected regularly to make sure that the weakness of the formation has not spread beyond the supports. Loosened rock shall be supported/ removed forthwith. All supports shall be checked occasionally to make sure that there is no member under distress. All scaling platforms shall be equipped with safe ladders.

6.3.6 Installation of supports

Following the basic philosophy elucidated in the earlier section, design and installation of appropriate supports within the stand-up time for the particular type of rock is the most important steps to ensure proper safety for all personnel inside the tunnels.

Special watch shall be maintained for uncontrolled collapse of the face or adjacent areas, sliding in of muck and water, etc.

6.4 Ventilation and Noise Protection

Ventilation shall be carried out in tunnels to make the working space safe for workers by keeping the air fresh and by eliminating harmful and obnoxious dust, explosive fumes, exhaust from operating equipment, particularly diesel-operated equipment, and other gases. Mechanical ventilation shall be adopted where necessary to force the 'air in or exhaust the air out from the working face to the portal through ducts. Externally located fans operate in forced ventilation and induced ventilation modes to supply air through rigid or more commonly, flexible ducts. Intermediate booster fans ensure better supply for longer ducts. Ventilation is also necessary to ensure temperatures of not more than 4°C dry and 29°C wet at the working place. Ventilation shall be properly designed considering the tunnel topography and emission levels inside. The volume of air required generally depends on length of heading, size of tunnel, type and amount of explosives used, frequency of blasting, and temperature and humidity. Where the temperature is high or heavy blasting is resorted to suitably augmented volume of air shall be provided.

It is important to be alert all the time for the presence of toxic gases in underground works and appropriate instrumentation should be provided to keep track of the ambient air quality at all times. Proper records should be maintained of specific measurements of air quality at regular intervals throughout the day after blasts or major rockfalls. Particularly after each blasting for underground rock excavation, the ventilation measures should be set in place quickly and effectively for de-fuming and personnel should be allowed to enter only after establishing that the air quality is sufficiently acceptable. In certain regions geothermal conditions prevail and cooled air should be supplied to enable safe and comfortable working conditions. In any case appropriate well designed ventilation systems should be put in place to ensure proper ambient conditions.

Air Quality Testing - The tests shall be carried out once every 24 hours but in any case after every blast or a major rock-fall. In case any of the gases are detected to have crossed the threshold value indicated therein, the workmen shall be withdrawn immediately till the percentage is brought down well below the threshold value by improving the ventilation or by other effective measures.

Apart from ventilation, Noise is another factor which is problematic in underground work. Sufficient steps should be taken to reduce the noise levels to acceptable limits and workmen and visitors should be asked to wear ear plugs/muffs, etc where required.

6.5 Lighting

Adequate lighting shall be provided at the face and at any other point where work is in progress and at equipment installations such as pumps, fans and transformers. A minimum of 50 lux shall be provided at tunnel and shaft headings during drilling, mucking and scaling. When mucking is done by tipping wagons running on trolley tracks a minimum of 30 lux shall be provided for efficient and safe working. The lighting in general in any area inside the tunnel or outside an approach road. etc. shall not be less than 10 lux.

Emergency lights (battery operated) shall be installed at the working faces and at intervals along the tunnel to help escape of workmen in case of accidents. All supervisors and gang-mates shall be provided with cap lamps or hand torches. It shall be ensured that at least one cap lamp or hand torch is provided for every batch of 10 people. Any obstruction, such as drill carriages, other jumbos and drilling and mucking zones in the tunnel shall be well lighted. Hand lamps shall be equipped with strong cover of glass or other transparent material, dust and waterproof, and equipped with a strong guard over the cover. The exterior of all hand lamp sockets shall be non-metallic.

6.6 Communication System

6.6.1 *Warning signs and notice boards*

Irrespective of length and bends in the tunnel, arrangements shall be made for transmitting of warning signals by any one of the following means: (a) By electrically operated bells, operated by battery/dry cells with the bell placed outside the tunnel and the position of the switch shifting with the progress of the tunnelling work. The position of the operating switch although temporary shall be so chosen as to ensure proper accessibility and easy identification. (b) By the use of field (magnet type) telephone. For tunnel lengths up to 100 m, only one of the systems mentioned above may be adequate whereas in tunnels of length more than 100 m at least two systems shall be installed with the wires running along opposite sides of the tunnel, if practicable.

6.6.2 *Telephone system*

A telephone system shall be provided to ensure positive and quick method of communication between all control locations inside tunnel and portal of the tunnels when longer than 500 m and for shafts when longer than 50 m.

6.6.3 *CCTV systems*

Closed Circuit TVs are often deployed to keep a continuous watch on underground installations from the Control Room on top.

6.7 Protection Against Fire

6.7.1 *General*

All combustible materials like rubbish shall be continuously removed from such areas where flammable liquids are stored, handled and processed. All spills of flammable liquids shall be cleared up immediately. Containers of flammable liquid shall be tightly capped. All waste and combustible rubbish shall be removed at least daily from the tunnel.

6.7.2 *Fire system*

Fire Incidence Detection Systems should be able to detect the fire very early in its development and also accurately locate the position of the fire. The degree of accuracy depends on the type of active fire safety systems that may be installed in the tunnel. It is recommended that fire-fighting equipment such as hydrants, hose reels and extinguishers are strategically located within the tunnel. Fire extinguishers and fire-buckets appropriate to the hazard shall be conveniently located and identified.

6.7.3 *Electrical installations*

The electrical installations should be carefully designed and executed and regular tests should be carried out to ensure safe conditions and emergency cut-off procedures. Electricity leakage monitoring systems should be in place.

All parts of the electrical installation shall have all conductors and contact areas of adequate current carrying capacity and characteristics for the work they may be called upon to do and all joints in conductors shall be properly soldered or otherwise efficiently made. They shall be so constructed, installed and maintained as to prevent danger of fire, external exposition and electric shock, be of adequate mechanical strength to withstand working conditions underground, be not liable to be damaged by water, dust or electrical, thermal or chemical action, to which they may be subjected, be efficiently insulated or have all bare live parts enclosed or otherwise protected, and be installed at such a location that dumpers or wagons do not come in contact with the same.

On the occurrence of a fire caused by any electrical apparatus or a fire liable to affect any electrical installation: the supply of electricity should be cut off from such apparatus or installation as soon as practicable, and the fire shall be attacked and reported to the nearest available supervisor. As far as practicable, combustible material shall not be used in the construction of any room or recess containing electrical apparatus. No flammable material shall be stored in rooms, recesses or compartments containing electrical apparatus.

Adequate fire extinguishing equipment suitable for use on live parts shall be kept ready for immediate use in or near any room, recess or compartment containing such parts as will be readily accessible safely for use in case of emergency. This equipment shall be inspected at least once in a month.

6.8 Housekeeping

6.8.1 *General*

Only the materials required for work in progress shall be kept inside the tunnel. All other materials shall be removed from inside the tunnel. Sufficient width of the formation as even as possible and without any obstacles shall be created to enable the workers to get out of the tunnel quickly in case there is any collapse or any other mishap inside the tunnel.

6.8.2 *Traffic control*

Transport of Material: Vehicles carrying pipe, rail and timber shall be properly loaded for safe passage through the tunnel. The load shall be kept within the side limits for the vehicle as loads projecting over the sides are dangerous to men working in the tunnel. For transportation of wide loads special care shall be ensured in the operation of the vehicles with prior warning to the workmen along the tunnel to ensure a safe journey.

Transport of Employees: A safe and smooth walkway system shall be provided for employees, suitable separated from vehicular roads by guard railing. For transportation of employees by vehicles proper safety precautions shall be taken.

6.8.3 *Pipes and cables*

All water and air pipes as well as electrical cable shall be arranged along the sides of the tunnel, duly supported at regular intervals and in a systematic and neat fashion.

6.8.4 *Water control*

Sudden water ingress can be a catastrophic situation in certain underground areas and emergency dewatering systems should be in place to tackle such situations.

Many times water seepage is encountered in underground excavations. Prima facie this is not a dangerous indication by itself. It is an indication of fissures in the rock and presence of water streams nearby, which have to be kept in watch. Excessive ingress of water can give rise to unstable conditions and has to be carefully monitored. Also, for good working conditions inside underground enclosures, continuous dewatering to remove the excessive inflow is essential.

A study of boring data and geological formations shall be made to have an indication of locations, where water can be expected. Water inflow may be reduced or even entirely stopped by grouting of the wet seams. A wet area covering more than a single seam shall be sealed off by installing a suitable section of concrete lining. In case of a steady flow of water from the roof or side of the tunnel the flow shall be deflected down the sides to sumps by metal shields. The number of pumps provided at site shall be 50 percent more than the requirements calculated on the basis of the estimated pumping needs, or at least one number, whichever is more. In case of steeply inclined tunnels steps shall be provided for quick exit in case of failure of haulage. Gutters and sumps shall be kept clean. Suitable arrangement shall be made to indicate the position of sumps in case tunnel invert is flooded.

6.9 Emergency Management System

An Emergency management Plan shall be part of the approved Project Safety Plan and shall be well communicated to all working personnel and well displayed at the site. Emergency Rescue Measures should be drawn up to take care of various possible contingencies. It would also be advisable to provide safe rooms in deep installations where people can take shelter for a few hours in case of an emergency. Buried large diameter pipe lines leading to outside can be provided to offer a medium for communication and feeding in air supply in case of any collapses and blockages of the entrance to underground installations.

7 VENTILATION AND LIGHTING

7.1 Ventilation

7.1.1 *Need for ventilation*

Ventilation is the process of expelling stagnant air and introducing fresh air in an enclosed space. In road tunnels almost all the vehicles using the tunnel are internal combustion engines. During their travel, these vehicles go on releasing a continuous stream of obnoxious exhaust fumes and smoke. These fumes and smoke escape into the atmosphere in case of an open road. However, inside a tunnel, these exhaust fumes and smoke collect and keep on hanging near the roof. If a tunnel is not properly ventilated, increase in concentration of the exhaust fumes and smoke results in reduced visibility and slowing down of traffic and discomfort to the vehicle users. The main intention of ventilation is to create user-friendly healthy environment inside a tunnel.

7.1.2 *Vehicle emission*

Internal combustion engines used for powering most of the vehicles plying on roads are either of spark-ignition type or of compression ignition type. Each of these types generates obnoxious exhaust fumes and smoke with different characteristics. Major constituents of these obnoxious exhaust fumes and smoke are carbon monoxide, carbon dioxide, oxides of nitrogen and sulphur dioxide. In addition to these components, spark-ignition type engines also emit un-burnt hydrocarbons to a very small extent.

- Carbon monoxide [CO] is an odorless toxic gas which when inhaled combines readily with blood hemoglobin in preference to oxygen, reduces oxygen carrying capacity of the blood and shows toxic effects which could be fatal after long exposure. The process gets reversed upon timely exposure to fresh air.
- Carbon Dioxide [CO_2] is toxic only at very high levels of concentration which are well above those found in vehicular traffic tunnels.
- Oxides of Nitrogen are of two types viz. Nitric Oxide [NO] and Nitrogen Dioxide [NO_2]. These oxides unite with water and form nitrous and nitric acid in the lungs and destroy the functioning of lungs.
- Sulphur Dioxide [SO_2] forms sulphuric acid and causes toxic effects. However, SO_2 is a very small component of vehicular emissions.
- Hydrocarbons are also a very small component of vehicular emissions.

7.1.3 *Effect of gradient and speed*

When a vehicle travels on an up-gradient, it needs extra power causing increased fuel consumption and resulting in increased quantum of pollutants, as compared to a vehicle moving on level road. A vehicle may have to slow down and move in low gears causing slightly increased emission of pollutants while traveling upgrade. When traffic comes to a halt and the vehicles are required to idle, production of CO increases. However, during idling, the rate of consumption of fuel is very low and the total emission of CO is generally not more than that for normal traffic.

