CHAPTER

3

Tunnel Requirements

3.1 GENERAL

The requirements of tunnels to be provided differ with the purpose for which the tunnel is being provided. The Traffic tunnels are provided for the purpose of transportation of goods and people and their requirements can be broadly classified as operational, structural, Constructional and maintenance. The conveyance tunnels are provided for conveying materials, water or sewage. The ones for conveying materials are generally limited to industries or the smaller areas and their requirements pertain mainly to the structural, constructional and maintenance aspects. Ones used for conveyance of water, sewage etc., have in addition to be taken care of in respect of surface finish, water tightness, velocity of flow through them etc., in addition to structural, construction and maintenance concerns.

3.2 OPERATIONAL REQUIREMENTS

These requirements cover such aspects as profile, gradient, curvature, ability to withstand pressures caused by moving vehicles in a confined space, ventilation, lighting, drainage and communication and fire fighting facilities in the case of accidents.

3.2.1 Profile

The cross-sectional profile of the tunnel has to allow movement of the largest vehicle it is designed for and provide for some additional safety margin. The
opposing streams of traffic have to be separated. This is done either by providing a median in a two-way highway tunnel or providing one separate tunnel for each direction.

For railways, even if separate tunnels are not available, the wheel guidance available and the additional guard rails installed between rails provide the necessary safety. The safety and lateral (sway and lurch) movement clearances over moving vehicle profiles or gauge is specified for straight alignment. On curves, the clearances are increased to provide for extra projections caused due to movement of vehicle over curves and by superelevations. An encompassing profile (internal dimensions) allows for these minimum horizontal clearances and also providing for space for other facilities, such as ventilation, ducts, lights and cable ducts/lines for highways, or for signals, traction gear and cable ducts/lines in the case of railway tunnels. These will be after allowing for lining to be provided where required.

The shape of the tunnel itself is dependent on purpose (traffic requirements in case of vehicular tunnels), location, type of soil, overburden depth and to a large extent on the method of construction to be followed.

### 3.2.2 Ruling Gradient

The maximum or ruling gradient to be used is decided based on the type of traffic. In a railway, the ruling gradient specified for the section of the line of which the tunnel forms part has to be decided taking into account the extra resistances on track through tunnels mentioned in Para 2.4.1. Steeper gradients enable shortening lengths of and thus less costly ghat/hill lines but put a severe constraint on train loads, resulting in reduced section capacity and speeds, which would lead to higher energy consumption. Maintenance costs also go up with steeper gradients. Based on long-term operational advantages and economies many planners now prefer flatter gradients of 1% or even 0.67% for busy freight traffic lines and lines on which medium high speed trains are likely to be run in future, e.g. Konkan Railway line in India.

On highway tunnels also the ruling gradient is dependent on type and volume of traffic to be catered for. Generally, the limiting grades at entry and exit ends are in the range of 2.5 to 3.0% while flatter gradients are adopted in the mid-section. A minimum gradient is also specified for tunnels in order to ensure proper drainage. Chapter 5 details this aspect.

### 3.2.3 Curvature

Curvature in railway tunnels depends on speeds to be permitted on the section and the gauge of the line. The wider the gauge, larger the radius of
the limiting curvature specified. At approaches to signals, curves are limited, taking into consideration safe sighting and braking distances. Spacing of tracks inside tunnels is to be such that the induced wind pressure on the bodies of coaches of crossing trains will not cause windows to shatter nor cause discomfort to passengers travelling with windows opened.

### 3.2.4 Ventilation and Lighting

Ventilation needs for railway and highway tunnels differ very much. In short tunnels the force of a moving train provides necessary ventilation by pushing out foul air left by the previous train and drawing in fresh air from the rear. Special ventilation arrangements are required in metro tunnels, for providing comfort to passengers and bringing down the temperature. In highway tunnels, due to the presence inside tunnel of large amounts of CO$_2$ and unburnt CO as well as smoke from diesel engine vehicles, continuous forced ventilation is called for.

Highway tunnels need to be illuminated well enough for clear view of the road for the drivers. The arrangements are thus more elaborate and complicated. Main line railway tunnels need minimal lighting for use by the maintenance crew and for use in emergencies while the lighting requirement for metro tunnels is much larger. The subject is dealt with in detail in Chapter 10.

