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RAILWAY RECRUITMENT BOARD

CIVIL ENGINEERING

TRANSPORTATION ENGINEERING

SELF STUDY MATERIAL

CIVIL ENGINEERING FOR ALL

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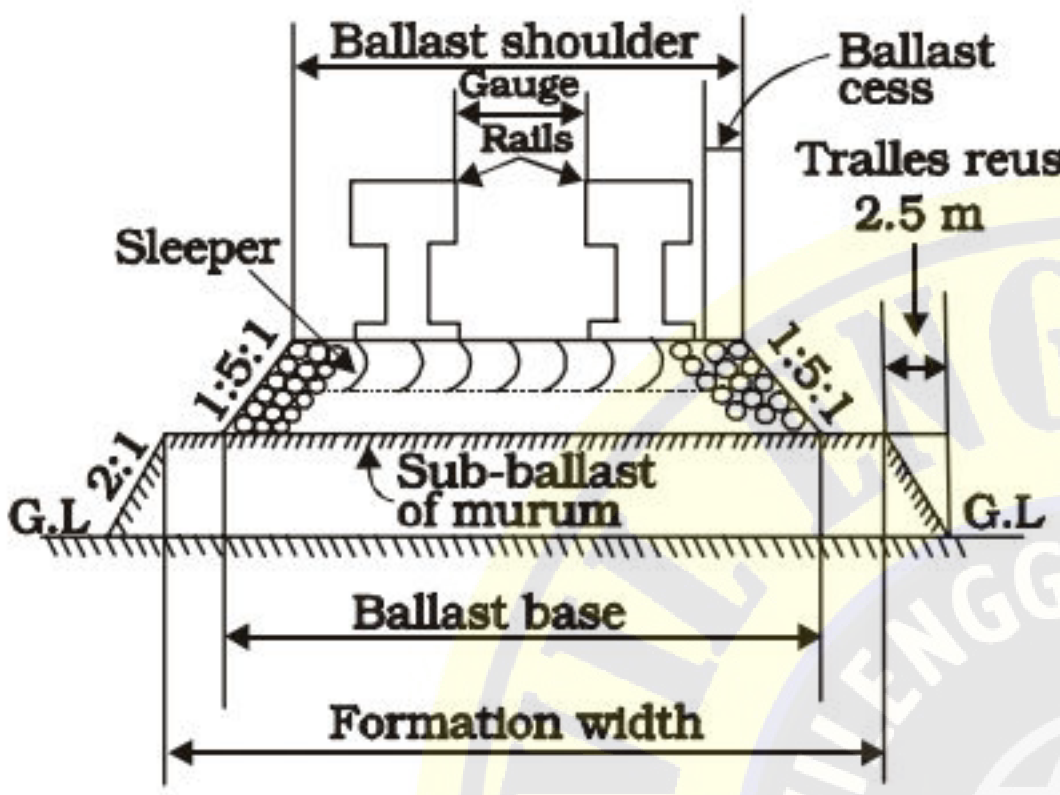
THE PERMANENT WAY :

The combination of rails, fitted on sleepers and resting on ballast and subgrade is called permanent way.



In a permanent way, the rails are joined in series by fit, plates and botts and then they are fixed to sleepers by different types of fastenings. The sleepers properly spaced, resting on ballast, are suitable packed with ballast. The layer of ballast rests on the prepared subgrade called the formation.

The rails acts as girders to transmit the wheel load to the sleepers. The sleepers holds the rails in proper position with respect to the proper tilt, gauge and level, and transmit the load from rails to the ballast.

The ballast distributes the load over the formation and holds the sleepers in positions.

On curved tracks, super-elevation is maintained by ballast and the formation is levelled. Minimum ballast cushion is maintained at the inner rail, while the rail gets kept more ballast cushion. Additional quantity of ballast is provided on the Quter cees of each track for which the base width of the ballast is kept more than for a straight track.

Requirements of an Ideal Permanent Way :

Permanent track is regarded to be semi-elastic in nature. There is possibility of track getting disturbed by the moving wheel loads. The track should therefore be constructed and maintained keeping the requirements of a permanent way, in view so as to achieve higher speed and better riding qualities while less future maintenance. Following are the some of the basic requirements of a permanent way :

(i) The gauge should be correct and uniform

(ii) The rails should be in proper level. In a straight track two rails must be at the same level on curves, the Quter rail should have proper superelevation and there should be proper transition at the junction of a straight and a curve.

(iii) The alignment should be correct i.e., it should be free from kniks or irregularities.

(iv) The gradient should be uniform and as gentle as possible. Any change of gradent should be followed by a smooth vertical curve to give smooth riding quality.

(v) The track should be resilient and elastic in order to absorb shocks and vibrations of running track.

(vi) The track should have enough lateral strength, so that alignment is maintained even due to effects of (a) side thrust on tangent lengths and centrifugal forces on curves (b) lateral forces due to expansion of rails particularly in case of welded rails.

(vii) The radii and superelevation on curves should be properly designed and maintained.

(viii) Drainage system may be perfect for enhancing saftey and durability of track.

(ix) Joints, including points and crossing which are regarded to be weakest points of the railway track, should be properly designed and maintained.

(x) Ifthereistroublefromthecreep,thepreventionary measures should be to prevent it.

(xi) The various components of the track, i.e., the rails, fittings, sleepers, ballast and formation must fully satisfy the requirements for which they have been provided. If any component is lacking in fulfilling its requirements have been provided. If any component is lacking in fulfilling its requirements then either it should be improved or replaced.

(xii) There should be adequate provision for easy renewals and replacements.

(xiii) The track structure should be strong, low in initial cost as well as maintenance cost.

CAPACITY OF A RAILWAY TRACK

Capacity of a railway track (or track capacity) is hourly capacity of the track to hands the trains safely or in other words it is number of trains that can be run safely on a track per hour. The track capacity can be increased by the following ways.

(i) By achieving faster movement of trains on a track, and

(ii) By decreasing the distance between successive trains.

The following are some of the general measurer which can be taken to increase the track capicity.

(i) All the trains should be made to run at the same speed for which uniformity of gauges and traction should first be achieved in the country.

(ii) All setions should be made of equal lengths.

(iii) Multi-aspect signalling should be adopted to alert the driver in advance of positions for various sections. For example, a multicolour light signal red, yellow, double yellow and green light colour will respectively give indication of danger (red), caution (Yellow), attention (double Yellow) and clear (green)

(iv) The speed of train can be increased by adopting diesel or electric traction.

(v) The speed can also be increased by making suitable improvements in the existing tracks and removing the speed restriction if any.

(vi) A reduction in the time of stoppages of trains.

(vii) The length of sections should be decreased by providing additional crossing sections.

(viii) The length of crossing sections (or looks) should be increased in order to enable the longer goods train to pass.

(ix) New lines should be constructed for operational and industrial purpose.

(x) A quick arrangement for shunting to attach ordetach the coaches ie., additional operating facilities in the station yards should be provided.

GAUGES IN RAILWAY TRACK :

The "gauge" of a railway track is defined as the clear distance between inner or running faces of two track rails. The distance the inner faces of a pair of wheel is called the "Wheel gauge.

DIFFEREN GAUGES IN INDIA AND ABROAD :

In 18^{th} century the British railways were using the flanges on the outside of rails and gauge was defined as the distance between the outer faces of the rails. The gauge then maintained was 5' (1.524 m). Subsequently, the adoption of flanges inside the wheel on rails changed the definition of gauge. The position of rails of tracks was not changed in view of economy and clear distance between inner faces was defined by gauge.

So present gauge = Past gauge – 2 × rail Width top

$$= 5' - 2 \times 1\frac{3}{4} = 4' - 8\frac{1}{2} \text{ or } 1.435 \text{ m.}$$

A gauge of 1.435 m. is the standard gauge in most of the countries even today.

In India, the east India company adopted 1.676m (5' – 6') gauge as the standard gauge. In 1871, in order to build cheap railways for the development of the country, the government adopted a metre gauge i.e., 1 m wide. In addition to broad gauge (Standard gauge) and metre gauge for hilly areas and for narrow gauge tracks and feeder gauge tracks respectively.

Thus in India the following gauges are used :

Type of gauge	**Gauge Width**
(i) Standard gauge (B.G)	= 1.67 m
(ii) Metre gauge (M.G)	= 1.0 m
(iii) Narrow gauge (N.G)	= 0.762 m
(iv) Feeder track-gauge (L.G) (or Light Gauge)	= 0.610 m

SELECTION OF GAUGE :

The following factors govern the choice among the different gauges :

(i) Cost of construction : There is little increase in the initial cost if we select a wider gauge (say B.G) this is due to following reasons.

(a) The cost of bridges, tunnels, stations building, staff quarter signals, cabins and level crossing is the same for all the gauges.

(b) The cost of earth work, (in making embankments and cuttings), ballast, sleepers, rails etc. Would proportionally increases with increase in gauge width.

(c) There is little proportional increase in the acquisition of land for permanent track with increase in gauge.

(d) The cost of rolling stock is independent of the gauge used for the same volume of traffic.

We can therefore concluded that there is notan appreciable increase in cost due to inrease in width of gauge. We can therefore concluded that there is not an appreciable increase in cost due to increase in width of gauge.