7.1.4 *Effect of traffic volume, traffic density and traffic composition*

Characteristics of Traffic are of paramount consideration for the designers of ventilation system. Traffic Volume, Traffic Density and Traffic Composition have a direct bearing on the vehicular exhaust emissions.

- Traffic Volume is the number of vehicles that pass in a given time period. Urban tunnels could develop traffic congestion during peak hours leading to stagnant but low traffic Volume.
- Traffic Density, expressed in vehicles/kilometer is number of vehicles occupying a given section. Traffic density would be highest during peak hours.
- Traffic Composition is the number of different types of vehicles in a given traffic Volume. In case of urban tunnels the composition would comprise mainly of passenger vehicles and buses. For a highway tunnel the composition could be mainly of commercial and goods transport vehicles.
- Capacity of a tunnel to carry traffic would depend on a number of factors. Traffic In a tunnel with unidirectional traffic moves faster than that with bi-directional traffic. Traffic on up-grade is slower that that on level road.

7.1.5 *Effect of elevation*

- In vehicles with spark-ignition engines, at higher elevations, air fuel mixture becomes richer due to lack of oxygen in the atmosphere. This results in higher concentration of CO in the exhaust.
- In case of compression-ignition engines, lack of oxygen in the atmosphere causes increase in smoke production.

7.1.6 *Quantum of introduction of fresh air*

Quantum of fresh air required to be introduced into a tunnel will depend on all the factors mentioned under **7.1.2** to **7.1.5** above and the permitted levels of the pollutants. For the purpose of design, the 'Traffic Model' should therefore be carefully developed on these considerations

7.1.7 *Vehicular tunnel ventilation systems*

All vehicular tunnels need ventilation. It is created by natural means or by mechanical means.

7.1.7.1 *Natural ventilation*

Natural Ventilation is caused by movement of air due to chimney stack effect created by the difference in level between two portals of a tunnel. Difference between the ambient temperature at the two portals and wind also plays a part in creating natural draft. Piston effect created by the vehicular traffic creates additional draft.

Normally for tunnels shorter than 500 m. in length, natural ventilation is enough. Exception would be urban tunnels with heavy traffic volume having possibility of congestion during peak hours where provision of mechanical ventilation becomes necessary. Another exception is tunnels longer than 500 m. having very low traffic volume.

Where technically feasible, provision of a vertical shaft near about the centre of a tunnel would effectively improve natural ventilation because of additional chimney stack effect created by it. If such a shaft is fitted with an exhaust fan, the chimney stack effect will not be affected by change in atmospheric conditions.

7.1.7.2 *Mechanical system of ventilation*

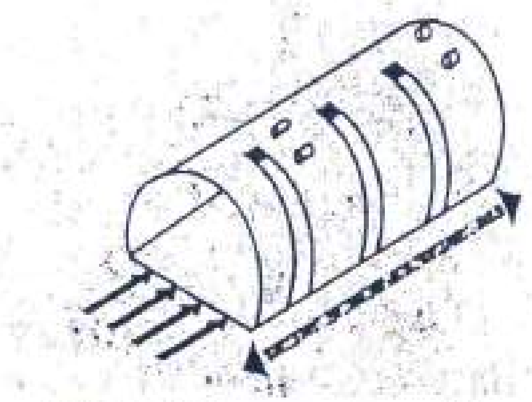
In case of all tunnels more that 500 m. in length, Mechanical System of Ventilation should be provided unless the traffic volume is very low.

A few types of ventilation Systems used separately or in combination are as follows:

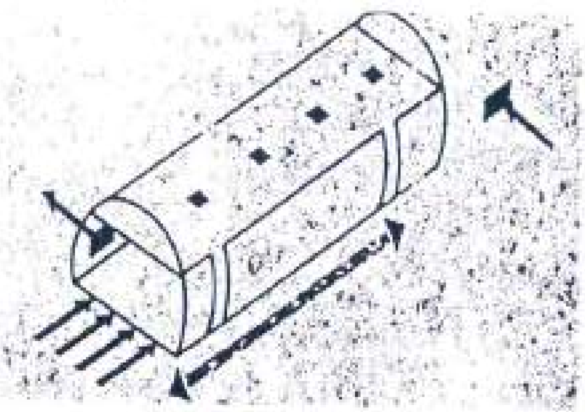
- *Linear System*: As the name suggests, the draft of air is linear for most of its length. Fresh air introduced at one end mixes with the air inside the tunnel and travels to the other end on account of its own pressure duly aided by the piston effect created by vehicular traffic. Where a central shaft is provided, fresh air introduced at both the ends travels upto the shaft and is exhausted through the shaft. This system is most effective for tunnels with unidirectional traffic. In case of long tunnels, the linear flow is aided by booster fans at intermittent locations located near and hanging from the arch of the tunnel. These fans boost the flow and hence are termed as Booster Fans.
- *Transverse system*: In Transverse system two types of systems are used,

  1) Semi Transverse
  2) Fully Transverse

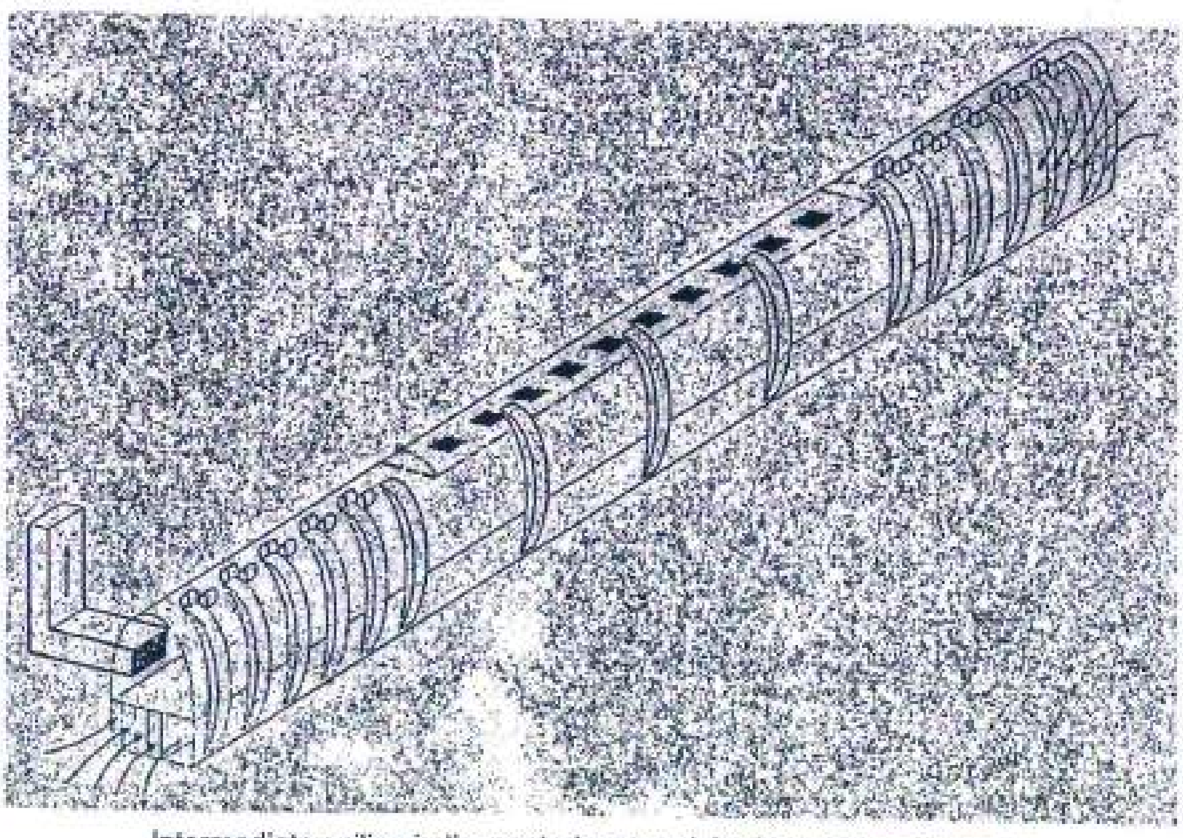
In Transverse system inlet and exhaust ducts are provided along the whole length of a tunnel either at ground level or around crown of the tunnel. Fresh air flowing through the inlet duct is uniformly released at various points along the length of the tunnel and foul air is uniformly sucked into the exhaust duct at various points along the length of the tunnel. Thus the system is linear only to the extent of travel of air from an inlet port to the nearest exhaust port. This system is most useful for tunnels with bi-directional traffic. In Semi transverse system only fresh air is supplied through the ducts but in Fully transverse system fresh air is supplied as well as foul air is sucked through independent ducts as shown in sketches given below:



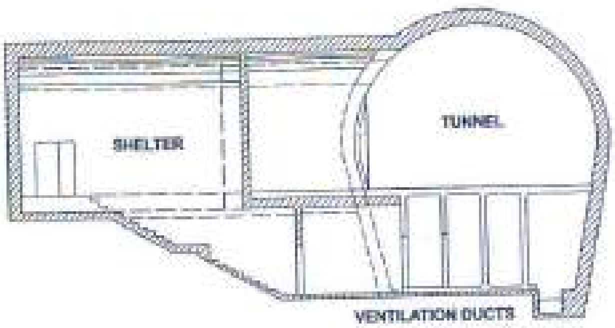
Jet Fans & Carneaux at every 100 m



Intermediate ceiling & Extracters

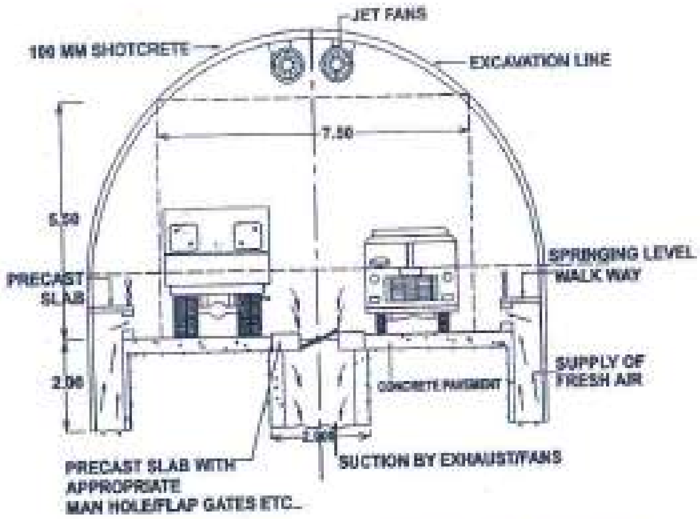


Intermediate ceiling in the central part and Jet fans at the entrances

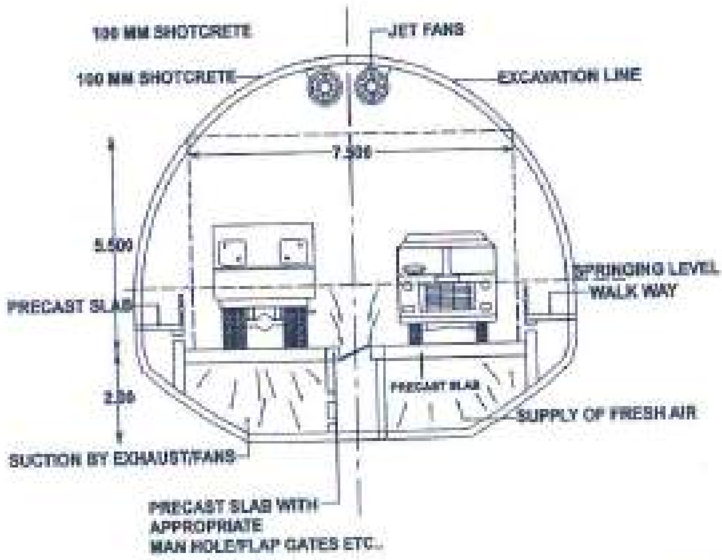


New shelter and connection with Fresh-Air Ducts

Smoke-extraction duct ("carnean")



Semi/Fully Transverse System of Ventilation



Longitudinal/Semi Transverse/Fully Transverse System of Ventilation

7.1.9 *Types of ventilation fans*

Three types of fans are used mainly for tunnel ventilation. They are axial flow, centrifugal flow and propeller fans. The choice depends on flow and pressure characteristics to match the ventilation needs.