### 3.2.5 Clearances

The additional dynamic vehicle clearances required in railway tunnels to allow for curves and superelevations are indicated in Figure 3.1. Figure 3.1 (a) conceptually indicates how the different parts of vehicle project out due to curvature and effect of cant provided in the track. Figures (b) and (c) indicate the quantum of such shift for a Standard Gauge (1435mm gauge) vehicle.

### 3.2.6 Aerodynamic Problems in tunnels$^{2,3}$

Aerodynamic problems in railway tunnels arise due to piston action of the train through a narrow tube. This pressure induces fluctuations in pressure inside the tunnel and on periphery of coaches. Due to narrow space availability between the train and tunnel surface, the reactive air that passes by the periphery of the coaches is at high velocity, causing shearing force along the sides of train and tunnel surface. One would feel its effect by way of rattling of doors and pressure felt, especially in ears if windows are open. On a double line single tube tunnels, the effect will be felt more pronounced
Figure 3.1 Additional Dynamic Vehicle Clearances for Railways.

(a) Additional dynamic vehicle clearance for curves

(b) Change in dynamic vehicle width due to curvature

(c) Change in dynamic vehicle width due to super elevation.

Source Morton, 1982
when another train passes in the opposite direction. At higher speeds, the aerodynamic effects will be more pronounced. The velocity of air passing by the train increases in proportion to square of velocity of the train and hence the effects of such pressure fluctuations become more pronounced in high speed rail tunnels. Japanese were the first to notice the adverse effects, in form of peeling of paint in the train, discomfort felt by passengers and damages caused to tunnel lining.

In case of high speed trains, as it enters the tunnel, there is an abrupt change on the practically stationary air in tunnel, which sets up some abrupt changes. Air ahead is compressed and is pushed through the tunnel at a speed close to sound. This 'column of air' is reflected back at the far end portal as 'a pulse of rarefaction' which causes a sudden reduction in reduction in pressure as it reaches back the train. A mechanism of pulses is set up and stream of air passes through the space in the periphery of train to the rear where a suction effect is created. The difference in pressure between front and rear of the train causes a braking effect on the train and also a frictional drag on same. These effects are more pronounced in longer tunnels. The pressure pulses, if too great, cause discomfort to passengers in their ears. The effects of such pulses are interrupted at any opening on sides of tunnels and at shafts, reducing their adverse effects. Larger spaces by adopting higher clearances around the train also reduce the adverse effects. Rapid changes in the pressures within the tunnel have to be avoided. A limit of 0.5 kN/ sqm. is set for frequently repeated pulses, such as the ones occurring in a tunnel with a number of shafts and cross passages. USDOT Handbook recommends a limit of 0.41kN/ sqm and upper limit for same. Upper limit for any change in pressure is set at 3 kN/ sqm.

The pressure waves (and consequently problems) occur when:

- trains enter or exit them
- trains pass sectional variations, if any
- trains pass any openings to cross passage to adjacent tunnels; pass shafts; pass other openings like intermediate adits

The pressure behaviour is as follows. In a 3 km long single track tunnel without intermediate openings, when a 350 m long train runs at 200 kmph, it will take 54 secs. for any point of the train to pass through the tunnel. In first 7 secs, a pressure of 4 kN/sqm occurs, dropping down slightly as tail enters. After further 7 secs, it drops down steeply to (–) 1kN/sqm, when wave of 'rarefaction' enters the tunnel at far end. After this it fluctuates through a 'diminishing range'. This drop of 5kN/sqm is not acceptable and provision of intermediate shafts or cross passage to adjacent tunnel is needed. (High speed lines will have to be double lines and hence an adjacent single track tunnel is a reality.) Alternatively, speed will have to be restricted to 150
kmph or provision of larger section, as has been done by German Railways (75 sqm as against Japanese practice of 64 sqm). Provision of flaring at portals (trumpet shapes) will help reduce pressure wave amplitude at entrance. But, if the exit portal is flared, there can be discomfort to passengers. Each of these remedial methods has advantage and disadvantage and a judicious choice has to be made, considering density of traffic and costs.

In a double track tunnel, the adverse effect at entry is reduced at entry points due to larger area availability. Problem arises when two trains pass each other. Then the aerodynamic effect causes discomfort to passengers, peeling of skin (paint) and rattling of doors. When a freight train with empty containers passed a high speed passenger train, there was a tendency for empty containers to lift off the wagons, if not held down by other means. It is desirable to go in for twin single tubes with interconnection at intervals, rather than a larger section with double line, from passenger comfort and safety points of view, specially in case of high speed lines and subways.