(ii) **Volume and Nature of Traffic :** It is evident that with greater traffic volume and greater load carrying capacity, the train should be run by a better traction techniques or beg better locomotives. For heavier loads and high speed, the wider gauges are required because subsequently the operating cost per tonne km is less for higher carrying capacity.

(iii) **Development of the areas :** Narrow gauges can be used to develop the thinly populated areas by joining the under developed areas within the developed or urbanised areas.

(iv) **Physical features of the country :** Use narrow gauge is warranted in hilly regions where broad and metre gauge are not possible due to steep gradient and sharp curves. In plains also where high speed is not required and the traffic is light, N.G. is a right choice

(v) **Speed of Movement :** The speed of a train is almost proportion to the gauge. Speed is the function of diometer of wheel, which in turn is limited by the gauge. The wheel diameter is generally 0.75 times that of the gauge. Lower speeds discourage the customers and so for maintaining high speeds, the Broad gauge is preffered.

UNIFORMITY OF GAUGES :

Gauge to be used in a particular country should be uniform through out as far as possible, because it will avoid many difficulties experienced in a non-uniform system. The uniformity of gauges result in the following advantages :

(i) The delay, cost and hardship in trans hipping passengers are goods from the vehicles of one gauge to another is avoided.

(ii) As the transhipping is not required, there is no breakage of goods.

(iii) Difficulties in loading and unloading are avoided and labour expenses are saved.

(iv) Possibility of theft and misplacement, while changing from one vehicle to another is eliminated.

(v) Large sheds to store goods are not required.

(vi) Labour strikes, etc. do not effect the service and operation of trains.

(vii) Surplus wagons of one gauge cannot be used to another gauge. This problem will not arise if gauge is uniform.

(viii) Locomotive can be effectively used on all the tracks if a uniform type of gauge is adopted.

(ix) Duplication of equipment such as platforms, sanitary arrangments, clocks etc is avoided. This saves a lot of extra expenditure.

(x) During military movement, no item is waste inchanging personnes and equipment from one vehicle to another if gauge is confirm

(xi) It is quite expensive to convert one gauge into another at a later stage as it may require new rolling stock, fresh construction and widening of bridges and tunnels.

(xii) Due to late arrival of trains at the junction, where change of guage is involved, the missing links result in number of difficulties. Passengers have to pass time on platforms. In uniform gauge, this problem does not arise.

(viii) Porter charges are increased when passengers have to change compartment due to a different gauge. This is avoided if gauge is uniform.

In India, efforts are being made to convert all N.G. and M.G. lines to B.G. lines on important sections as and when funds are available.

RAILWAY TRACK CROSS-SECTIONS

The typical cross-sections of a single line and double line, in cutting and embankment, on straight and curved tracks, for steam traction and electric traction, have been shown in Figs. 'a' to 'b'

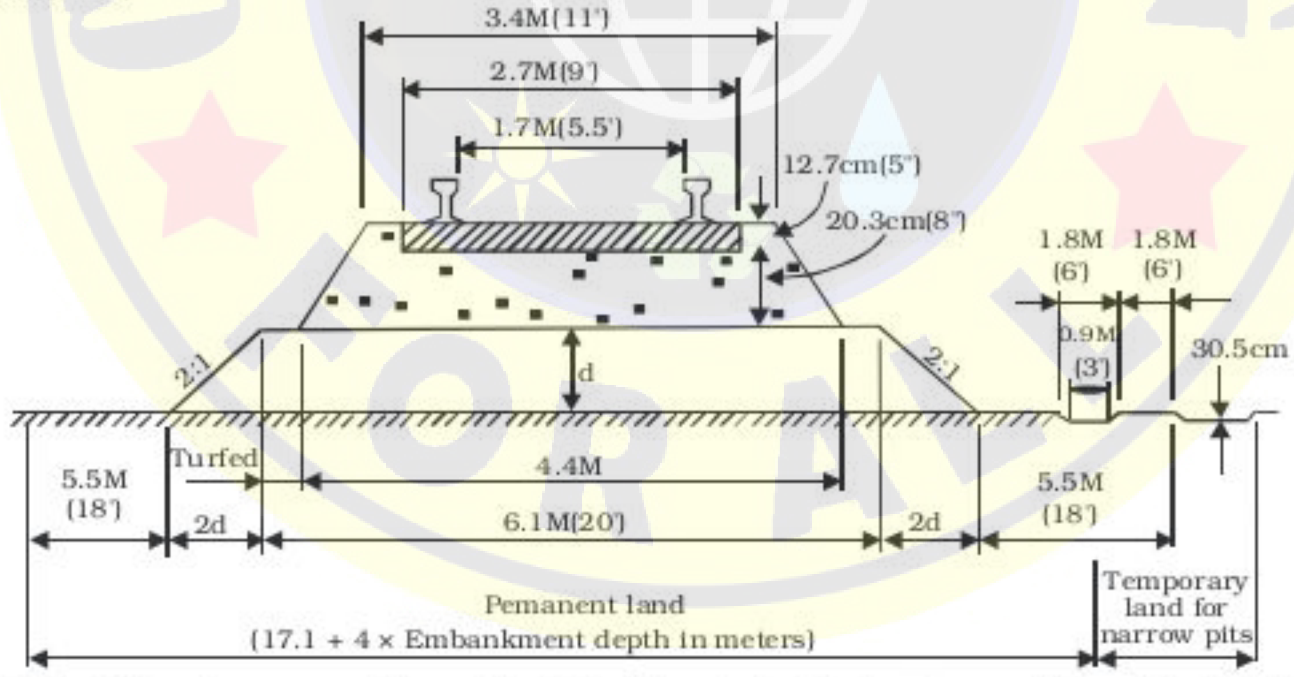


Fig. (a) The Cross-section of a B.G. Track in Embankment (on Straight Track)

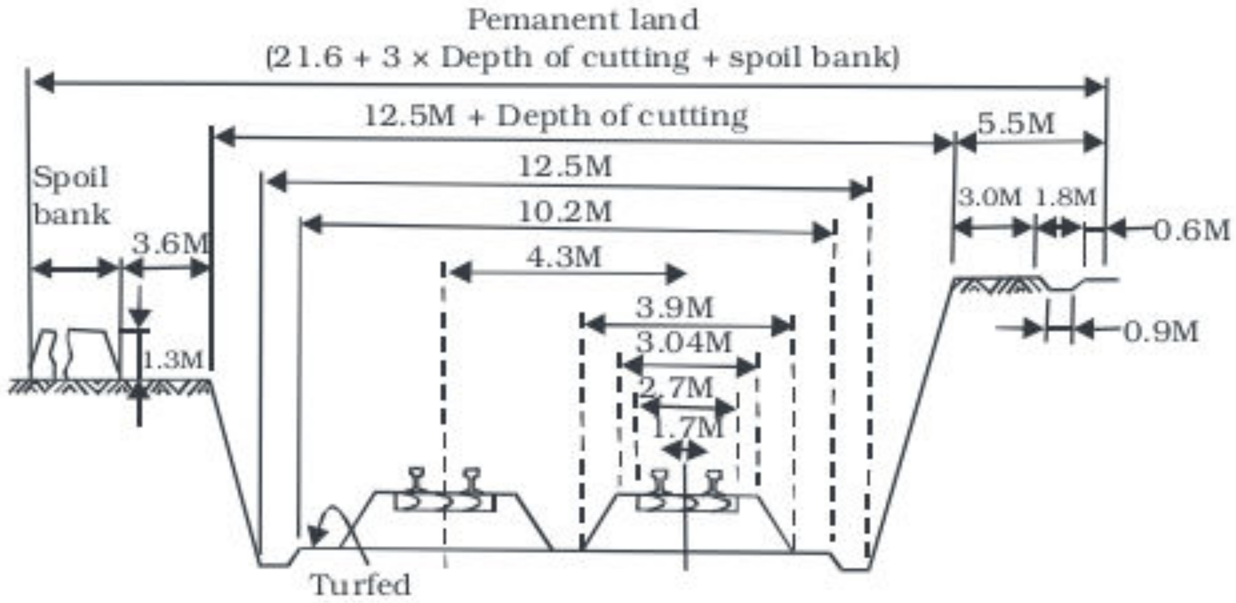


Fig. (b) The Cross-section of a B.G. Track in Cutting for Double Line (on Straight Track)