7.2 Tunnel Lighting

7.2.1 *Need for lighting*

A tunnel is a linear enclosed space, covered by ground all around. Thus even in broad daylight or in a moonlit night, space inside a tunnel is always dark.

Purpose of a Road Tunnel is to create a user-friendly facility for smooth, efficient and speedy movement of road traffic. None of these purposes would be met if a tunnel is dark. Though vehicles would move with their own lights on, speed of traffic would get reduced. It would create congestion and movement could be in fits and starts.

It is, therefore, necessary to create a well lit environment in side a road tunnel. The environment should be comfortable to human eyes and should make driving easy. Such environment is created by provision of various forms of Tunnel Lighting. The choice would depend on the shape, size and length of the tunnel. Provision of adequate lighting helps the motorists avoid using bright head lights which could blind the motorists coming from opposite direction in bidirectional tunnels. Also, some people experience claustrophobia (fear of enclosed spaces) and good lighting helps alleviate this fear to some extent.

7.2.2 *Peculiar factors needing consideration*

- During daytime when a vehicle approaches and enters a tunnel, a motorist has to travel from a brightly lit area into a lightly lit area. Thereafter when the motorist leaves the tunnel, he has to travel from a lightly lit area to a brightly lit area.
- At night the situation gets totally reversed. When a motorist approaches and enters a tunnel, he has to travel from a dark area to a brighter lit area. Thereafter when the motorist leaves the tunnel, he has to travel from a brighter lit area to a dark area.
- Thus when a motorist travels through a tunnel, his vision has to get adopted to changing lighting conditions. This adaptation is not instantaneous but takes a short time. Such adaptation has to be a smooth transition. Such smooth transition can be produced only by

suitably designed lighting conditions at the entry and exit areas of the tunnel and the portion of the tunnel in between these areas.

7.2.3 *Zoning of a long tunnel*

Properly designed tunnel lighting ensures smooth transition of lighting environment between approaches to the tunnel and the tunnel itself. This helps the vision of a motorist to get smoothly adapter to changing lighting environment. This time for such smooth adjustment is generally considered as about 4 seconds. At a speed of 60 kmph, the length traveled in 4 seconds would be about 70 m.

To enable the vision of a motorist to get smoothly adjusted to changing lighting environment, the approaches to a tunnel and the tunnel itself are divided into various zones as given below. For design speed of 60 kmph, length of these zones would be about 70 m.

Access Zone

It is the portion of the open/approach cut of the tunnel immediately adjacent to Tunnel Portal.

Threshold Zone

It is the first zone next to the entrance to a tunnel. In the Threshold Zone, the intensity of lighting is gradually adjusted from that outside the entrance to that in the beginning of the transition zone.

Transition Zone

It is the zone next to the Threshold Zone. In the Transition Zone, the intensity of lighting is gradually adjusted to that in the Interior Zone.

Interior Zone

It is the zone beyond the transition Zone. It is sometimes also termed as Normal Lighting Day Zone. In the Interior Zone, the vision of a motorist needs no further adaptation. This is the longest zone in case of very long tunnels. The Luminance Level in this zone is generally kept at around 15 to 20 candelas/sq.m. of road surface.

It would be good practice in the case of very long tunnels to provide some variations in lighting at regular intervals, through variation in intensity or colour of lighting, etc, so as to break the monotony of traveling under the same conditions for a long distance. Extra lighting is required in lay-bys, emergency parking locations and at locations of escape paths and emergency services access locations.

Exit Zone

It is the zone beyond the Interior Zone and between/before the exit portal of the tunnel. In the Exit zone, the intensity of lighting is gradually adjusted to that in the portion just beyond the Exit Portal.

7.2.4 *Lighting installations*

The purpose of properly designed tunnel lighting is to ensure smooth transition of lighting environment so as to enable smooth adjustment in the vision of a motorist.

Since requirement of intensity in the Threshold, Transit and Exit Zones during day time is different than that during night time, required intensity can be achieved by putting the luminaries in two different circuits. Alternatively, luminaries that can give variable output by use of dimmers can also be used.

Gradual increase or decrease in the intensity of lighting within different zones, as described above, can be achieved by installing different types of luminaries or by using one or two types of luminaries at a closer or wider spacing as required. For easier adjustment in spacing, the luminaries can be mounted on sets of ladders arranged in longitudinal direction and hung from the crown of the tunnel.

Tunnel lighting has to be highly reliable. Tunnel lighting is required round the clock. It is therefore necessary to install and maintain a 100 percent back-up system.

7.2.5 *Maintenance*

The amount of maintenance required would depend on where the tunnel is located, the type and volume of traffic it is required to handle, quality of ventilation and the size and grade of the tunnel itself.

The luminary units should be sealed so as to prevent entry of water from water sprays, dust and smoke. The luminaries have to be cleaned frequently to clear dust and soot that may collect on their outer surface. Proper routine maintenance programme should be conceived and implemented.

Instead of waiting for the luminaries to fail before replacement, systematic replacement and renewal programme should be conceived and implemented.

8 OPERATION AND MAITNTENANCE

8.1 Introduction

The over all aim of operation and maintenance of a road tunnel shall be to maintain a specified level of safety for the road users, with an optimal level of expenditure and without adverse environmental effect. Decisions at the design stage as regards the tunnel geometry, tunnel shape, maintenance access, type and extent of the plant and equipment installed, and their configuration in operation, have a significant bearing on the overall Operation and Maintenance aspects. Therefore, the maintenance shall be planned and performed in such a way that the operational assumptions made at the design stage remain validated throughout the long operational life of the road tunnel. The Operation and Maintenance activities of the road tunnel shall be planned to achieve the following objectives:

a) Safety of the road users
b) Ensuring free flow of traffic
c) Operational economy
d) Dealing with abnormal situations

Normal tunnel operation shall provide for maintenance of the structure, equipments and installations, manning of control rooms, inspection and examination of vehicles. The operating manuals for various activities, plants and equipment, overall maintenance schedules shall be prepared in detail and shall be made available to the operating staff. The overall scheme shall make provision for the periodical replacement and improvement of equipment and installations, maintaining appropriate stock of spare parts and special tools. Actions for imparting training to operating staff, updating of techniques and updating of O&M manuals shall be taken from time to time.

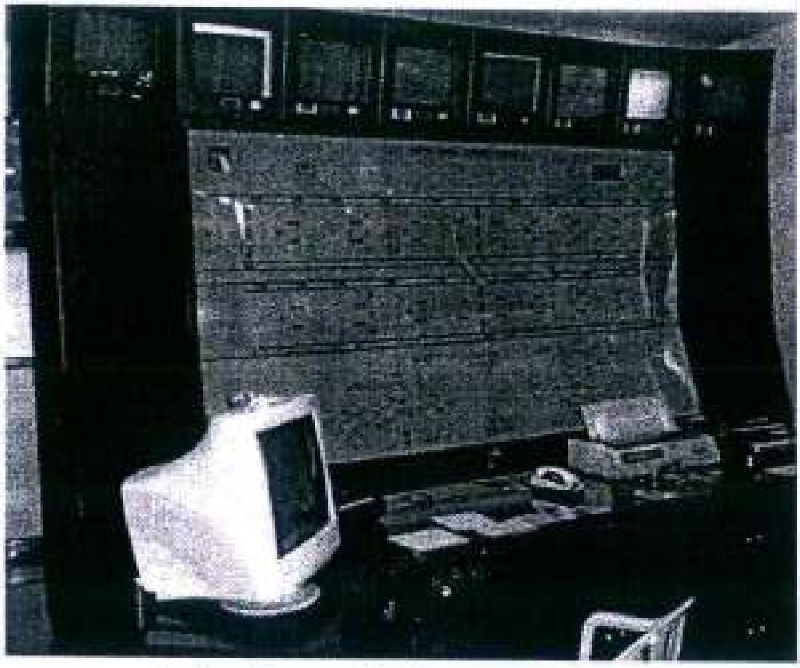
Preparation for dealing with accidents and abnormalities which have a greater impact for tunnel due to the confined space and restricted access as compared to road in open area shall be given special importance. Abnormal operational situations call for a command structure to deal with the situation and deployment of rescue vehicles, ambulances, signal system, communication facilities and fire fighting equipments.

8.2 Operation and Maintenance Functions/Activities

Operation and maintenance of tunnels involve following functions/activities:

a) Traffic related functions:

These include control and supervision of traffic and operation of system for ventilation and lighting, signal systems, access control systems, which are generally having automatic controls and are controlled from control room (see picture below). Even though the operations might be automatically controlled, the control room shall be manned by trained personnel. Maintenance of smooth traffic flow and taking quick remedial actions in case of any accident shall be the responsibility of operations staff so as to prevent potential panics as space inside the tunnel is confined.



Control Room with Automatic Controls

b) Maintenance of tunnel:

Maintenance of tunnel covers preventive maintenance as well as corrective maintenance as enumerated below;

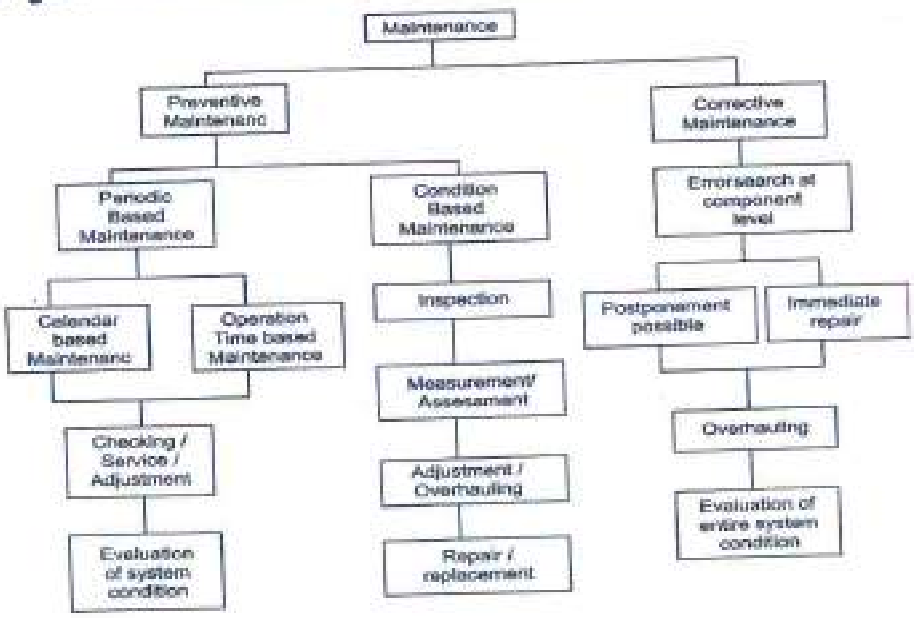
- Preventive maintenance is the one which keeps the systems in a good and safe condition preventing an operational breakdown. Preventive maintenance is safer, more effective and more economic than maintenance based on repairing faults or damage. Without preventive maintenance, the systems could become unsafe and/ or could only be brought back to a safe condition at high cost. The preventive maintenance of tunnel covers routine periodic-based maintenance as well as condition-based maintenance.