3.3 STRUCTURAL REQUIREMENTS

3.3.1 Supporting Structure

The temporary support structure inside a tunnel has to first support the surrounding soil from caving in and to facilitate easy installation of lining (permanent structure). Preferably, it should be capable of being incorporated as part of the permanent structure. During construction, when compressed air is used for drilling ahead, such support should be airtight and should withstand induced pressure. In service, it has to withstand the vertical load from soil above, and the side thrust from the most saturated condition of soil around.

Lining or permanent structure has to transfer all the superimposed load, the self-weight of the structure itself and the vehicle loads, including impact to the base soil below, without causing any relative settlement along the line. It should be capable of resisting the weathering action over time and chemical action due to fumes and gases emitted by passing vehicles. In subway/metro tunnels it should be leak proof so that ingress of moisture into the tunnel is eliminated or minimal. In the case of tunnels in open country also, the body should be watertight but where there is heavy seepage or where a tunnel cuts through a spring which can build up pressure around if not let free, provision should be made to let such water into the side drain of the tunnel at appropriate places and the tunnel suitably graded towards adits for quick clearance. In seismic areas tunnel structure is designed to
withstand seismic forces also in combination with other loads. The different combinations of loads for which a subway tunnel structure is to be designed are given in an example at Annexure 4.1 and in Para 8.10. Similar principles apply to highway tunnels also.

### 3.3.2 Portals

Tunnel portals are the entry points to the tunnels at either end. Except in case of subways and those used in urban areas for roads, the surface of the ground at the entry points will be having a natural slope. The Adits/ approaches will be in a cutting. From economic and stability considerations, their depths are restricted to about 20 to 25 metre. The portal is a solid structure (face wall) in form of a retaining wall across the tracks depending on depth of cutting. The slope of ground above is protected by a headwall support over the tunnel, as shown in Figure 3.22. It should be such that it can properly retain any sliding mass of soil from above. It is necessary to investigate structure of the rock and soil conditions above the tunnel at this length. Normally conditions met with at these locations will be presence of weathered, fractured and loose layers of rock/ soil where the tunnel pierces through. The type of soils and rocks underlying such layer should be examined to see how the separating sliding planes are sloping/ and if they are towards the cutting, such sliding planes will provide no resistance for the soil above to slide down, when lubricated by percolating water (in rain) etc, The protecting Head wall should extend upto the surface of the soil at the slope it would assume in worst conditions. The adits should not be located in the sliding layer and cutting depth also restricted to 20 to 25 m. The coping of the portal should reach a few decimeters above the natural slope at which the fractured/ loose layer will assume. The coping should be adequately designed to resist the pressure exerted by the sliding soil (in wet condition). The portal face wall itself has to be designed to resist the earth pressure building behind. There has been a case or two where the tunnel failed at entry due to such pressure before the required structure could be completed.

![Figure 3.2 A Typical Location of Portal and Forces acting on same.](image-url)
The portals should be located, as far as possible, in firm ground. They are like end abutments of a bridge and have to be designed to resist the pressure developed by the soil behind. If, for any unavoidable circumstances, it has to be located in soft ground, in order to restrict the pressure developed by the ground behind, the overburden over the tunnel at entry should be restricted and / or it should be supported in front with wing walls/return walls extending into the approach cutting (Figure 3.3). Alternatively, the tunnel body itself is extended into cutting till it reaches beyond the toe of the ground slope on the approach formation.

![Portal with Wing walls in soft ground- Pir Panjal Tunnel North Portal.](image)

### 3.3.3 Invert Types

Invert of a tunnel refers to the base of the tunnel, over which the utility (road, rail track, canal etc..) are laid. There are two ways of providing same viz., directly laying over the exposed base or to provide a structural slab spanning the face walls and creating space below for ventilation, drainage and other utilities. First method is used mostly for railway lines and the second method for highway tunnels.