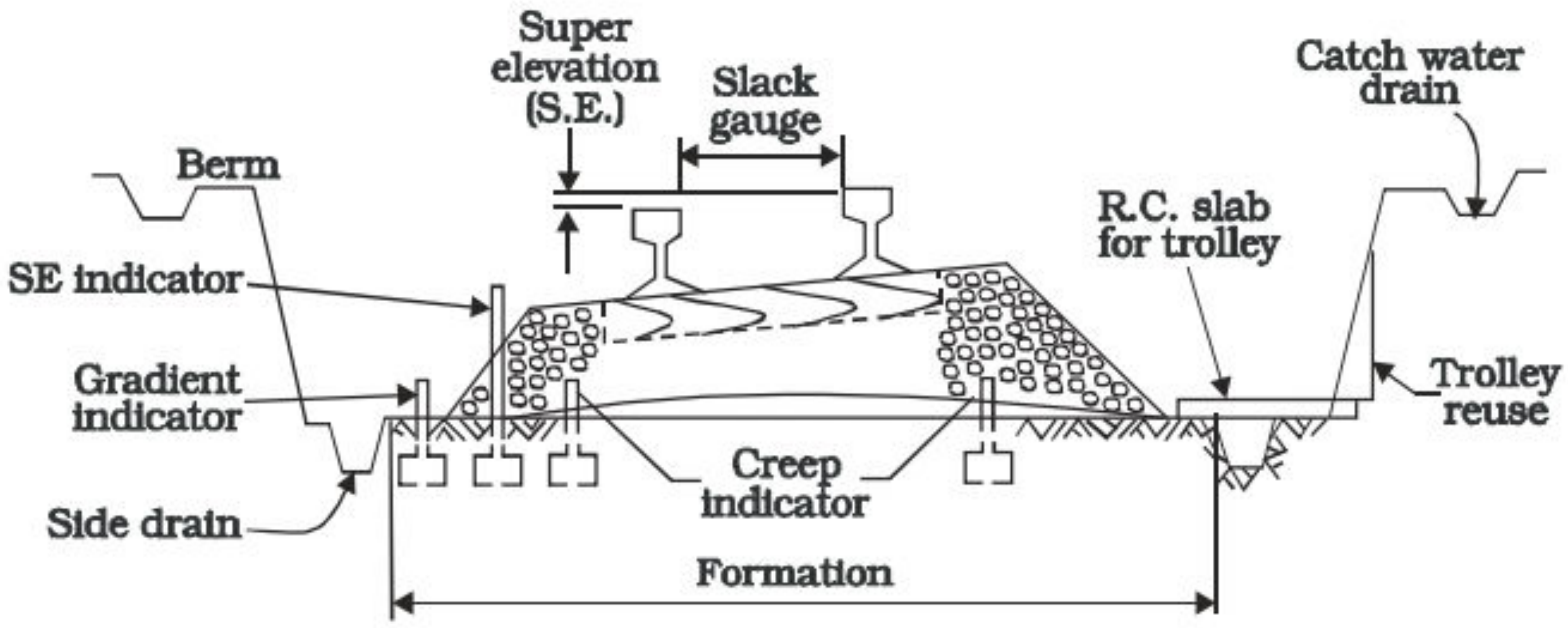


Fig. The Cross-section of a B.G. Track for a Single Line (on Curved Track)

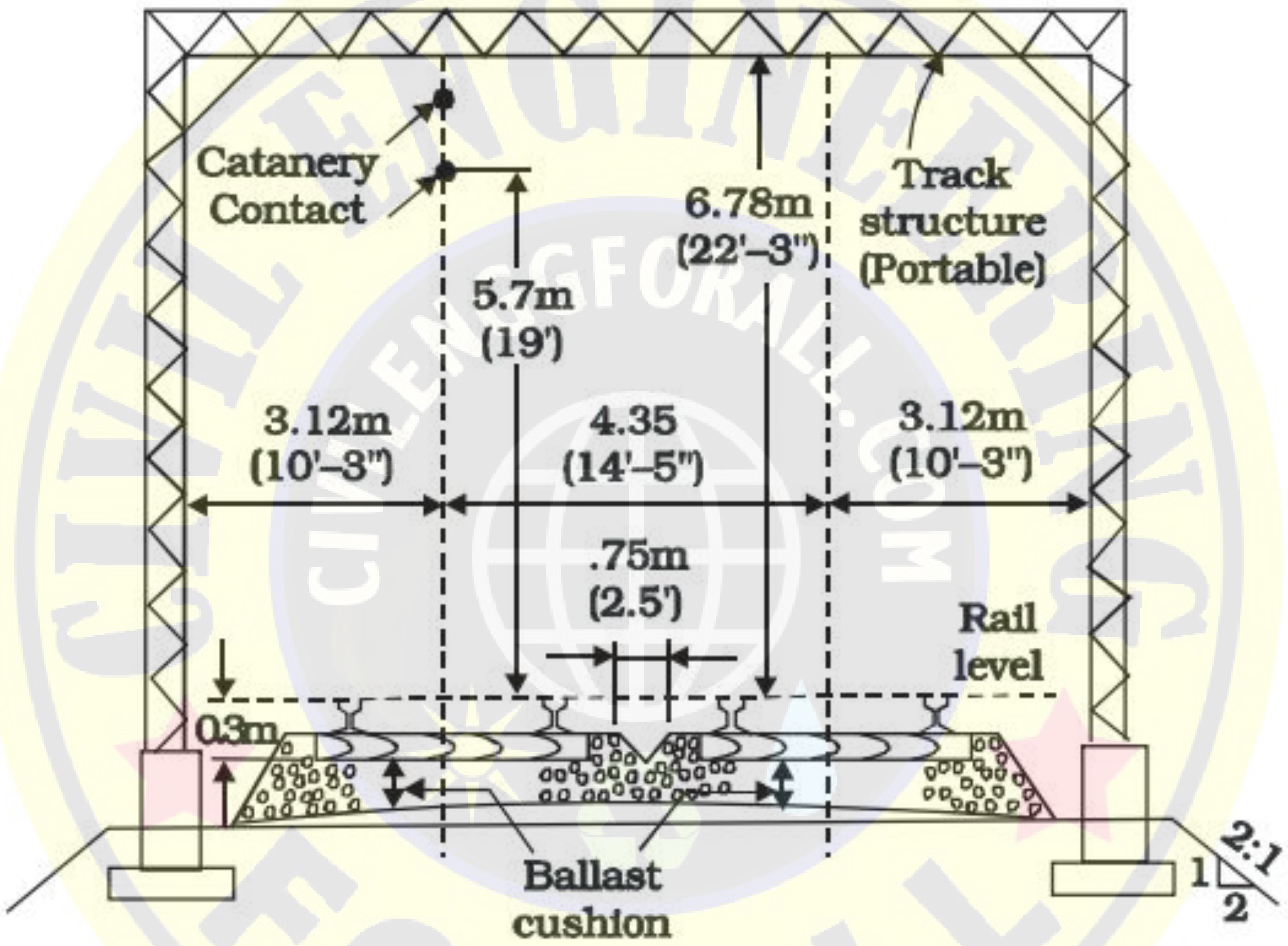


Fig. The Cross-section of a B.G. Track for Double Line with Electric-traction

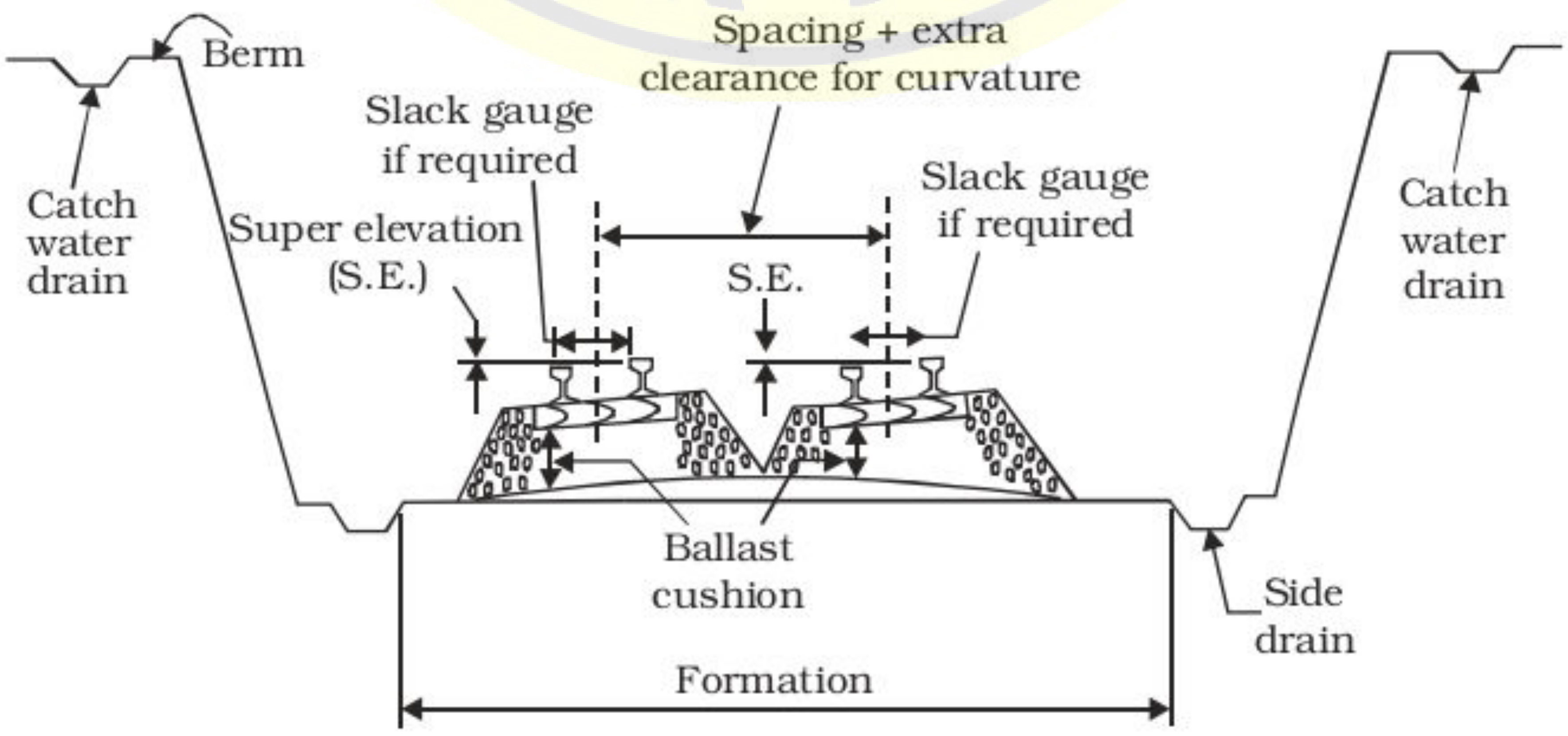


Fig. The Cross-section of a B.G. Track for Double Line in Cutting (on Curved Track)

CONING OF WHEELS

The distance between the inside edges of wheel flanges is generally kept less than the gauge of the track. So there is a gap between the wheel flanges and running edges of the rails, nearly equal to 1 cm. $\left(\frac{3}{8}\right)$ on either side. Normally, the tread of wheels is absolutely dead centre of the head of the rail, as the wheel is coned to keep it in this central position automatically. These wheels are coned at a slope of 1 in 20 (as shown in Figure).