The periodic-based maintenance is normally calendar based or operation time based maintenance which can be easily planned and ensures safe and optimum performance of the facility without surprise failures. The routine periodic-based maintenance includes maintenance of permanent fixtures, lining, portals, washing and cleaning of tunnel interiors, drains and drainage system, painting, cleaning and replacement of consumable parts such as lamps, filters and batteries, etc.

The condition-based maintenance, arising from the results of routine inspections, covers major/minor repairs. Routine inspections by trained personnel shall be carried out to identify these items and actions shall be taken to carry out repairs with all due safety precautions. The condition-based maintenance includes renewal and repair of structural components, road surfacing, road signs and other fixtures.

- Even with preventive maintenance components will be subject to malfunction or damage may be due to accident. In such situation Corrective maintenance needs to be resort which involves carrying out maintenance measures after an operational breakdown or an accident has occurred. Although preventive maintenance is generally preferable, in some cases parts of the installation may be maintained on the basis of corrective maintenance. i.e. the parts in question are not maintained, but replaced after expiry of service life or when a defect arises. Planning is difficult in corrective maintenance since the same is taken up after systems have become critical or failed.

The figure below illustrates the different types of planned maintenance:



c) Maintenance of plant and equipment:

This includes keeping all operational devices in proper condition by carrying out time to time repairs by scheduled maintenance and tests, replacing faulty parts, electric fittings etc. Periodic maintenance schedule shall be prepared for lighting, signaling, communication, emergency and monitoring equipments. Complex equipments need proper and special maintenance. Care shall be taken right from the design stage to ensure that the equipments shall be so selected that the necessity for specialist agencies is minimised and it shall be possible to change the maintenance agencies as and when required.

d) Incidence and Emergencies Management:

Necessity for Incidence and Emergencies Management arises due to various types of incidences likely to be met with in road tunnel. A common event is a vehicle accident or breakdown which causes a degree of lane blockage. Prompt remedial actions shall be taken to restore free flow of traffic there by minimizing congestion conditions that in themselves can aggravate the risk of further breakdowns. Another situation involving collision is possible fire or explosion which is potentially more dangerous for tunnel users, and which requires rapid response from emergency services. The various types of incidences likely to be met in road tunnels are listed below:

i) Vehicle related incidence

Fire in tunnel

Vehicle accident

Vehicle breakdown

Debris on the road

Over dimensioned vehicle getting stuck

Overloaded slow moving vehicles

Chemical spillage

ii) Non-Vehicle related incidence:

Light failure

Ventilation failure

Power failure

Leakages inside Tunnel

Telephone out of order

Pedestrians on carriageway

Animals in tunnel

iii) Weather hazards:

Fog

High winds

Dazzle from the Sun particularly for East - West alignment

Flood

Snow

iv) Human hazards: (vehicle occupants, operator and emergency service staff)

Panic under stress,

Lack of knowledge (procedures, equipment, location, etc.),

Disregard towards instructions and advice,

Jamming communication channels,

Injury during rescue,

Vandalism,

Terrorist activity.

The strategies for dealing with the various incidences shall be decided taking into consideration available resources, procedures laid down in the manuals and communications requirements of the various parties involved and the needs of the road user. Response strategies shall deal with the initial occurrence of a situation and also with any resulting developments, as for example, a breakdown in a tunnel may lead to initial local queuing which may further lead to traffic jam on the road for long duration.

8.3 Organization for Operation and Maintenance

8.3.1 The authority responsible for operation and maintenance of the road on which tunnel/s is constructed shall establish a separate organizational structure for operation and maintenance of the tunnel/s. The operational organization shall be responsible for the operation and maintenance, fire fighting and rescue procedures, as well as traffic control operation. The operational organization shall also be responsible for preparing and updating procedures, manuals, specifications, etc.

8.3.2 The structure of the operational organization depends on several factors, of which the most important are:

- Type and extent of technical equipment in the tunnel,
- Extent of automatic surveillance and alarms deployed,
- Traffic flow details,
- Geographical location,
- Magnitude of the tasks to be carried out.

8.3.3 The tasks required to be handled by the operational organization are:

- Surveillance tasks

  These involve surveillance for events that normally result in the alerting of police, fire or rescue services. Tunnel personnel along with others agencies like police, fire brigade etc. deals with these tasks.

- Operational tasks

  The tunnel personnel or an agency carries out these tasks, which can be planned in advance such as cleaning, washing, sweeping etc.

- Preventive maintenance tasks

  These tasks are carried out by the tunnel personnel or an agency, and can be planned, in detail, in advance.

- Corrective maintenance tasks

  These tasks cannot be planned in advance. However, the procedures to be followed in the event of failure or damage must be planned for.

8.4 Documentation

In order to achieve the appropriate standards for the operation and maintenance of tunnels it is essential that the operating manuals for equipment, maintenance schedules etc. shall be prepared and shall be readily available for reference of the concern staff of the operational organization. The manuals shall contain procedures to address a whole range of scenarios. Each procedure shall contain a number of instructions to be undertaken, each of which initiates an action in one of the manuals. The individual manuals might cover the following aspects:

i) Administration manual

   The administration manual contains personnel registers including the competence, skills and training records for individuals. It shall clearly define staff responsibilities. It shall also describe the whole financial system and the budget

ii) Inventory manual

It is essential that the operator is fully familiar with the equipment and systems installed in the tunnel, their location and performance characteristics within the tunnel engineering framework. For that purpose an Inventory Manual shall be prepared which shall include a complete list of equipment (type, quantity, etc.) with all the necessary information, including relevant drawings and geographical information. It shall also contain information on spare parts (e.g. supplier/producer with contact details, equipment/spare part descriptions and identifying codes, etc.), the location where these spares are stored if already procured, etc. It shall also have details of how these spare parts are to be changed, their life period, etc.

iii) Technical operation manual

This manual shall describe how different tunnel equipment and systems are used in normal operation, the capabilities of equipment and the actions to be undertaken in specific situations. The instructions for the operation of all the equipment shall be available and shall be entered in the technical operation manual. If these instructions do not exist they shall be prepared by experienced personnel. Threshold levels shall be set for each of equipments according to local regulation and experience for operating the system.

iv) Traffic manual

This manual shall include all the procedures and instructions that are applicable to traffic situations occurring during normal, congested, incident and emergency operations including schemes and procedure for traffic diversion. For instance, if a collision is detected in the tunnel, the operator must close the tunnel or divert the traffic to other tube in case of twin tube tunnel. Police, fire fighting and ambulance services shall be informed according to the emergency plan. Detailed emergency instructions for the operator shall be included in the traffic manual which shall be got approved from the appropriate authorities.

v) Maintenance and inspection manual

This manual shall give instructions for the maintenance of the whole tunnel structure and all the equipment, including the individual components of the different systems. The instructions for the maintenance and inspection of tunnel structure and all the equipment shall be available in the maintenance and inspection manual. The manual shall also list the regulations that apply to maintenance work, like for instance:

- During hours with heavy traffic;
- If nuisance is caused to others (e.g. acceptable noise levels during the night hours, smoke and dust regulations, etc);
- Night time work;
- Traffic regulations; etc.

vi) Safety Manual

This manual shall include all the procedures and instructions that are to be followed in operation and maintenance of tunnel.

8.5 Safety Requirements

8.5.1 Tunnel maintenance activities both planned and unplanned shall be carried out by proper traffic management. The tunnel shall be equipped in such a way that as many maintenance operations as possible can be carried out off-site in work shop or other places where it is not necessary to interference with traffic flow in any way. To plan maintenance and operation that affect vehicle traffic, as these may be cause of accidents involving user of the tunnel or the workers operating the maintenance equipments, certain precautions as enumerated below shall be taken for safety of traffic as well as maintenance staff.

- Maintenance staff working in the tunnel shall be protected from errant vehicles entering into the tunnel. For that purpose warning signs shall be posted at appropriate location and one driving lane shall be closed completely by barriers and providing proper warning signage/signals well in advance for safety of coming traffic.
- The closer of lane shall be indicated before the road enters tunnel. Variable messages, traffic signs, barriers shall be used for the purpose.
- In twin tube tunnel one tube can be closed for maintenance while temporarily bi-directional traffic flow allowed in other tube.

8.5.2 Safety equipments that shall be readily available in Tunnel are listed below:

Supervision and alarm equipments:

- CCTV
- IDS (incident detection system)

- emergency telephones
- fire alarms
- automatic fire detectors
- instruments for measuring visibility
- instruments for measuring gas concentrations
- sensors for doors, alarm boxes
- devices for detecting vehicle height
- Emergency power UPS

Escape routes and communication:

- emergency doors
- radio transmission
- communication equipment
- public address system
- escape route signs
- smoke-free escape routes
- emergency lighting
- variable message signs

Traffic regulation equipments:

- Lane signals
- Blinking red light
- Variable text signs
- Barriers
- Emergency Road Sign

Fire fighting equipments:

- hand-operated fire extinguishers
- fire hydrants
- water reservoir
- fire-hose coil with supply
- sprinkler (if used)
- closed drainage system
- fire engines (if owned)

8.5.3 *Additional safety considerations*

Depending upon the importance of the tunnel, length of the tunnel some restrictions and additional facilities as enumerated below shall be considered.

8.5.3.1 Restrictions on tunnel use

Restrictions may be imposed from safety considerations on type of traffic permitted to use a road tunnel. In long tunnel pedestrian, cycles, two wheelers, animal drawn vehicles shall not be permitted, provided alternative routes are made available for such slow moving traffic. Similarly transportation of high levels of dangerous goods may be prohibited entirely or for certain period of time or can be permitted only with escort. Such escort operations shall be thoroughly planned in close co-operation with other organizations like fire, traffic police departments.

8.5.3.2 Speed limits

For safety reasons speed limit within road tunnel may be imposed taking into consideration geometric design of the tunnel. Generally speed within tunnel is marginally lower as compared to speed on open road.

8.5.3.3 Separate service tunnel

A separate service tunnel, adjacent to the traffic tunnels could be considered at design stage only, provided land is available and additional cost can be incurred. This additional tunnel provides access for maintenance without requiring tunnel closure. This service tunnel can be used as escape passage during an emergency. Also during construction stage this tunnel is used as pilot tunnel and for ground treatment. During operation stage this tunnel can be used for dewatering, ventilation and for placing service cabling and other operating equipments.

Annux-A
(Clause 1.4)

TERMINOLOGY

Advance: Length by which 'Working Face' of a tunnel under construction is advanced in one 'work cycle' also termed as 'Pull' for 'Drill and Blast' method.

Adit: A tunnel driven from the surface to create additional working faces for the main tunnel or for access, ventilation, or emergency evacuation.

Controlled Blasting: Blasting operation carried out to keep vibrations within specified limits and to prevent uncontrolled flying away of rock fragments.

Cover: The perpendicular distance to nearest ground surface from periphery of the tunnel.

Cut & Cover: A method of construction wherein a duct is constructed in 'Open/ Approach Cut' and then covered with selected backfill.

Defuming: The operation of exhausting obnoxious fumes due to blasting from the tunnel face to enable safe approach to the face for commencement of further activities.

Detonator: A device initiated by safety fuse, by electricity or by shock tube, to ignite/ detonate an explosive charge.

Drift: A near horizontal tunnel of a small cross-section and short length driven either from surface or from underground face for exploration or any purpose.

Drill Jumbo: A rail or tyre mounted equipment on which one or more drill booms are mounted to facilitate faster deployment of the drills.

Drilling Pattern: An arrangement showing location, direction and depth of the blast holes to be drilled into the face of tunnel.

Egress: A small parallel tunnel/passage or adit leading to outside open space for emergency escape of people.

Explosive: A mixture or chemical compound capable of producing an explosion by its own energy. This includes black powder, dynamite, nitroglycerine compounds, emulsion based explosive, ANFO (Ammonium Nitrate and Fuel Oil mixture), fulminate or explosive substance having explosive power equal to or greater than black powder.