In the first method also, there are two types. One is to just provide kerbs and drains alongside the side walls and lay the track on ballast between them directly on exposed grade. This is possible in case of tunnels through hard rock and was the traditional practice. In case, the grade is on disintegrated rock or soil, a concrete base is provided at grade first over which track is laid. This practice is now being given up in favour of provision of ballastless track, by laying a lightly reinforced slab and providing track over a plinth or embedding PSC sleepers in concrete. Except in hard rocks, where the base of the side walls and supports are keyed into rock and provided a base, struts spanning tunnel supports or a RCC base slab has to be provided below or as part of base for resisting horizontal thrust. Figure 3.4 shows the different types.
Figure 3.4 Different Types of Invert in Vehicular Tunnels

(a) Ballasted Track on Grade-Rocky base

(b) Ballasted Track on Concrete Base + Strut

(c) Ballastless track on slab-

(d) Road on Structural slab with duct below
3.4 CONSTRUCTION AND MAINTENANCE

Type of soil, end use and construction methodology govern the choice of shape of tunnel. Thus construction methodology plays an important role. In open country and in hard rock, generally an elliptical shape or a segmental arch over a rectangular section is adopted. In soft rocks and medium cohesive soils also, such a shape is adopted so that the top portion is excavated and supported by arched ribs first and the lower portion extended by benching. In non-cohesive mixed soils or sandy/mixed strata, generally the shield tunnelling method is used. This calls for a circular profile. In subway tunnels for which the cut-and-cover method is used, mostly rectangular sections are adopted. If in cohesive soils, shield tunnelling or boring using moles is adopted (with or without compressed air) and a circular profile has to be adopted. The dimensions of tunnel have to be the minimum necessary for traffic requirements and at the same time large enough for use of mucking machines, trollies / trains or trucks for clearing away the tunnelled soil. In long tunnels shafts are provided at intervals to clear the muck. They are spaced at intervals of about 1 km to 2 km and at sharp bends.

The minimum maintenance requirement is good drainage. As already mentioned, a suitable grade in the line of the tunnel should be provided and in long tunnels, if possible, sumps are provided, cross-drains are drilled through and/ or suitable pumping arrangements are made. The minimum ventilation requirement will call for some shafts at intervals in long tunnels, generally over 2 km long. Inspection squads and maintenance men in railway tunnels will need some shelters in form of niches in which to take refuge when trains pass, and for this trolley refuges have to be cut into alternate sides at about 90-m intervals. For example, on the Pir Panjal tunnel built recently in Kashmir a 3 m wide paved pathway has been provided for the full 10.9 km length of tunnel for maintenance and emergency evacuation vehicles to be taken in.

Subway tunnels do not provide for such facilities as maintenance is to be done when there is no traffic. The track, these days, is made ballastless, thus serving as a paved way for emergency evacuation of passengers. Such provision minimizes maintenance requirements also. Subway tunnels have to provide for increased safety requirements, as they deal with large passenger traffic. Stations also being in same level experiencing large movement of people in opposing directions, this becomes more important. They need good ventilation and lighting arrangements. They also call for a high degree of cleanliness. Such tunnels are, in most cases, partially or fully below sub-soil water level and in granular or clayey strata. The lining or shell has to be completely waterproof, to combat consequent seepage.
In highway tunnels footpaths serve the purpose. On Konkan Railway some of these refuges in a long tunnel cut in rock had been used for reversing and passing mucking trucks coming from opposite directions, thus increasing speed of mucking operations during construction. During emergencies the staff in the case of railways or users in the case of highway tunnels must have access to some communication facilities with staff at portals or in neighbouring stations. Hence telephone plug points have to be provided at intervals. In long highway tunnels emergency equipment in the form of fire tenders and towing cranes is maintained at either end of the tunnel. Fire fighting water pipe lines can be run over the length of tunnel with fire hydrant points at intervals also in long tunnels in remote areas and in subway tunnels.

3.5 CANAL/NAVIGATION TUNNELS

Navigation canals connecting natural streams or on their own formed the backbone of large traffic in seventeenth and eighteenth centuries. Where they had to cross from one valley to another in hilly terrain, taking them through tunnels became necessary. The earliest known navigation tunnel is the Maples tunnel opened in 1679. Canal tunnel construction had practically stopped after nineteenth century. Last perhaps is the one connecting to smooth water strip along coast near Marseilles and mouth of Rhone, in Golfe de Fos, an inland lagoon. Work on this 7.2 km tunnel crossing was started around 1905 and completed in 1927, work having been interrupted by the First World War. This is believed to be the largest canal tunnel, about 22m wide at springing and 15.4 m from invert to crown, The depth of water in canal itself is about 3m and it has two toe paths 2m wide each on the sides. See Figure 3.5. Large vessels including those with bow of beam of 8m and 1200 ton displacement capacity could use this tunnel safely.

They are similar to Highway tunnels, but with a level gradient. Their width has to be large enough to provide for maneuvering of the boats, though most of them have been built for unidirectional movement of boats. For example, the smallest section of such tunnel in UK is 3063 yard long Butterfly tunnel 4'-10" wide and 8'-10" high and the largest 3036 yard long Netherton tunnel 15'9" wide and 27' high roof. They are mostly inverted U shaped with vaulted elliptical circular roof.