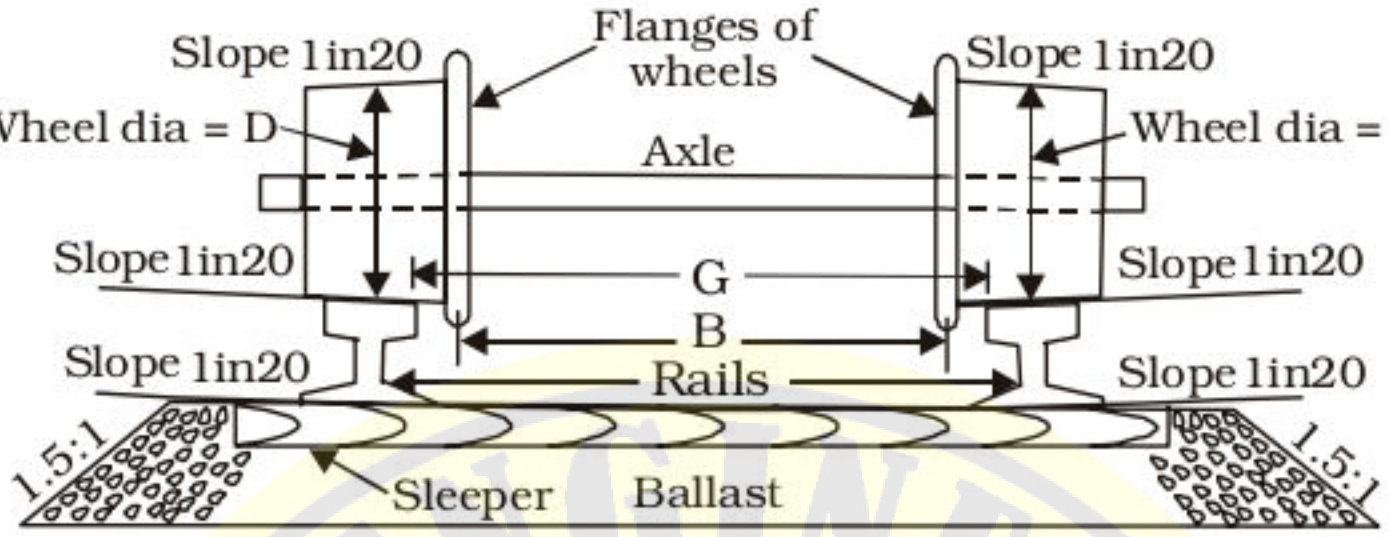


Fig. Coning of Wheels on Level-track

The advantages of coning the wheels are :

(i) To reduce the wear and tear of the wheel flanges and rails, which is due to rubbing action of flanges with inside faces of the rail head.

(ii) To provide a possibility of lateral movement of the axle with its wheels.

(iii) To prevent the wheels from slipping to some extent.

Theory of Coning On a level track, as soon as the axle moves towards one rail, the diameter of the wheel tread over the rail increases, while it decreases over the other rial. This prevents the further movement and axle retreats back to its original position (i.e., with equal diameters on both rails and equal pressure on both rails).

On a curved path, (the behaviour of wheels on rails is explained under the article on resistance due to curves), it is seen that due to rigidity of the wheel base either of the wheel must slip by an amount equal to the difference of length of the axle must slightly move outwards to provide a tread of longer diameter over the outer rail and smaller diameter over the inner rail as shown in Fig. 3.8.

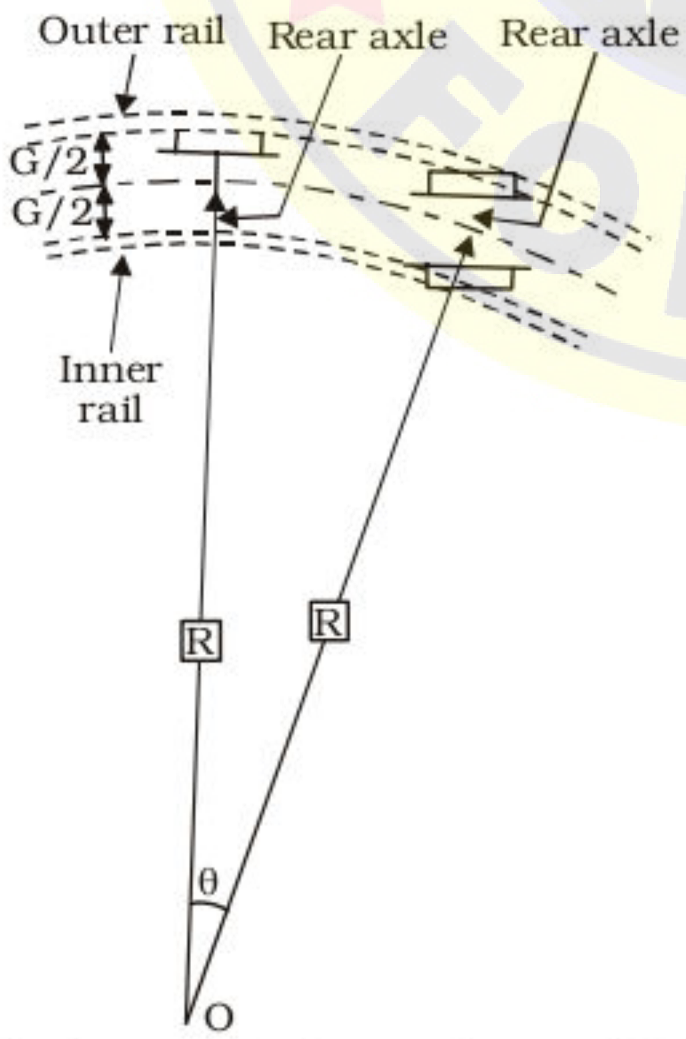


Fig. Behaviour of Coning on Curves (Plan)

If the tread diameter on both the rails is same, the amount of slip will be given by

Slip = $\theta\,(R_2 - R_1)$

Where, Outer Radius, $R_2 = R + \frac{C}{2}$

Inner Radius, $R_1 = R - \frac{G}{2}$

G = Gauge

θ = Angle at centre in radians

$\therefore$ Slip = $\theta \times G$

For B.G. track, G = 1.676 metres

and Slip = $\frac{2}{360} \times 1.676$

where $\theta°$ - angle at centre in degrees, say 1°

$\therefore$ Slip = 0.029 (approx. for 1° of central angle)

Therefore, the slip is about 0.029 m per degree of central angle.

Coning of wheels on curves is not of much use as the leading axle if due to centrifugal force moves towards the outer rail the rear axle (or trailing axle) will move towards the inner rail and the full advantage of coning wheels cannot be availed. In other words, there is no free lateral movement of wheels and this leads to following disadvantages :

(i) Pressure on outer rail is more while on inner rail it is less. This results in wear of outer rail.

(ii) Due to the centrifugal force, the horizontal components tend to turn the rail out and gauge has widening tendency.

(iii) If no base plate is used under the voids sleepers under the edge of the rail are damaged.

In order to eliminate or minimise the above demerits "tilting of rails" is done. In tilting of rails, the base plate or sleeper is not laid horizontal but at a slope of 1 in 20 inwards. This is known as "adzing of sleepers" as shown in Fig. 3.9.