Explosive Charge: Pre-determined and planned quantity of explosive placed in the blast holes for getting planned 'advance' in a 'work cycle'.

Forepole : Steel rods/sections, pointed boards or pipes driven in the roof ahead of the face prior to excavation. Grouted pipe forepoles are used as Spiles.

Full face excavation: Excavation of the face of tunnel carried out in one operation instead of by 'Heading and Benching' or 'Multi-drifting'.

Half Tunnel: Tunnel section on steep hill slope with one side remaining uncovered and exposed on the valley side.

Heading and Benching: A Tunnelling method in which 'Heading' i.e. the top section (generally up to around springing level) is excavated first, followed by 'Benching' i.e. removal of lower portion.

Lagging: Planks/Precast slabs made of reinforced cement concrete or steel plates spanning between steel rib supports to cover excavated periphery of tunnel and to serve as formwork for backfill material.

Look-out: The angle with respect to the centerline of a tunnel at which the peripheral holes are required to be drilled so as to provide adequate space for drilling equipment.

Minimum Excavation Line: The line within which no unexcavated material of any kind is permitted to remain. This line could vary along the length of the tunnel depending upon strata.

Mucking: The operation of removal of excavated material and haulage for disposal.

NATM: New Austrian Tunnelling Method (NATM) is a philosophy, which takes into account inherent properties of the rock mass and suggests methods and supporting measures for the newly exposed rock mass in conjunction with continuous monitoring.

Niche: Local widening of tunnel over a short length.

Open/Approach Cut: Excavation open to sky to gain access to 'Tunnel Portal'.

Overbreak: The portion excavated/dislodged beyond the desired excavation line i.e. 'Payline'. This could be due to natural/geological reasons or faulty workmanship.

Pay Line: An assumed line (beyond minimum excavation line) as specified in the contract which governs payment of items of work.

Probe Holes: Holes of suitable diameter and length drilled into the face or around the tunnel for assessment of the strata.

Q: Rock Mass Quality Index based on geomechanical properties of the rock mass used in the empirical "NGI - Q" system for rock mass classification for design of ground supports in under ground works.

Rock bolt: An untensioned or tensioned linear reinforcement element installed in holes drilled into the rock mass.

RMR: Rock Mass Rating based on geomechanical properties of the rock mass used in the empirical "CSIR - RMR" system for rock mass classification for design of ground supports in under ground works.

Scaling: An operation to remove all loose/potentially unstable fragments of rock from the blasted surface.

Shaft: A linear well like excavation/structure, usually vertical but may be at angles up to 60^0 from vertical.

Shotcrete: Plain or Fiber Reinforced Concrete (with small size aggregates) shot i.e. sprayed on any surface.

Specific Charge/Powder Factor: Quantity of explosives consumption expressed in kilograms per cubic meter of rock excavated in an excavation cycle.

Specific Detonators: Quantity of detonators expressed in numbers per cubic meter of rock excavated in an excavation cycle.

Specific Drilling: Quantum of drilling expressed in meters per cubic meter of rock excavated in an excavation cycle.

Squeezing Rock: A type of rock mass condition in which the rock mass has time dependent plastic deformation when exposed.

Stand-up-Time: Time duration for which newly exposed periphery of a tunnel is able to stand on its own without exhibiting significant deformation/distress.

Stemming: Inert material packed near the open end of a blast hole to lock the explosive charge in place.

Tunnel Lining: Concrete, Shotcrete or any other material installed over exposed surface.

Tunnel Portals

Excavated Portal: Entrance location where the 'open/approach cut' ends and full tunnel section starts.

Tunnel Portal: A facade structure surrounding tunnel opening and extending upto adjacent sides of 'Open/Approach Cut', constructed in front of the excavated portal. Where constructed at the end of 'Cut and Cover' portion, it is termed as 'False Portal'.

Tunnel Support: Shotcrete, Steel ribs, Rock bolts/anchors or Tunnel lining placed to support the excavated periphery of a tunnel.

Work Cycle: Sequence of operations to be carried out for each 'advance'.

Working Face: Blind end inside a tunnel from where next 'working cycle' starts.

Annex-B
(Clause 2.6)

ENVIRONMENTAL MANAGEMENT PLAN FOR ROAD TUNNELS

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
1)	**Transport of construction machinery -Damage to road surface**	Heavy equipments (above 15-20 tonnes), crawler-mounted machinery and steel wheel mounted rollers shall be mobilized to construction site without causing any hazardous condition and any damage to network roads enroute to site. Such heavy equipments shall be preferably mobilized on multi-axial heavy trucks.	Source to construction sites	Contractor	Engineer's Representative	Random checks	Visual inspection record
2)	**Construction traffic - A - Damage to network roads**	Movement of tunnel construction machinery shall not cause damage to network roads and shall always be maintained in good condition.	Network roads used for the construction	Contractor	Engineer's Representative	Routine inspection	Visual inspection record
	B - Compliance to road safety rules	The driver shall be trained regarding traffic rules, safer driving practice, road courtesies etc. Copies of valid driving license shall be furnished.	At all construction sites	Contractor	Engineer's Representative	Monthly/ Random checks	No incident or accident record with traffic police and in the driving license

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
	C - Large Volume of Construction Traffic	Mass movement of vehicle in and out of construction site such as debris removal vehicles, machinery and material transportation vehicles, RMC Trucks, etc. shall be preferably planned during non-peak hours. Movement of vehicles through congested roads, narrow lanes having sharp turning radius shall be avoided and instead alternate road networks available shall be preferred. All Over-Dimensioned cargo/ elements projecting out and beyond the truck outline shall be flagged with red flags in the day time and with red lamps in the night time. Assistance from traffic Police shall be sought wherever required	At all the roads used for construction	Contractor	Engineer's Representative	Fortnightly/ Random checks	Visual inspection, plan of vehicular movement, record of the transport vehicles and the transport network roads.
	D – Damage to road surface	Vehicles exiting from construction site on to public roads shall have their tyres washed to remove all mud clinging to tyre surface	At all the roads used for construction	Contractor	Engineer's Representative	Weekly/Random checks	Visual inspection of the public roads

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
3)	Parking construction vehicles	Parking shall be in such a way that traffic flow along the road is not hampered. Heavy machinery equipment or parts thereof which are suspended or held aloft by the use of slings, hoists or jacks shall be blocked or cribbed to prevent falling or shifting. Bulldozers, scraper blades, Loaded buckets, dump bodies and similar equipments of construction machinery parked outside the project site or in areas of considerable public movement and near children playing area, shall be fully lowered or blocked. All controls shall be in neutral position and motors/Engines stopped and parking brakes set.	At all the roads used for construction and parking areas	Contractor	Engineer's Representative	Weekly/Random checks	Visual inspection record of the transport roads and Parking places
4)	Air Pollutants Emissions ***Air pollutant emissions are regulated under Rule 115 of CMV Rules, 2000.***	Construction site should be adequately watered periodically to minimize fugitive dust generation.	At all construction sites	Contractor	Engineer's Representative	Weekly	Visual inspection record of dust cloud at the site, sprinkling frequency

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
		All trucks/dumpers carrying construction material prone to create dust pollution should be covered during transportation.	Source to construction sites	Contractor	Engineer's Representative	Weekly	Visual inspection record of dust cloud at the site, sprinkling frequency.
		All equipment/vehicles should be kept in good state of repairs.	At project sites	Contractor	Engineer's Representative	Quarterly	Equipment maintenance records to be maintained
		All vehicles registered under Central Motor Vehicle Rules, 2000 shall have valid certificate issue by authorized agency throughout their deployment period at construction site. A Separate or master register of vehicle's shall be maintained at construction site office containing details of vehicles under deployment and a copy of PUC certificates	At project sites	Contractor	Engineer	Quarterly	A copy of Pollution Under Control (PUC) certificate.

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
5)	**Noise Emissions** *Under Environment (Protection) Rules, 1986 (Schedule VI, Part E) the noise generation standards applicable for construction equipment, machinery and vehicles.*	All in-built noise-silencing device such as silencers and mufflers shall be maintained and any defective device shall be promptly replaced. Equipment's shall be maintained as per manufacturers guidelines to reduce tonal components, frequency modulations or impulses, which will increase the annoying effect of any noise, generated.	At construction sites	Contractor	Engineer's Representative	Monthly	Noise monitoring report generated from any equipment, Vehicle or machinery
		Noise generation due to vibration of loose parts during operation, unstable foundation at temporary installations etc shall be immediately attended and rectified.	At construction sites	Contractor	Engineer's Representative	Monthly	Noise monitoring record due to vibration
		Stationary DG sets, if provided at the construction site shall adhere to noise emission guidelines and regulations in Schedule I of EP Rules 1986.	At construction sites	Contractor	Engineer's Representative	Monthly	Stationery DG sets adhering to EP Rules, 1986. Noise monitoring record

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
6)	**Ground Vibrations**	Ground vibrations during construction shall be controlled by properly designed charges and use of controlled blasting techniques.	At construction sites	Contractor	Engineer's Representative	Continuous monitoring during blasting cycles	Ground vibrations within permissible limits particularly for Urban tunnels
7)	**Muck disposal Locations**	Muck disposal shall be carried out at pre determined authorized locations only. In case disposal is carried out on other than authorized Sites, landowner approval shall be obtained before starting the activity. Approval shall be obtained even if the land is owned by government. Muck disposal area as well as the roads leading up to the area shall be kept watered regularly by sprinkling to prevent unwanted generation of dust. However it shall be ensured that large quantities of water are not dumped in this process, as it would lead to forming slush. The route from the tunnel portal to the Muck Dumping Area shall be regularly cleaned up to remove all muck which might	At construction sites	Contractor	Engineer's Representative	Monthly	Approval papers from authorised person.

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
		have fallen off from the dumpers during transit. Before commencing the muck stacking operations, a retaining wall of suitable design shall be constructed for a suitable height to retain the muck and prevent it from spreading out to undesirable locations, particularly in slopes to prevent the muck from sliding down to the river or valley or to any undesirable locations. The retaining wall shall have sufficient weep holes to drain out water retained in the muck arising from atmospheric precipitations, etc so as to preserve the safety of the stack as well as to collect the muck-contaminated water in collection pits. Ring drains shall be constructed all-round the retaining walls to collect the drain water and conduct the same to collection pits from where it shall be led off to holding ponds. Contaminated water shall not be allowed to drain out of the Muck Disposal Area without treatment. . Suitable landscaping shall be done					

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
		over the muck piles for better aesthetics and for proper preservation of the slopes/pile.					
8)	**Labour Camps, Health and hygiene**	Construction of labour camps shall be located away from the nearest habitation to avoid conflicts and stress over infrastructures facility. The contractor shall provide, erect & maintain necessary temporary living accommodation, ancillary facilities such as toilet blocks, potable water supply, canteen etc. as per standards set by various acts (Labour Act 1951) Contract Labour Act 1970, Construction Worker Act 1996, Construction Workers Rules 1998. The contractor shall supply all necessary safety appliances such as safety goggles, helmets, safety belts, earplugs (wherever applicable), masks etc. to the worker and staff. The contractor shall make	At construction sites	Contractor	Engineer's Representative	At start of work & Monthly thereafter	Visual inspection, Records

Sr. No.	Environmental Issue	Mitigation Measure	Location	Responsibility		Supervision Frequency	Performance Indicator
				Implementation	Supervision		
		arrangements for providing water for drinking and other ancillary purposes and proper disposal of wastewater from the labor camps. A readily available first aid unit including an adequate supply of sterilized dressing material and appliances shall be provided as per the requirements under the various acts (such as Factor Act 1948, Labour Act 1951. All anti-malarial measures be complied with, including filling up of borrow pits.					