Alternatively, poling or shafting was used in manual haulage. If canal floor was lined with only clay puddle, the alternative forms of haulage by rope from ends or use of railings was resorted to. With the advent of diesel engines diesel powered tugs have been to haul a ling of boats. Steam
powered tugs also had been used in some, but they resulted in the soot covering the roof and sides, which had to be periodically cleaned.

Walkways were provided for use by men or horses for toeing the boat. Paddling and rowing is not permitted in such tunnels for want of adequate width for rowing. Where space cannot accommodate such walkways, some form of railing or chain links have been fixed on short brackets for men to hold and move boats. Some form of control system between the portals has been provided to regulate the movement. In some wider canals, bi-directional traffic could be provided for smaller boats. Height has to be adequate to provide for vertical projections from the craft like chimneys and use of ores, as necessary. An additional and important requirement is that the floor and sides of the canal have to be watertight. Earlier ones were lined suitably with clay and puddle. Such tunnels cannot be provided in porous grounds. Channel section in tunnels in rocky soils are lined with concrete and well finished. In case of large width compared to height of the tunnels calls for adoption of vaulted structures. They are not safe to be provided in terrain subject to tectonic movement.

![Typical section of navigation tunnel](image)

*Adapted from Szechy 1970*

**Figure 3.5** A Typical Large Navigation Tunnel

Curved alignments are avoided for better sighting and easy maneuvering of boats. Driving the tunnels is done by heading and benching or by driving through a number of drifts and widening, depending on type of soil. Long ones are done by sinking a number of shafts at intervals and opening out a
number of faces, Some of these shafts are lined and retained for natural ventilation. Canals in long tunnels are generally divided into a number of sections with provision for inserting temporary shutters so as to isolate a section at a time for maintenance purpose, by pumping out the water for cleaning and any repairs. Long tunnels should be provided adequate lighting for the boatmen to toe and maneuver boats safely.

3.6 ADDITIONAL REQUIREMENTS IN WATER CONVEYANCE TUNNELS

3.6.1 Hydro-electric Power Plant Tunnels

Water has to be conveyed to power plants located down the hill in the valley from storage reservoirs at higher levels. This can be done directly to the turbines in the power house through Pressure tunnels drilled through the hill or by pressure conduits or pipes laid on the sloping surface of the hill. In the latter case also, tunneling is done through any intervening ridge from reservoir outlet to the top of the conduit. In latter case, the tunnel is known as Discharge tunnel. The pressure tunnel will be subjected to comparatively higher outward pressure than the resistance that can be offered by the surrounding rock and overburden. Hence they have to be designed as a pressure pipe and the lining has to be suitably reinforced. A circular section is preferable for same, which will be easier to drill also. A horse shoe type also can be used, but adequately reinforced. Such pressure tunnels can be provided only through solid rock and are not suitable for rocks with fissures and cracks. They have to be highly water proof also. On the other hand, Discharge tunnels are designed and constructed like a railway tunnel and a horse shoe shape with inverted base is preferred. They also have to be made water proof. Figure 3.6 shows a typical layout of such tunnels serving a Hydro-power plant.

3.6.2 Water Supply Tunnels

Water supply tunnels are provided for conveying water from storage reservoirs or streams to the treatment plants or ground storage at distribution centres across an undulating country. They are similar to the Discharge tunnels mentioned above. In most cases, they will be at shallow depths and can be built by cut and cover method, in which case they can be designed like subway tunnels. In many cases in past, they have been built with RCC base, brick side walls and arch roofs with water proof lining inside.
It is desirable to carry utilities like liquid / gas pipe lines and cables underground housing them in larger conduits in from of circular or rectangular tunnels. Two typical examples are shown in Figure 3.7. Conveyor belt systems in power houses and large industries may also be housed in rectangular tunnels similar to the cable utility tunnel shown in the figure. The minimum internal dimension of any such tunnel should be 2.5 m for facility of maintenance and inspection personnel to move in them freely.

3.6.3 Utility Tunnels

Adapted from Szechy, 1970

Figure 3.6 Typical Water Conveyance and Pressure tunnels for a Power plant

Figure 3.7 Typical Utility Tunnels

Adapted from Szechy, 1970

Figure 3.7 Typical Utility Tunnels
3.7 REFERENCES