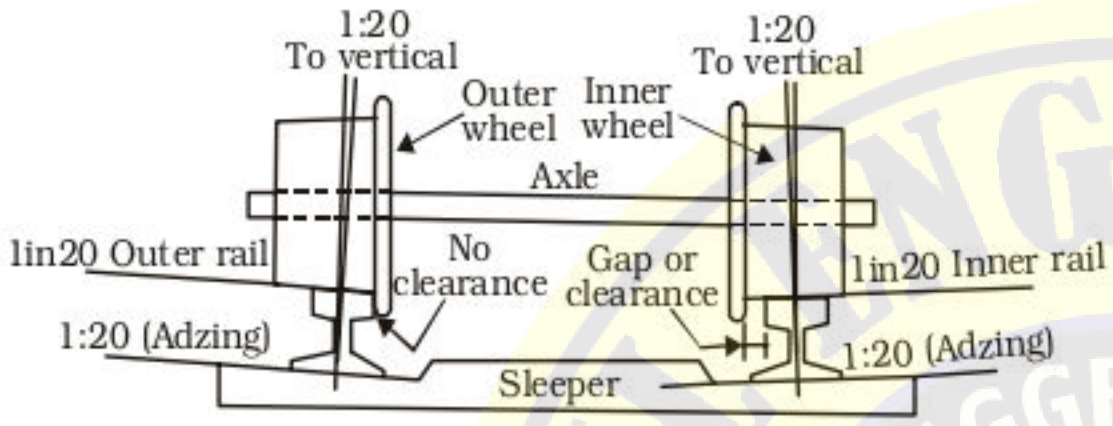


Fig. Behaviour of Coning on Curves (Elevation)

To minimise the wear and tear of the rails and wheels on curves, the american practise is to reduce wheel coming to 1 in 40 and in some cases even 1 to 100.

TRACK STRUCTURE FOR B.G. AND M.G. ROUTES ON INDIAN RAILWAYS :

The following track structure has been recommended for B.G. and M.G. Routes.

(i) B.G. Routes : B.G. routes have been grouped into 5 broad categories based on speed critérical, viz. Groups A, B, C, D and E routes.

(ii) M.G. Routes : M.G. routes have also been groupes into 5 broad categories based on speed and G.M.T. Criteria viz Q, R_1, R_2, R_3 and S.

The structure provided by Rails, sleepers and Ballast over the formation for the movement of trains is called a railway track. For achieving high speeds with comfortable riding qualities the basic requirements of an ideal permanent way should be satisfied.

Geometric Design of the Track

NECESSITY OF GEOMETRIC DESIGN OF A RAILWAY TRACK

Most of the train derailments are due to the following reasons :

(i) Track defects

(ii) Vehicular defects

(iii) Operational defects.

The Civil Engineer is mainly concerned with track defects. He should be aware of the track defects and how to remove these defects so that no derailment takes place. Railway track should be designed, suiting to load and speed of the train, and meeting the safety and economy requirements.

A train may derail on the straight track due to the following defects in the track :

(i) Defective cross-levels,

(ii) Defective alignment,

(iii) Defective Gauge, and

(iv) Low Joints.

In addition to this, on curved tracks, the derailment may occur due to additional following causes :

(i) Improper superelevation,

(ii) Improper radius of the curve,

(iii) Improper speed, and

(iv) Unequal distribution of loads on two rails.

The derailments over the turn-outs and crossings may occur due to the following reasons :

(i) Gaping points,

(ii) Lifting of toe of switch due to inadequate fittings.

(iii) Improper assembly of crossing, loose crossing bolts or wing rails than the crossing nose.

(iv) Excessive wear in switches.

(v) Tight gauge and defective check clearances at the nose of crossing.

Therefore, if all the above elements are properly designed, the possibility of derailments due to defects in the track can be avoided.

Cross levels, alignments, gauges and joints have already been discussed in previous chapters, and elements of turnouts will be discussed in the chapter that follows. In this chapter, the study will be confined to the following elements of Railway track :

(1) Gradients and Grade compensation.

(2) Speed of train

(3) Radius or Degree of the curve

(4) Cant or Superelevation.

(5) Curves.

(6) Widening of Gauge on Curves.

GRADIENTS AND GRADE COMPENSATION

(A) GRADIENT

Any departure of the track from the level is known as grade or gradient, An up or rising gradient is one when the track rises in the direction of movement, and a down or falling gradient is one when the track falls in the direction of movement.

Gradient is measured either (i) by the extent of rise/fall in 100 units horizontal distance or (ii) the horizontal distance travelled for a rise/fall in 1 unit. An alignment which rises 2 m in a horizontal distance of 50 m would be shown either as 4 in 100 i.e., 4% or 1 in 25.

Gradients are provided on the tracks due to the following reasons :

(i) To provide a uniform rate of rise or fall as far as possible.

(ii) To reach the various stations located at different elevations, and

(iii) To reduce the cost of earth work.

Various gradients used on railway tracks can be classified under the following heads :

(1) Ruling gradient.

(2) Momentum gradient.

(3) Pusher or Helper gradient.

(4) Gradients at station yards.

(1) Ruling gradient : The ruling gradient on a section may be defined as the gradient which determines the maximum load that the engine can haul on the section. In other words, it is the maximum gradient allowed on the track section.

It is remarkable that steep gradients necessitate more powerful locomotives, smaller train loads, lower speed and costly haulage. It is, therefore, desirable to climb a slope at as a gentle rate as possible. As a rule, rising gradients must be followed by falling gradients. With this, the amount of energy which was used up in climbing, is saved in descending. A train is able to climb a rising gradient more easily if this rising gradient follows a falling gradient as the train has an opportunity of attaining high speed over the falling gradient before reaching the rising gradient.

In determining the ruling gradient of the section, it will not only be the severity of the gradient that will come into play but also the length of the gradients and its position, such as other grades on the track.

Considering these factors, the ruling gradient depends upon the additional power of the locomotive which shall be able to pull up its train load along the gradient. The extra pull required = $W \times \sin\theta \quad W \times \tan\theta = W \times$ gradient.

For example, if a train weighing 500 tonnes travels over a rising slope of 1 m in 100 m, the additional force required is $\frac{1}{100} \times 500 = 5$ tonnes. If the same height 1 m is to be attained in 200 metres, the additional force required would be only $\frac{1}{200} \times 500 = 2.5$ tonnes (i.e., additional force also gets halved).

Indian standards do not specify any fixed ruling gradient due to the varying nature of the country, speed and traffic. Generally, with one locomotive train, the following gradients are adopted.

In Plain terrain	1 in 150 to 1 in 200
In hilly regions	1 in 100 to 1 in 150

As a rule, once the ruling gradient is specified for a section there should be no grade steeper than this ruling gradient. Therefore, all the gradients provided after compensation for the curvature, should be either equal or flatter but in no case greater than the ruling gradient specified.

(2) Momentum gradient. "Those gradients on a section which though more severe than the ruling gradient, do not determine the maximum load of the train but on account of their favourable position on track, the train before approaching them (i.e. such gradients) acquires sufficient momentum to negotiate them, are known as momentum gradients"

For example, in valleys, a falling gradient is usually followed by a rising gradient. A train while coming down a falling gradient acquires sufficient momentum. This momentum gives additional kinetic energy to the moving train which would enable the train to overcome a steeper rising gradient than the ruling gradient for a certain length of the track. **This rising gradient is called as momentum gradient and in such cases a steeper grade than the ruling grade can be adopted.**

A necessary qualification for a momentum grade is that the train should not be stopped in the territory where it acquires the sufficient momentum to negotiate it. Due to this qualification, the obstacles like signals should not be provided at momentum gradients. By an introduction of a halt at a critical point on a momentum grade, the grade may be converted into a ruling grade.

(3) **Pusher or Helper gradient** The important effect of a ruling grade is its limit on locomotive capacity. If the ruling grade is severe, it may mean that during larger portion of its journey, the locomotive would have its unused capacity for carrying higher loads. But if the grade is concentrated in a specific section such as mountainous section, instead of limiting the train load, it may be operationally easy or even be economical to run the train on the basis of load that the engine can carry on the remaining portion of track and arrange for an assisting engine (or pusher engine or a banking engine) for the portion where the gradient is severe. Such gradients are known as "Pusher" or "Helper" gradients.

Pusher gradients are very important in mountainous terrain where steeper gradients are necessary to reduce the length of the track. In such cases, one locomotive being incapable, extra engine or engines are provided. Before deciding the pusher gradients the capacity of the engine and maximum load should be compared and optimum conditions should be attained so that no carrying capacity is wasted.

There are many examples of pusher gradients in India. On Western Ghats with B.G. track, pusher gradients of 1 in 37, on Darjeeling Railway with N.G. track, a ruling gradient of 1 in 25 is provided. A Helper Gradient of 1 in 75, 1 in 100 with additional one engine, is generally used.

(4) **Gradients in station yards** The gradients at station yards have to be sufficiently low due to the following reasons :

(i) To prevent the movement of standing vehicles on the track due to the effect of gravity combined with a strong wind and/or a gentle push.

(ii) To prevent additional resistance due to grade on the starting vehicles. which is about twice at the start than vehicle in motion. However, a certain minimum gradient is required to be provided for drainage. On Indian Railways, for all the gauges, the maximum gradient permitted in station yards is 1 in 400 while a minimum gradient of 1 in 1000 is recommended from drainage point of view.

(B) Grade compensation on curves The ruling gradient is the maximum gradient on a particular section, but if a curve lies on a ruling gradient, the resistance due to gradient is increased by that due to curvature and this further increases the resistance beyond the ruling gradient. In order to avoid resistances beyond the allowable limits, the gradients are reduced on curves and this reduction in gradients is known as grade compensation for curves. The curve resistance is expressed as a percentage per degree of the curve. The curve resistance is greater at lower speeds.

In India, compensation for curvature is given at 0.04% per degree of curve for B.G., 0.03% for M.G. and 0.02% for N.G. In terms of radius of curves in metres 4 is 70/R for B.G.. 52.5/R for M.G. and 35/R for N.G.