Annex-C
(Clause **3.3.3.3**)

CORE LOG - 1

Client : Drill Hole No. 1 Date:
Site:

Operator Name: Top R.L - _ _m _____ Diameter of bore (mm) :- 100 & Nx.

Core Drill Run (m)	Serial No of core pieces	Length of Core Removed (cm)	Piece No	Length of Piece(cm)	Nature of Fracture at Lower End of Piece	Angle of joint with Vertical	Joint at Bottom of core Piece(m)	Core Recovery(%)	Rock Quality Designation (%)	Petrographic Description	Remarks
1	2	3	4	5	6	7	8	9	10	11	12
0.00 to 2.00										OVER BURDEN	
2.00 to 3.50	1 to 4	21	1 2 3 4	2 5 5 9	J J J J	H H H H	*	42	NIL	All joints are stained with iron oxide and calcium carbonate	Total drill water loss throughout the length of the bore drilled.
3.50 to 5.00	5 to 15	99	5 6 7 8 9 10 11 12 13 14 15	29 13 11 2 2 6 10 6 10 6 4	J J J J J J	V H 45° V V V		66	49	From P.No. 1 to 96 porphyritic basalt with green infillings	* R.L. to be calculated & Filled
5.00 to 6.50	16 to 30	10 2	16 17 18 19 20 21	10 6 5 3 7 3	J J J J J J	H H 80° H 45° V		68	23		

Note: The information filled above is typical for guidence J - Joint, V - Vertical joint, H - Horizontal joint.

Annex-D
(Clause 3.4.3)

TUNNEL INSTRUMENTATION

Though underground excavations are designed based on different numerical and empirical methods, there is a need to evaluate the stability of the openings and optimize the design through instrumentation. Instrumentation provides vital information on ground movement and stress build-up in the surrounding ground mass, and thus enables one to check the validity of the design. Based on the analysis of the data, the strata behavior and support performance are evaluated, and recommendations made for proper further action.

In Tunnel construction instrumentation is used for evaluation of the performance of the support systems, monitoring the stability around underground excavations and ensuring overall safety of operations. In poorer strata it would also be advisable to maintain permanent instrumentation and keep the same under periodic observation and monitoring.

In general, ground mass deformation characteristics measurements are done using Convergence meters and Multi-point borehole extensometers. Load measurements are carried out using Load cells. In-situ stress is monitored using Stress cells. Regarding the supports, capacity of rock bolts is monitored using instrumented bolts, testing the anchorages of the bolts and using torque meters. Efficacy of shotcrete is measured using shotcrete bond tester and shotcrete stress cells. Electrical Load cells of strain gauge type are used to monitor the behavior of rock bolts installed.

Convergence Measurement

Convergence measurement shall be performed in underground excavation works to determine the relative displacement of opposite measuring points placed around the excavation perimeter.

The measuring points shall consist of the convergence bolts made of stainless steel pins mounted on a short reinforcing bar grouted into predrilled hole.

The tape extensometer with steel tape of a low thermal coefficient shall be set between the opposite convergence bolts. The convergence shall be read on a digital gauge with a resolution of 0.01 mm.

The convergence bolts shall be installed within the heading zone after the installation of supports. At the beginning, the measurement shall be carried out daily. Later, weekly readings shall be taken for several months up to the cessation of any movement but latest when the placing of the concrete lining commences.

The convergence measuring tape and the digital gauge shall be calibrated on their corresponding calibration devices before and after each measurement. Digital readout shall be in metric units.

Borehole (Rod) Extensometers – Single and Multipoint

Single point or multipoint borehole extensometers are used in underground excavations to measure displacements in the rock mass surrounding the excavation.

Borehole (Rod) extensometers shall be installed at location as indicated on the Drawings. Borehole diameter shall be 76 mm. However at mouth, the size of recess shall be 125 mm for a length of 500 mm.

For underground excavations single-point extensometers will have a length upto 10 m, while three-point extensometers will have a typical rod length of 4, 7 and 10 m. On surface excavation single point extensometers shall be up to 15 m long while for three-point extensometers, rod lengths shall be 10, 15 and 25 m long.

Borehole extensometers required could either be of mechanical or electrical type. For mechanical extensometers the system consists of groutable anchors, fiber glass continuous length extensometer rods, and protective sleeves; Head of MPBX/SPBX shall be sealed with a protective cover. For mechanical type Borehole Extensometers readings shall be taken with a micrometer depth gauge of 0.01 mm scale division.

For electrical type Borehole extensometers an electronic potentiometer type transducer with the following specifications shall be used:

Sensor Type	Potentiometric
Range	50 mm
Resolution	0.1 percent fs with readout unit
Overall accuracy	0.2 percent fs.
Temperature Range	0 - 55°C
Casing	Stainless steel

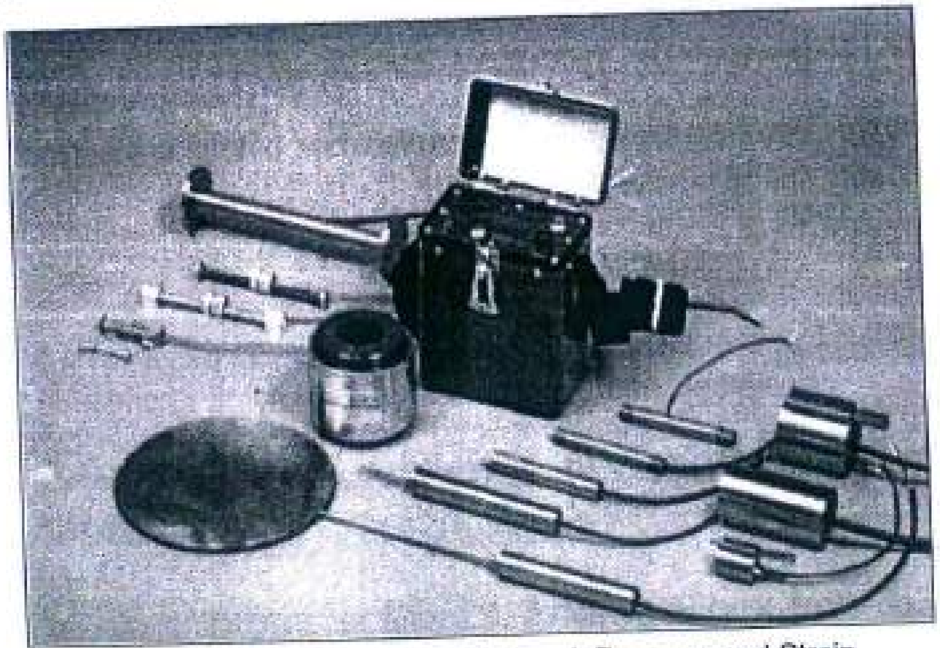
Monitoring of micro-seismic networks is useful for evaluating ground stability in underground excavations and to locate areas of potential ground failure. The various methods used are:

- Characterizing fracture propagation, 3D stress-deformation and failure mechanism using real time micro-seismic monitoring system.
- Developing short-term precursor model to warn occurrence of rock failure
- Application of Geophysical Techniques for assessing stability of excavations in rock mass
- Use of Geophysical tool in designing excavation.

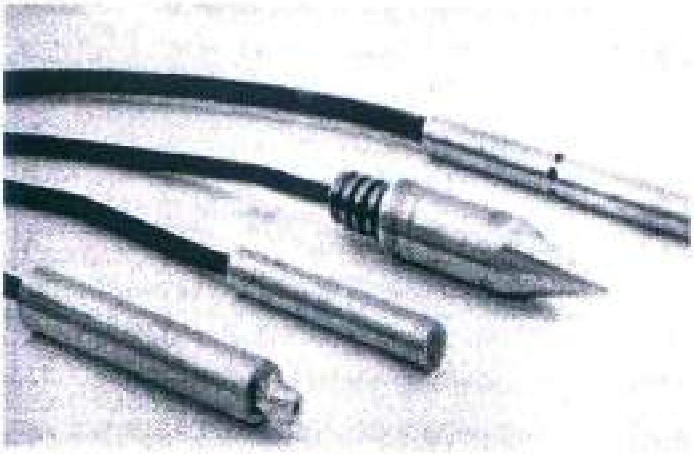
Some of the commonly used instruments are:

1) Convergence Indicators
2) Tape Extensometers
3) Multi-point Bore Hole Extensometers
4) Rock Stress Gauges
5) Shotcrete Stress Gauges
6) Pillar Strain Meters
7) Crack Extensometers
8) Load Cells
9) Instrumented Bolts
10) Piezometers
11) Total Stations

Some of the commonly used instruments are shown below:



Vibrating Wire Transducers for Load, Pressure and Strain



Vibrating Wire Piezometer

Inclinometer

MPBX Unit

Crack Monitoring

Tape Convergence

Electric Centre Load Cell

Appendix–I
(Clause **4.4.2**)

CLASSIFICATION & CHARACTERISTICS OF ROCKS

1. Characteristics of Rock

Parent strength of rock stratum is materially affected by characteristics like weathering, hardness, joint spacing and bedding and rock quality designation (RQD). Broad recommended descriptions of these characteristics are given in tables below. The extent to which these characteristics will affect the parent strength of the rock will vary from case to case and will have to be decided upon based on engineering judgment to access the factors of safety to be allowed for arriving at the allowable bearing pressures. These decisions should be taken as per the advice of the engineering geologist

Table 1 Weathering

Fresh	Rock fresh, crystals bright, few joints may show slight staining. Rock rings under hammer if crystalline.
Very slight	Rock generally fresh, joints stained, some joints may show clay if open crystals in broken face show bright. Rock rings under hammer if crystalline.
Slight	Rock generally fresh-joints stained and discolouration extends into rock up to 25 mm. Open joints contain clay. In granitoid rocks some occasionally feldspar crystals are dull and discoloured. Crystaline rocks ring under hammer.
Moderate	Significant portions of rock show discolouration and weathering effects. In granitoid rocks must feldspar are dull and discoloured; same show clayey. Rock has dull sound under hammer and shows significant loss of strength as compared with fresh rock.
Moderately Severe	All rock except quartz discoloured or stained. In granitoid rocks all feldspars dull and discoloured and majority show Kaolinization. Rock shows severe loss of strength and can be excavated with geologist's pick. Rock goes "clink" when struck (Saprolite).
Severe	All rock except quartz discoloured or stained. Rock "Fabric" clear and evident but reduce in strength to strong soil. In granitoid rocks all feldspars Kaolinized to some extent. Some fragments of strong rock usually left (Saprolite).
Very Severe	All rock except quartz discoloured or stained. Rock "Fabric" discernible but mass effectively reduced to "soil" with only fragments of strong rock remaining.
Complete	Rock reduced to "soil". Rock "fabric" not discernible or discernible only in small scattered locations. Quartz may be present as dyke or stringers.

Table 2 Hardness (for Engineering Description of Rocks – Not to be Confused with Mohr's Scale for Minerals)

Very Hard	Cannot be scratched with knife or sharp pick. Breaking of hand specimens requires several hard blows of geologist's pick.
Hard	Can be scratched with knife or pick only with difficulty. Hard blow of hammer required to detach hand specimen.
Moderately	Can be scratched with knife or pick. Gouges or grooves to 6mm deep can be excavated by hard blow of point of geologist's pick. Hand specimens can be detached by moderate blow.
Medium	Can be grooved or gouged 1.5 mm deep by firm pressure on knife or pick point. Can be excavated in small chips to places about 25 mm maximum size by hard blows of the point of a geologist's pick.
Soft	Can be gouged or grooved readily with knife or pick point. Can be excavated in chips to pieces several cms. in size by moderate blows of a pick point. Small thin pieces can be broken by finger pressure.
Very soft	Can be carved with knife. Can be excavated readily with point of pick. Pieces 2.5 cm or more in thickness can be broken by finger pressure. Can be scratched readily by finger nail.

Note: For specific projects involving only a limited number of rock types, subdivision of major groupings may be desirable. Numerical or alphabetical subscripts may be used to identify such subdivisions.

Table 3 Joints and Bedding in Rock

Spacing	Joints	Bedding	Remarks
Less than 50 cm	Very close	Very thin	
50 mm to 300 mm	Close	Thin	
300 mm to 1 m	Moderately Close	Medium	
1 m to 3 m	Wide	Thick	Massively bedded
More than 3 m	Very wide	Very thick	Massively bedded

Note: joint spacing refers to the distance normal to the plane of the joints of a single system "set" of joints which are parallel to each other or nearly so. The spacing of each "set" should be described, if possible to establish.

Table 4 Rock Quality Designator (RQD)

RQD	Diagnostic Description
Exceeding 90%	Excellent
90-75	Good
75-50	Fair
50-25	Poor
Less than 25	Very poor

Note:
1. RQD should always be given in percentage. Diagnostic description is intended primarily for evaluating problems with tunnels or excavations in rock.
2. If RQD is t o be determined, double tube N size core barrel with non-rotating inner barrels must be used.

PROCEDURE FOR PREDICTING ROCK MASS RATING (RMR)

To apply the geo-mechanical classification system, a given site should be divided into number of geological structural units in such a way that each type of rock mass present in the area is covered. The following geological parameters are determined for each structural unit:

a) Uniaxial compressive strength of intact rock material(IS 8764),

b) Rock quality designation[IS 11315(Part 11)],

c) Spacing of discontinuities[IS 11315(Part 2)],

d) Condition of discontinuities[IS 11315(Part 4)],

e) Ground water condition[IS 11315(Part 8)] and

f) Orientation of discontinuities[IS 11315(Part 1)].

- Uniaxial Compressive Strength of Intact Rock Material (q_c)

  The strength of the intact rock material should be obtained from rock cores in accordance with IS 9143 or IS 8764 or IS 10785 as applicable based on site conditions. The rating based on uniaxial compressive strength and point load strength are given in **Appendix-II (Item I)**. However the use of uniaxial compressive strength is preferred over the point load index strength.

- Rock Quality Designation(RQD)

  Rock quality designation (RQD) should be determined as specified in IS 11315 (Part 11). The detail of rating are given in Appendix - II (Item II).

- Spacing of Discontinuities

  The term discontinuity covers joints, beddings or foliations, shear zones, minor fault, or other surfaces of weakness. The linear distance between two adjacent discontinuities should be measured for all sets of discontinuities. The details of ratings are given in Appendix – II (Item III).

- Condition of Discontinuities

  This parameter includes roughness of discontinuity surfaces, their separation, length or continuity, weathering of the wall rock or the planes of weakness, and infilling (gauge) material. The details of rating are given in Appendix –II (Item IV). The description of the term used in the classification is given in the IS 11315 (Part 4) and IS 11315 (Part 5).

Appendix-II
(Clause **4.4.2**)

DATA SHEET FOR GEOMECHANICAL CLASSIFICATION OF ROCK MASSES AND ASSESSMENT OF ROCK MASS RATING (RMR) (AFTER BIENIAWSKI 1989)

I. STRENGTH OF INTACT ROCK MATERIAL (MPa)

	Uniaxial Compressive Strength MPa	Point Load Strength MPa	Rating
Exceptionally Strong	> 250	> 8	15
Very Strong	100 - 250	4 - 8	12
Strong	50 - 100	2 - 4	7
Average	25 - 50	1 - 2	4
Weak	10 - 25	} Use of Uniaxial	2
Very Weak	2 - 10	} Compressive Strength	1
Extremely Weak	< 2	} Preferred	0

II. ROCK QUALITY DESIGNATION (RQD)

	RQD %	Rating
Excellent	90 - 100	20
Good	75 - 90	17
Fair	50 - 75	13
Poor	25 - 50	8
Very poor	< 25	3

III. SPACING OF DISCONTINUITIES

	Spacing m.	Rating
Very Wide	> 2	20
Wide	0.6 - 2	15
Moderate	0.2 0 - 0.6	10
Close	0.06 - 0.2	8
Very Close	< 0.06	5

NOTE- If more than one set of discontinuity is present and the spacing of discontinuities of each set varies, consider the set with lowest rating.

IV. CONDITION OF DISCONTINUITIES

Condition of Joints	Very rough surface, Not continuous, No separation, Unweathered wall rock	Slightly rough surfaces, Separation < 1 mm, Slightly weathered walls	Slightly rough surfaces, Separation < 1 mm, Highly weathered walls,	Slickensided wall surface or 1 - 5 mm thick guage or 1 - 5 mm wide separation, Continuous,	> 5 mm thick soft gouge, > 5 mm wide separation, Continuous
Rating	30	25	20	10	0

V. GROUND WATER CONDITION

Groundwater Condition	Inflow per 10 m. tunnel length (lit./ min.)	none	< 10	10 - 25	25 - 125	> 125
	Joint water presure/major principal stress	0	0 - 0.1	0.1 - 0.2	0.2 - 0.5	> 0.5
	General condition	completely dry	damp	wet	dripping	flowing
Rating		15	10	7	4	0

VI. ORIENTATION OF DISCONTINUITIES

ADJUSTMENT FOR JOINT ORIENTATION

Average Orientation of dip and strike of joints		Very favourable	Favourable	Fair	Un-favourable	Very ui-favourable
Rating	for tunnels	0	- 2	- 5	- 10	- 12
	for foundations	0	- 2	- 7	- 15	- 25
	for slopes	Use Slope Mass Rating (SMR) as per IS 13365 (Part 3)				

VII. ROCK MASS RATING (RMR)

Rock Mass Rating (RMR) Value is total of the following ratings

1) Rating for Intact Rock Material as per I above
2) Rating for Rock Quality Designation (RQD) as per II above
3) Rating for Spacing of Discontinuities as per III above
4) Rating for Condition of Discontinuities as per IV above
5) Rating for Ground Water Condition as per V above

   Total Original RMR (Total of I to V)

6) Adjustment for Orientation of Discontinuities as per VI above

   Adjusted RMR (Total of I to VI)

VIII. NET SAFE BEARING PRESSURES BASED ON ROCK MASS RATING (RMR)

Description of Rock	Very Good	Good	Fair	Poor	Very Poor
RMR	100 - 81	80 - 61	60 - 41	40 - 21	20 - 0
Bearing Capacity t/sq.m.	400	300 - 200	150 - 100	80 - 50	40 or < 40

Appendix-III

(Clause **4.4.3**)

DATA SHEET FOR GEOMECHANICAL CLASSIFICATION OF ROCK MASSES FOR ASSESSMENT OF TUNNELLING QUALITY INDEX " " (AFTER BARTON ET AL 1974)

Q-system for rock mass classification (Barton)

$$Q = \frac{RQD}{Jn} \circ \frac{Jr}{Ja} \circ \frac{Jw}{SRF} \qquad \text{(EQ 1)}$$

1) Rock Quality Designation	**RQD**
A Very Poor	0 - 25
B Poor	25 - 50
C Fair	50 - 75
D Good	75 - 90
E Excellent	90 - 100

Note: i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q.
ii) RQD interval of 5, i.e., 100,95,90,etc., are sufficiently accurate.

2) Joint Set Number	**Jn**
A Massive, no or few joints	0.5 -1
B One joint set	2
C One joint set plus random joints	3
D Two joint set	4
E Two joint set plus random joints	6
F Three joint set	9
G Three joint set plus random joints	12
H Four or more joint sets, heavily jointed	15
J Crushed rock, earthlike	20

Note: i) For intersections, use (3.0 x J_n). (ii) For portals, use (2.0 x J_n).

3) Joint Roughness Number	**Jr**
a) Rock-wall contact, and b) Rock wall contact before 10 cm shear	
A Discontinuous joints	4
B Rough or irregular, undulating	3
C Smooth, undulating	2
D Slickensided, undulating	1.5
E Rough or irregular, planar	1.5
F Smooth, planar	1.0
G Slickensided, planar	0.5

Note: i) Descriptions refer to small and intermediate scale features, in that order.

c) No rock-wall contact when sheared

H Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0

Note: ii) Add 1.0 if the mean spacing of the relevant joint set ≥ 3 m.
iii) Jr = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength.

4) Joint Alteration Number	Φ_r approx	J_a
a) Rock-wall contact (no mineral fillings, only coatings)		
A Tight healed, hard, non-softening, impermeable filling, i.e., quartz or epidote	-	0.75
B Unaltered joint walls, surface staining only	25-35°	1.0
C Slightly altered joint walls. Non-softening mineral coating, sandy particles, clay- free disintegrated rock, etc.	25-30°	2.0
D Silty-or sandy-clay coatings, small clay fraction (non-softening)	20-25°	3.0
E Softening or low friction mineral coatings, i.e.,Kaolinite or mica. Also chlorite, talc, gypsum,graphite, etc., and small	8-16°	4.0

b) Rock wall contact before 10 cm shear (thin mineral fillings)		
F Sandy particles, clay-free disintegrated rock, etc.	25 - 30°	4.0
G Strongly over-consolidated non-softening clay mineral fillings (continuous, but <5 mm thickness)	16 - 24°	6.0
H Medium or low over-consolidated softening clay mineral fillings (continuous, but < 5 mm thickness)	12 - 16°	8.0
J Swelling-clay fillings, i.e.montmorillonite (continuous, but <5 mm thickness). Value of Ja depends on percent of swelling clay size particles, and access to water, etc.	6 - 12°	8 -12
c) No rock-wall contact when sheared (thick mineral fillings)		
K,L, M Zones or bands of disintegrated or crushed rock and clay (see G,H,J for description if clay condition)	6-24°	6,8,or 8-12, 5
N Zones or bands of silty-or sandy-clay fraction (non- softening) O,P, R Thick, continuous zones or bands of clay (see G,H,J for) clay condition description	6-24°-	10,13,or 13-20

5) Joint Water Reduction Factor	Water pressure	J_w
A Dry excavation or minor inflow, i.e., <51/min locally	<1(kg/cm²)	1.0
B Medium inflow or pressure, occasional outwash of joint fillings	1-2.5	0.66
C Large inflow or high pressure in competent rock with unfilled joints	2.5-10	0.5
D Large inflow or high pressure, considerable outwash of joint fillings	2.5-10	0.33
E Exceptionally high inflow or water pressure at blasting, decaying with time	>10	0.2-0.1
F Exceptionally high inflow or water pressure continuing without noticeable decay	>10 (kg/cm²)	0.1-0.05

Note: i) Factors C to F are crude estimates. Increase J* if drainage measures are installed.
ii) Special problems caused by ice formation are not considered.