Example 1. If the ruling gradient is 1 in 150 on a particular section of Broad Gauge and at the same time a curve of 4 degree is situated on this ruling gradient, what should be the allowable ruling gradient ?

Solution. As per recommendation of I.S., grade compensation of B.G. is 0.04 percent per degree of curve.

Then compensation for $4°$ curve $= 0.04 \times 4$

$= 0.16$ percent.

Now, ruling gradient 1 in 150 $= \frac{1}{150} \times 100$

$= 0.67$ percent

So maximum allowable gradient or actual gradient to be provided $= 0.67 - 0.16 = 0.51$ percent.

or, $\frac{0.51}{100}$ i.e., 1 in 196.

Example 2. What should be the actual ruling gradient ?

(a) If the ruling gradient is 1 in 200 on a B.G. and (b) A curve of 3° is superimposed on the above track section of B.G.

Solution. Assume grade compensation on B.G. equal to 0.04% per degree of curve.

Compensation for $3°$ curve $= 3 \times 0.04 = 0.12\%$

Whereas, ruling gradient is 1 in 200 i.e.. 0.50%.

So actual ruling gradient to be used

$= 0.5 - 0.12 = 0.38\%$

or $\frac{0.38}{100} = \frac{1}{\frac{100}{0.38}}$ = 1 in 264

15.3 SPEED OF THE TRAIN

The speed of the train depends upon the strength of the track and the power of the locomotive. The use of diesel traction and electric traction, which can run the trains at higher speeds, also requires the strengthening of the existing tracks. Though the increased speed increases the capacity of the track and provides prompt service to the customers of the railways but the high speed ($\geq$ 120 km.ph.) trains have to face the following dynamic effects in their operation :

(i) Various parasitic motions such as pitching, rolling, bouncing and lateral oscillations of the vehicles.

(ii) Resonance between the frequency of application of load and elastic oscillation of the track structure as a whole or its components.

(iii) Inertia or springing action of the track in, from and behind the wheels.

(iv) Effect of unbalanced weights.

(v) Effect of unspring masses and

(vi) Suspension characteristics of the locomotive and carriages.

For high speed traffic, the track and rolling stock have to be designed and maintained properly so as to limit these oscillations which cause wide variations in the vertical and lateral forces.

In foreign countries, like U.K., U.S.A., Japan and Germany, the trains usually run at 145 km. p.h. with electric and diesel tractions. The trains, in future, may run with speeds, more than 330 km. p.h. In India, maximum speeds achieved by steam locomotives are as follows :

(i) For Broad Gauge = 96 km. p.h. (60 m.p.h.)

(ii) For Metre Gauge = 72 km. p.h. (45 m.p.h.)

(iii) For Narrow gauge = 40 km. p.h. (25 m.p.h.)

With modernization of Indian Railways and use of electric- traction it has now become possible to attain trains speeds upto 160 km. p.h. on B.G. routes and upto 100 km.p.h. on M.G. routes.

Safe speed on curves. Safe speed for all practical purposes means a speed which is safe from the danger of overturning and derailment with a certain margin of safety. This speed, to negotiate curves safely, depends upon the following factors :

(i) The gauge of track.

(ii) The radius of the curve.

(iii) The distance at which the resultant of the weight of vehicle and its centrifugal force acts from the centre of the track.

(iv) Amount of superelevation provided.

(v) The presence or absence of transition curves at the ends of the circular curve.

In India, the following formulae given by martin were generally employed to work out empirically the safe speed on curves : (Old Practice)

(a) Where transition curves exist i.e., on transitioned curves

(i) For B.G. and M.G. : The safe speed V in km. p.h. is given by :

$V = 4.35\sqrt{R-67}$ or $V = 4.4\sqrt{R-70}$ ..... (A)

(ii) For N.G. $V = 3.6\sqrt{r-6.1}$ or V

$= 3.65\sqrt{R-6}$ ..... (B)

Subject to a maximum of 50 km. p.h.

(b) Where transition curves are absent i.e., on non-transitioned curves.

(i) For B.G. and M.G.

$V = \frac{4}{5}$th of speed calculated in (A) above.

i.e., on non-transitioned curves, the above speed is reduced by 20%.

(ii) For N.G.

$= \left(\frac{4}{5}\text{th of speed calculated in (B) above}\right)$

i.e., $V = 2.92\sqrt{R-6}$ ...... (C)

Subject to a maximum of 40 km. p.h.

(c) For high speeds — Generally the following empirical formula is used

$V = 4.58\sqrt{R}$ where V = Speed in km. p.h. .... (D)

R = Radius of the curve in metres.

Note : The empirical formulae given by Martin for calculations of safe speed on curves are no longer followed on Indian Railways.

The maximum speed for transitioned curves is now determined on Indian Railways as per revised formulae given below.

(a) On B.G. track.

$V = \frac{(Ca + Cd) \quad R}{13.76}$ OR V

$= 0.27\ (Ca + Cd) \times R$ .... (E)

where V = maximum speed in km.p.h.

Ca = Actual cant (i.e. superelevation) in mm

Cd = Cant deficiency permitted in mm

R = Radius in metres

(b) On M.G. track

$V = 0.347\ (Ca + Cd)\ R$ ..... (F)

(C) On N.G. track.

$V = 3.65\sqrt{R-6}$ subject to a maximum of 50 km.p.h. .... (G)

Note : These equations for maximum speed for B.G. and M.G. tracks are derived from formula of equilibrium superelevation i.e. $e = \frac{G\,V^2}{127R}$ on assumption that G for B.G. is 1750 mm (which is centre to centre distance between rail heads) while for M.G. G is 1058 mm.

The maximum speed on curves without transition is now based on concept of virtual transitions (This virtual transition distance is 14.6 m on B.G., 13.7 m on M.G. and 10.3 on N.G.) so the safe speed is worked out on the basis of cant and permissible amount of cant deficiency as applicable. The cant gradient over transition distance specified should not exceed J in 360 (2.8 mm/metre) on B.G and 1 in 720 (1.4 mm/metre) on M-G. and N.G.

The maximum cant deficiency. Values for different Gauges for Indian Railways are :

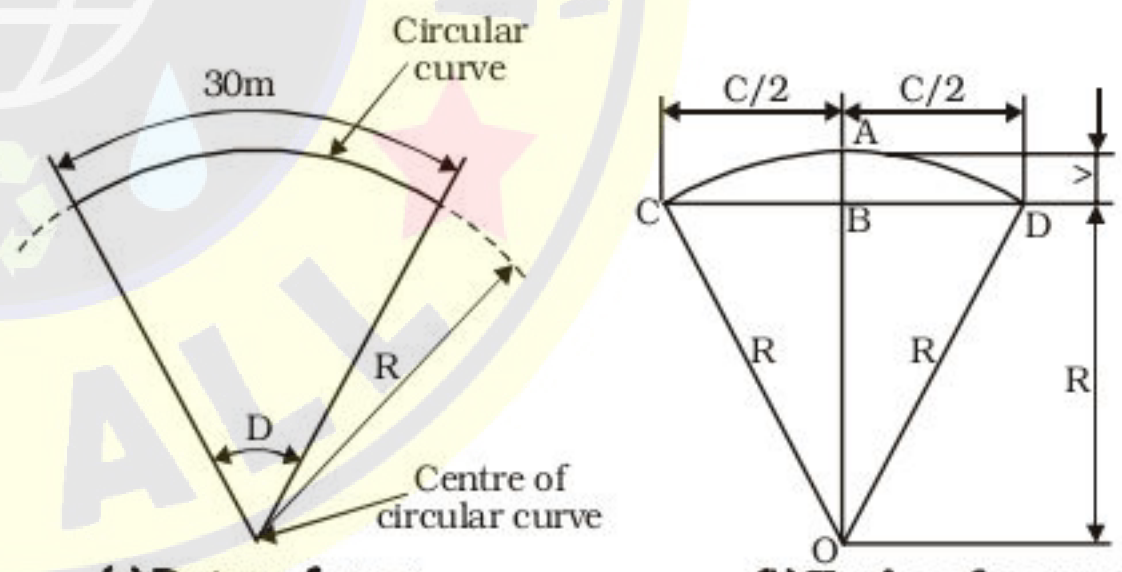
(i) B.G. track — 75 mm

(ii) M.G. track — 50 mm

(iii) N.G. track — 40 mm

RADIUS OR DEGREE OF THE CURVE

Curves on the railways are generally circular i.e., each curve should have the same radius on every portion of it. As mentioned in the previous article, the speed of train on transitioned curve is given by $V = 4.4\sqrt{R-70}$ or $V = 4.35\sqrt{R-67}$ for B.G. and M.G.



(a) Degree of curve. **(b) Versine of a curve**

and $V = 3.6\sqrt{R-6.1}$ OR V (km. p.h.) $= 3.65\sqrt{R-6}$ for N.G.

By these relations the value of R (i.e., radius of the curve) in metres can be calculated for the given speed.

The radius of a curve is, sometimes, represented by the degree of curve of curvature. The degree of the curvature is defined as the degree of curvature is "D" then this value in terms of radius of the curve will be as below :

In metric units,

$$\frac{D}{30} = \frac{360}{2\ R} \text{ (where length of chord = 30 m)}$$

$\therefore D = \frac{1720}{R}$

where 'R' is radius of curve in metres. So for 1° curve

R = 1720 m and for 2° curve R = 860 m

N. B. (1) The degree of a curve is also defined as the angle subtended at the centre by a chord of 100 feet 'or' 30.48 metres length.