6) Stress Reduction Factor		SRF
a)	*Weakness cones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated*	
A	Multiple occurrences of weakness zones containing clay chemically disintegrated rock, very loose surrounding rock (any depth)	10
B	Single weakness zone containing clay or chemically disintegrated rock (depth of excavation ≤50 m)	5
C	Single weakness zone containing clay or chemically disintegrated rock (depth of excavation > 50 m)	2.5
D	Multiple shear zones in competent rock (clay-free) (depth of excavation < 50 m)	7.5
E	Single shear zone in competent rock (clay-free) (depth of excavation ≤ 50 m)	5
F	Single shear zone in competent rock (clay-free) (depth of excavation > 50 m)	2.5
G	Loose open joint heavily jointed (an depth)	5

Note: i) Reduce SRF value by 25-50% if the relevant shear zones only influence but not intersect the excavation.

b)	*Competent rock, rock stress problems*	σ_c/σ_1	σ_θ/σ_c	*SRF*
H	Low stress, near surface, open joints	>200	< 0.01	2.5
J	Medium stress, favorable stress condition	200 -10	0.01 - 0.03	1
K	High stress, very tight structure. Usually favorable to stability, may be unfavorable to wall stability	10 - 5	0.3 - 0.4	05 - 2
L	Moderate slabbing after >1 hour in massive rock massive rock	5 - 3	0.5 - 0.65	5 - 50
M	Slabbing and rock burst after a few minutes in massive rock	3 - 2	0.65 -1	50 - 200
N	Heavy rock burst (strain-durst) and immediate dynamic deformation in massive rock	< 2	> 1	200 - 400

Note : ii) For strongly anisotropic virgin stress fields (if measured): when $5 \le \sigma_1 / \sigma_3 \le 10$, reduce to σ_c to 0.75 σ_c; when $\sigma_1 / \sigma_3 > 10$, reduce σ_c to 0.5 σ_c; where σ_c is unconfined compressive strength, σ_1 and σ_3 are major and minor principal stresses, and σ_θ is maximum tangential stress (estimated from elastic theory).

iii) Few cases records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases (see H.)

c)	***Squeezing rock : plastic flow in incompetent rock under the influence of high rock pressure***	σ_θ/σ_c	**SRF**
O	Mild squeezing rock pressure	1 - 5	5 - 10
P	Heavy squeezing rock pressure	5	10 - 20

Note: iv) Cases of squeezing rock may occur for depth $H > 350\ Q^{1/3}$. Rock mass ompressive strength can be estimated from $Q = 7\ \gamma\ Q^{1/3}$ (MPa), where γ = rock density in g/cm³ .

d)	***Swelling rock: chemical swelling activity depending on presence of water***	**SRF**
R	Mile swelling rock pressure	5 -10
S	Heavy swell rock pressure	10 -15

Note: v) and Ja classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance

Q-value	Class	Rock mass quality
400 ~ 1000	A	Exceptionally Good
100 ~ 400	A	Extremely Good
40 ~ 100	A	Very Good
10 ~ 40	B	Good
4 ~ 10	C	Fair
1 ~ 4	D	Poor
0.1 ~ 1	E	Very Poor
0.01 ~ 0.1	F	Extremely Poor
0.001 ~ 0.01	G	Exceptionally Poor

APPENDIX-IV

(Clause **4.4.2**)

EXAMPLE OF DETERMINATION OF 'RMR' & 'Q' VALUES & SUPPORT REQUIREMENTS

(Refer IS 13365: Part 1 & 2, 1992)

A proposed Irrigation Project involves construction of two 'D' shaped parallel tunnels, each about 690 m. long connecting two reservoirs. The alignment of the tunnels is almost in N S Direction. Width of each Tunnel is 11 m. wide with semi-circular roof. Clear gap between the two tunnels is 33 m. The tunnels are to be excavated by Conventional method of Drilling and Blasting.

Following Geological and Geotechnical Data was collected.

Regional Geology:

The area is predominantly occupied by Charnockite and Garnetiferous Gneiss. Regional trend of rock formations is tending in NE-SW direction with steep dips of 600 to 80^0 towards south east.

Local Geology:

Geological Mapping along the proposed alignment indicated that the alignment is covered thin layer of soil and scree material underlain y moderately weathered to fresh Charnockite and Gneiss.

Sub-surface Exploration:

Lithological Longitudinal Section along the alignment indicated that Entry Channel will have to be constructed from Ch. 30 m to Ch. 60 m and Exit Channel from Ch. 750 m to Ch. 790 m Thus the tunnel is expected to stretch between Ch. 60 m. and Ch. 750 m.

Engineering Properties of the Rock Mass at the Tunnel were expected to be generally as follows:

Particulars	Value
Unit Weight of Rock Mass	2400 kg./cum.
Specific Gravity	3.1515
Uniaxial Compressive Strength	108.9 MPa
Tensile Strength [Brazilian Test]	13.71 MPa
Modulus of Elasticity	21.27 GPa
Poisson's Ratio	0.1963
Angle of Friction	43^0
Porosity	0.79%
Average Vertical Stress at Tunnel Grade	3.6 MPa

Rock Mass Classification:

In order to arrive at preliminary characterization of the rock mass, the tunnel length was divided in three reaches as follows:

From Ch. m.	To Ch. m.	Length m.	Particulars
60.00	90.00	30.00	Inside Entry Portal
90.00	720.00	630.00	Inner Tunnel
720.00	750.00	30.00	Inside Exit Portal

Rock Mass Characterization of the tunnel medium has been carried out as per ' RMR ' - Rock Mass Rating [Bieniawski] and ' Q " -Rock Mass Quality [Barton]. The mechanics of arriving at the 'RMR' and 'Q' is indicated in the following Tables

Zone from Ch. 90 m to Ch. 720 m:

'RMR "- Rock Mass Rating [Bieniawski]

Sr. No.	Parameter	Condition of Rock Mass	Rating
1)	Strength of Intact Rock Material	Uniaxial Compressive Strength : 100 to 200 MPa	12
2)	RQD ' - Rock Quality Designation	75 - 90	17
3)	Spacing of Discontinuities	0.6 m. to 2.0 m.	15
4)	Condition of Discontinuities	Very rough unweathered wall, Rock tight and discontinuous. No separation,	30
5)	Ground water condition	Completely dry	15
6)	Adjustment for orientation of discontinuities	Very favourable	0
7)	**RMR ' - Rock Mass Rating**		**89**
8)	Classification of rock mass	Very Good Rock	1
9)	Stand up time of roof span of 11 m. wide tunnel	13 years	
10)	Suggested Method of Excavation	Full Face with 3.0 m. advance	
11)	Likely Requirement of Supports	Generally no support required except for occassional spot bolting	

Zone from Ch. 90 m to Ch. 720 m

'Q' - Rock Mass Quality:

Sr. No.	Parameter	Condition of Rock Mass	Rating
1)	RQD " - Rock Quality Designation	75 to 90	80.00
2)	Joint Number [Jn]	1 Joint Set + random	3.00
3)	Joint Roughness [Jr]	Discontinuous joints	4.00
4)	Joint Alteration [Ja]	Tightly healed	0.75
5)	Joint Water Reduction Factor [Jw]	Dry excavation or minor inflow < 5 lit./ min. locally	1.00
6)	Stress Reduction Factor [SRF]	Medium stress	1.00
7)	**Q = RQD/Jn x Jr/Ja x Jw/SRF = 80/3 x 4/0.75 x 1.00/1.00**		**142.00**
8)	Classification of Rock Mass	Extremely Good	1.00
9)	ESR: 1.6 Span 11 m. Span/ESR = 11/1.6		6.88
10)	Support Requirement	Support Category 1, Unsupported	

Appendix-V

(Clause **4.5.1 (c)**)

SUPPORTS IN THE TUNNEL

Average RMR & Q	Category of Support	Immediate Roof Support for 6 m. Wide Heading		Immediate Roof Support for 12 m. [2/3 rd] Width		Immediate Roof Support for 18 m. [Full] Width		Immediate Support for Benching		Ultimate Roof & Side Support for 18 m. [Full] Section
		Rock Bolt Pattern	Shotcrete Thickness	Rock Bolt Pattern	Shotcrete Thickness	Rock Bolt Pattern	Shotcrete Thickness	Rock Bolt Pattern	Shotcrete Thickness	MB 200 Rib Support
		m	mm	m	mm	m	mm	m	mm	mm
20 [0.07]	Immediate	1.5 x 1.5	100							
20 [0.07]	Immediate			1.5 x 1.5	150					
20 [0.07]	Immediate					1.5 x 1.5	150	1.5 x 1.5	150	
20 [0.07]	Ultimate									Placed at 500 mm Spacing & Embedded in 350 mm. thick M 20 Concrete Covering full Overt & Invert
30 [0.21]	Immediate	1.5 x 1.5	100							
30 [0.21]	Immediate			1.5 x 1.5	150					
30 [0.21]	Immediate					1.5 x 1.5	150	1.5 x 1.5	150	
30 [0.21]	Ultimate									
40 [0.64]	Immediate	2.0 x 2.0	100							
40 [0.64]	Immediate			2.0 x 2.0	150					
40 [0.64]	Immediate					2.0 x 2.0	150	2.0 x 2.0	150	
40 [0.64]	Ultimate									
50 [2.00]	Immediate	2.0 x 2.0	50							
50 [2.00]	Immediate			2.0 x 2.0	100					
50 [2.00]	Immediate					2.0 x 2.0	100	2.0 x 2.0	100	
50 [2.00]	Ultimate									
60 [6.00]	Immediate	Spot	Nil							
60 [6.00]	Immediate			Spot	100					
60 [6.00]	Immediate					2.5 x 2.5	100	2.5 x 2.5	100	
60 [6.00]	Ultimate									

CODES OF PRACTICE/ACTS/RULES

FOR TUNNELLING WORK

The following Codes/Acts/Rules and their revised/updated versions, if any, will be applicable to the Tunnelling work. This list is not exhaustive and all other relevant Codes/Acts/Rules and their revised/updated versions, if any, will be deemed to be applicable to the Tunnelling work.

IS 5878	1971	[Part I] Precision Survey and Setting out.
IS 5878	1971	[Part II, Section 1] Underground Excavation in Rock, Section I Drilling and Blasting.
IS 5878	1971	[Part II, Section 2] Underground Excavation in Rock, Section 2, Ventilation, Lighting, Mucking and Dewatering.
IS 5878	1971	[Part II, Section 3] Underground Excavation in Rock, Section 3, Tunnelling Methods for Steeply Inclined Tunnels, Shafts and Underground Power Houses.
IS 5878	1971	[Part III] Underground Excavation in Soft Strata.
IS 5878	1971	[Part IV] Tunnel Supports.
IS 5878	1971	[Part V] Concrete Lining.
IS 5878	1971	[Part VI] Grouting.
IS 4081	1986	Safety Code for Blasting and other related Blasting Operations.
IS 4756	1978	Safety Code for Tunnelling Work.
IS 9103	1979	Admixtures for Concrete
IS 9012	1978	Recommended Practice for Shotcreting
IS 3764	1966	Safety Code for Excavation Work.
IS 4138	1977	Safety Code for Working in Compressed Air
IS 7293	1974	Safety Code for Working with Construction Machinery.
IS 823	1964	Code of Practice for Manual Metal Arc Welding of Mild Steel.
IS 816	1969	Code of Practice for Manual Metal Arc Welding for General Construction in Mild Steel.

IS 1566 1967 Hard-drawn Steel Wire Fabric for Concrete reinforcement.

IS 817 1966 Code of Practice for Training and Testing of Metal Arc Welder [Revised].

IS 226 1975 Structural Steel [Standard Quality].

IS 456 2000 Code of Practice for Plain and Reinforced Concrete.

IS 4086 1967 Methods of Tests for Distributors.

IS 1893 1975 Criteria for Earthquake Resistant Design of Structures.

IS 1200 1971 [Part XXV] Method of Measurement of Building and Civil Engineering Works.

IS 1200 1971 [Part XXV] Method of Measurement of Building and Civil Engineering Works - Tunnelling.

IS 1905 1980 Code of Practice for Structural Safety of Buildings.

IS 1256 1967 Code of Practice for Building Bye-laws.

IS 800 2007 Code of Practice for Use of Structural Steel in General Building Construction.

IS 13365 1992 Quantitative Classification Systems for Rock Mass (Part 1 & 2)

IS 13372 1992 Seismic testing of Rock mass (Part 1 & 2)

IS 14436 1997 Resistivity of Rock

Indian Explosives Act - 1884.

Indian Explosive Rules - 1983.

Indian Mines act – 1952

Indian Mines Rules – 1955

PIARC Guidelines

Report of PIRAC Committee on Good Practice for the Operation and Maintenance of Road Tunnels (C5) -2005