Hence, (i) $D = \frac{5730}{R}$ (F.P.S. units)

or, (ii) $D = \frac{1746.50}{R}$ (Equivalent in metric units)

$\frac{1750}{R}$

or, (iii) $D = \frac{1720}{R}$ (Metric units as derived above)

In (i) 'R' is the radius of curve in feet, whereas in (ii) and (iii) R is in metres.

(2) When radius is very large, the are of circle is almost equal to the chord connecting the two ends of the arc.

(3) In this book, formula, $D = \frac{1720}{R}$ has been used throughout assuming chord length of 30 m, being in metric units.

Actually speaking a straight railway (track is an ideal condition but the curves are to be provided on railway track for several reasons such as to connect important points, avoiding obstructions, to have longer and easier gradients. etc. Following are the main effects or objections of providing curves on a railway track :

(i) The working of trains is seriously affected such as restriction in speed, prevention of use of heavy locomotives and limitation on the length of the train.

(ii) There are possibilities of derailment or accident or collision on curvature.

(iii) The running of trains on curvature is not smooth due to unequal distribution of loads or extra load on inner or outer rail depending upon superelevation used and speed of the train.

(iv) To provide extra strength to curved track, many more fittings are used and even then there is every likelihood of the lateral bending of rails due to rigid wheel base. So the operating and maintenance cost increases due to heavy wear and tear of rails, and equipment. To take into account the various effects on a curvature, the smallest radius and the largest degree are restricted on the basis of two factors given below.

(i) **Wheel base of a vehicle.** If a degree of the curve is large for the length of the wheel base, which forms a chord on the curve, the vehicle does not run freely round the curve and is liable to derailment. The wheel base is comparatively small in case of vehicles with bogies.

(ii) **Sharpness of the curve.** In case of sharp curves, the greater effort is required by engines in hauling vehicles than on straights.

In case of through tracks, the limiting factor is the superelevation on curves. The superelevation increases with the degree of curvature. This superelevation is limited to keep stability of vehicles on a curved track. The superelevation also varies as the square of the speed. So the radius of the curve should be much larger on through track, where high speeds prevail, than on sidings where speeds are generally low.

In India, curves on through tracks, are limited to the following maximum radii :

(i) Maximum degree of curvature for B.G. =10° (min. R = 175 m)

(ii) Maximum degree of curvature for M.G. = 16° (min. R = 109 m)

(iii) Maximum degree of curvature for N.G. = 40° (min. R = 44 m)

Relationship between Radius and Versine of a curve. [Fig. 15.1 (b)]

Let R be the radius of circular curve.

C be the length of the chord

and V be the versine on the above chord length i.e., C,

Then from the property of a circle,

AB × (2 AO – AB) = CB × BD

or $V \times (2R - V) = \frac{C}{2} \cdot \frac{C}{2}$

or $2RV - V^2 = \frac{C^2}{4}$

as V < < R (i.e., V is very small as compared to R), hence V^2 can be neglected

$$2RV = \frac{C^2}{4}$$

$$\text{or } V = \frac{C^2}{8R}$$

But, if R = Radius in metres.
C = Chord in metres.
V = Versine in cms.

Then the above relation in metric units becomes,

$$\frac{V}{100} = \frac{C^2}{8R}$$

$$\text{or } V = \frac{100}{8} \cdot \frac{C^2}{R} = \frac{12.5\, C^2}{R} \text{ cms}$$

$$\text{or } V = \frac{12.5\, C^2}{R} \text{ mm}$$

SUPERELEVATION OR CANT

When a train moves round a curve, it is subjected to a centrifugal force acting horizontally at the centre of gravity of each vehicle radially away from the centre of the curve. This increases the wight on the outer rail. To counteract the effect of centrifugal force, the level of the outer rail is raised above the inner rail by a certain amount to introduce the centripetal force. This raised elevation of outer rail above the inner rail at a horizontal curve is 'called superelevation'. The term 'cant' is frequently used as a synonym for superelevation but truly speaking cant should be used to represent the angle of a transverse slope. Mathematically speaking, the object of providing the superelevation, is to make the force of reaction equal at both the rails and perpendicular to the track and thus equalize the weight on either rail. Superelevation is denoted by "e".

Objects of providing superelevation

The following are the objects of providing superelevation on curves :

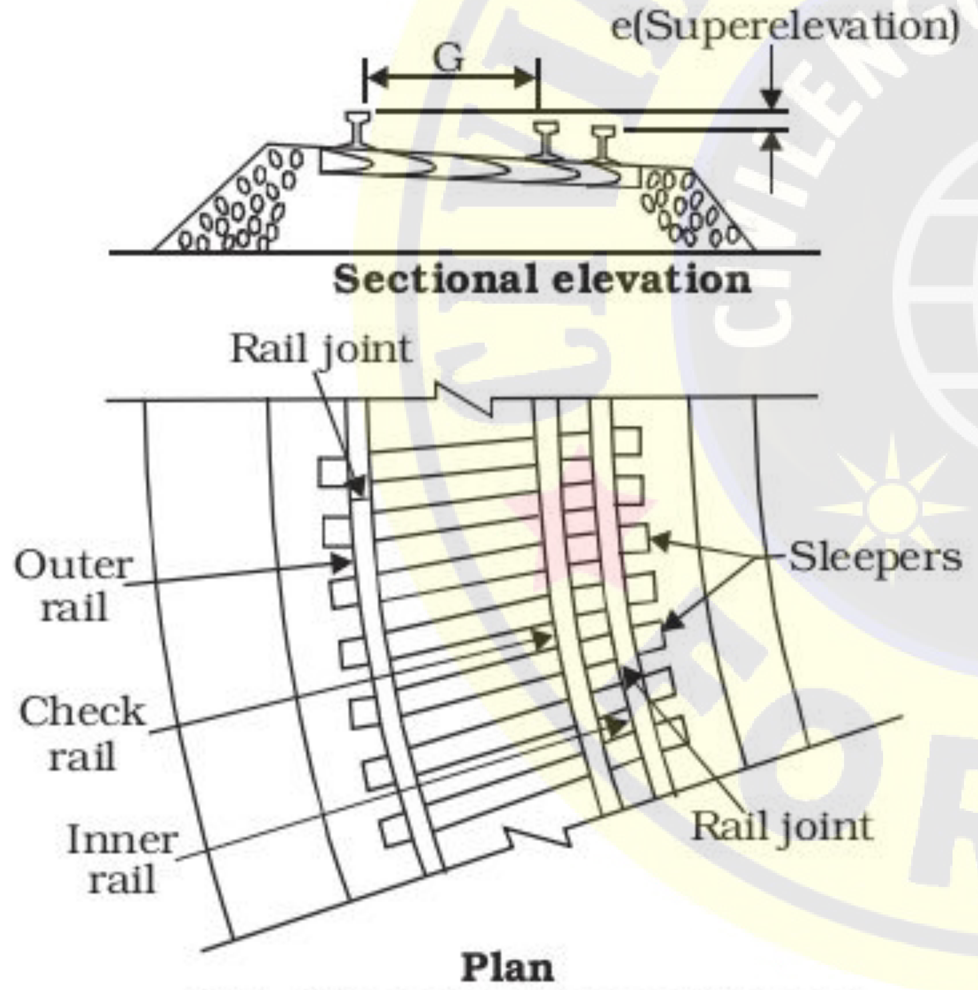


Fig. Superelevation on Curves.

(i) To introduce the centripetal force for counteracting the effect of centrifugal force, this will result in the faster movement of trains on curves. This will also prevent derailment and reduce the side wear and creep of rails.

(ii) To provide equal distribution of wheel loads on two rails so that there is no tendency of track to move out of position due to more load on outer rail. This reduces the wear of rails, equipment and results in saving in maintenance cost.

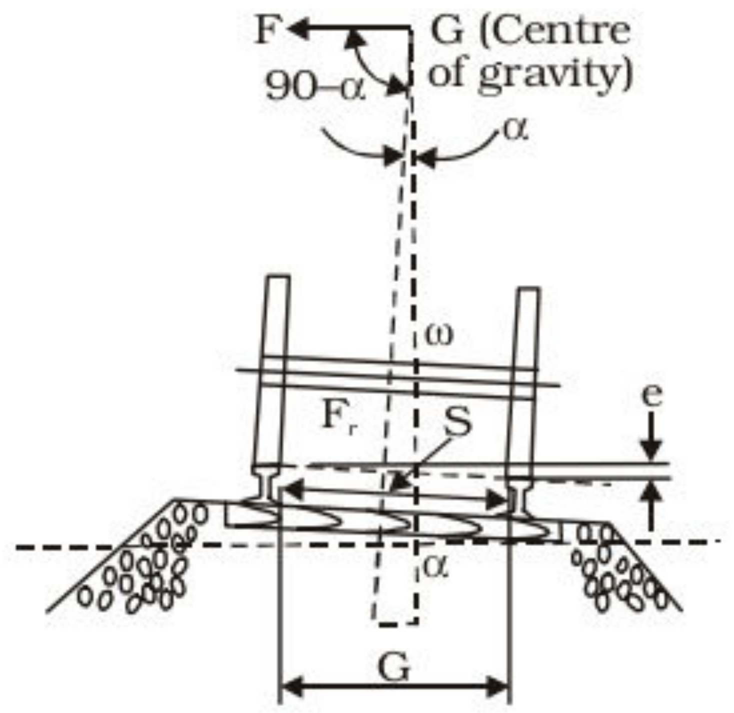


Fig. Relationship between Superelevation, Gauge and Curve

(iii) To provide an even and smooth running track to ensure comfortable ride to passengers and safe movement of goods.

Relationship of superelevation (e), with gauge (G), speed (V) and radius of the curve (R). Using the following notations and Fig. 15.3.

W = Weight of moving vehicle in kg.

v = Speed of vehicle in m/sec

V = Speed of vehicle in km. p.h.

R = Radius of curve in metres.

G = Gauge of track in metres.

g = Acceleration due to gravity in m/sec^2.

α = Angle of inclination.

S = Length of inclined surface in metres.

Centrifugal force is given by the following expression.

$$F = \frac{Wv^2}{gR} \quad \text{....... (1)}$$

Now resolving the forces along the inclined surface we get

$$F \cos \alpha = W \sin \alpha \quad \text{........(2)}$$

where $F = \frac{Wv^2}{gR}$, $\cos \alpha = \frac{G}{S}$

and $\sin \alpha = \frac{e}{S}$

Therefore equation (2) becomes $\frac{Wv^2}{gR} \times \frac{G}{S}$

$= W \times \frac{e}{S}$

Therefore, $e = \frac{v^2}{gR} \times G$ metres ......(3)

where, v is in m/sec.

$$= \frac{G(0.278\ V)^2}{9.81\ R} \text{ m. where, V is in km. p.h.}$$

$$= \frac{GV^2}{127\ R} \text{ m.} \qquad \ldots\ldots\ (4)$$

$$= \frac{GV^2}{1.27\ R} \text{ cm.} \qquad \ldots\ldots(5)$$

where G is in metres

V is in km. p.h.

R is in metres.

In India, G for B.G. = 1.676 m

M.G. = 1.0 m

and N.G. = 0.762 m.

$$\text{So for B.G., } e = \frac{1.676\ V^2}{1.27\ R} = 1.315\ \frac{V^2}{R} \text{ cm} \quad \ldots.(5a)$$

$$\text{for M.G., } e = \frac{1.0\ V^2}{1.27\ R} = 0.80\ \frac{V^2}{R} \text{ cm.} \quad \ldots\ldots\ (5b)$$

$$\text{for N.G., } e = \frac{0.762\ \ V^2}{1.27\ R} = 0.60\ \frac{V^2}{R} \text{ cm.} \quad \ldots..\ (5c)$$

The cant or superelevation obtained from equation (4) or (5) is known as **Equilibrium cant. When the lateral forces and wheel loads are almost equal, the cant is said to be in equilibrium. This equilibrium cant is provided on the basis of average speed of the trains.**

It should be noted that the trains pass over the curve with different speeds, the superelevation provided for a speed of 90 km. p.h. would not suit any other speed. The question arises as to what speed, the superelevation should be provided for. In both the cases, whether the speeds are higher or lower than the speed on which superelevation has been calculated, a certain type of inequilibrium will develop. Because superelevation increases with the square of the speed, so at higher speeds, the centrifugal force will not be counter balanced and will result in overturning of vehicles, while at lower speeds, the tilt of the vehicles towards the inside for not having been completely counterbalanced by the centrifugal force, may result in derailment. This is due to the fact that the centre of gravity may fall outside the base of support.

A compromise, therefore, has to be achieved by providing superelevation in a way that faster trains may travel safely without danger of overturning or discomfort to the passengers and slower trains may run safely without fear of derailment due to excessive superelevation.

On some railways, the superelevation is provided for maximum speeds if most of the trains using the existing track are fast trains. However, the majority of Indian Railways provide superelevation for Equilibrium speed or Average speed under average conditions on level track, as follows.

(a) Where the maximum sanctioned speed of the section on B.G. and M.G. is over 50 km p.h. (i.e. V_{max} > 50 km. p.h.)

(i) Average speed = $\frac{3}{4} \times V_{max}$

subject to a minimum of 50 km p.h.

or (ii) Safe speed on curves given by formula.

Then average speed is (i) or (ii) whichever is less

(b) Where the maximum sanctioned speed of the section on B.G. and M.G. is 50 km p.h. or less :

(i.e., $V_{max} \leq$ 50 km. p.h.)

(i) Average speed = V_{max}

or (ii) Safe speed of the curve (given by Martin's formula or superelevation equilibrium equation)

(i) or (ii) whichever is less.

(c) On some railways "weighted average" is calculated for finding out the equilibrium speed of the trains,

Equilibrium speed

$$= \frac{n_1V_1 \quad n_2V_2 \quad n_3V_3 \ \ldots..}{(n_1 \quad n_2 \quad n_3 \ \ldots.)} \qquad \ldots\ldots.(6)$$

$$= \frac{n\,V}{N} \text{ known as 'Weighted Average'}$$

Where n_1, n_2, n_3 etc. denote the number of trains running on track at speeds of V_1, V_2, V_3 etc. respectively.

and N = Total number of trains on track.

Limits of Superelevation and Cant-Deficiency. As discussed in the previous article, superelevation should be provided in such a way as to accommodate various trains running with different speeds from time to time. There are limits to the amount of superelevation which may be provided safely.

Normally, the maximum value of superelevation, according to the Railway Board is $\frac{1}{10}$th of gauge.

Therefore, the maximum permissible values in India for different gauges are :

(i) Maximum S.E. for B.G. = $\frac{1}{10} \times 1.65$ m

= 0.165 m = 16.5 cm.

(ii) Maximum S.E. for M.G. = $\frac{1}{10} \times 1\text{m} = 0.1$ m

= 10 cm.

(iii) Maximum S.E. for N.G. = $\frac{1}{10} \times 0.76$ m

= 0.076 m = 7.6 cm.

In Britain maximum. S.E. = 19 cm (i.e., 7.5")
In America maximum. S.E. = 15.2 cm (i.e., 6")

for 4' – $8\frac{1}{2}$ gauge.

But, recently, the following values of maximum superelevation have been prescribed on Indian Railways varying from $\frac{1}{10}$th to $\frac{1}{12}$th of gauge.

Table Limits of Superelevation

Gauge	Maximum S.E. when V ≤100 km. p.h.		Maximum S.E. for high speeds i.e., V ≥120 km. p.h.		
	Under ordinary conditions	Under special permission of Chief Engineer	120 km. ph.	160 km. ph.	200 km. ph.
B.G.	14.0 cms	16.5 cms	16.5 cms	18.5 cms	18.5 cms
M.G.	9.0 cms	10.0 cms	Not specified	Not specified	Not specified
N.G.	6.5 cms	7.6 cms	—Do—	—Do—	—Do—

The superelevation should be provided smoothly and uniformly by use of transition curves in between the straight track and circular curve. Superelevation varies from zero at the beginning of a transition curve to the full amount at the junction of transition and circular curve and the correct amount is obtained at every point of the transition curve by appling cant gradient over transition length.

It is worth recording that a single deficiency or excess of superelevation does not produce as high rough running and wear and tear of rails and equipment as lack of uniformity of superelevation. So the constant superelevation should be maintained at circular curve and varied at uniform rate over the transition curve. (max. cant gradient = 1 in 360 on B.G. and 1 in 72 on M.G. and N.G.)

Cant Deficiency. The equilibrium cant is provided on the basis of equilibrium speed (or Average speed, or weighted Average speed) of different trains. But this equilibrium cant or superelevation falls short of that required for the high speed trains. This shortage of cant is called 'Cant Deficiency".

In other words, cant deficiency is the difference between the equilibrium cant necessary for the maximum permissible speed on a curve and the actual cant provided (on the basis of average speed of trains).

This cant deficiency is limited due to two reasons :

(i) Higher cant deficiency gives rise to higher discomfort to passengers.

(ii) Higher cant deficiency means higher would be the balanced centrifugal forces and hence extra pressure and lateral forces on outer rails. this will require strong track and fastenings for stability.

Therefore, maximum value of cant deficiency prescibed for Indian Railways is as follows :

Table Limits of Cant Deficiency

Gauge	Cant deficiency for speeds upto 100 km. p.h.	Cant deficiency of speeds higher than 100 km. p.h.
B.G.	7.6 cm (76 mm)	10.0 cm (100 mm)
M.G.	5.1 cm (51 mm)	not specified
N.G.	3.8 cm (38 mm)	—Do—

Maximum permissible speed on a curve. The maximum permissible speed on a curve is taken as minimum value of the speed calculated by the following methods :

(i) Maximum sanctioned speed of the section. This is the maximum speed authorized by Additional Commissioner of Railways. This is based on track conditions, type of traction, standards of signalling and interlocking, etc.

(ii) Safe speed over the curve. This is the speed calculated by Martin's formulae based on gauge type or equilibrium speed based actual cant and cant deficiency for different gauges (Ref. Equations A to F of Article 15.3).

(iii) Speed based on the consideration of S.E. This is calculated by formula of equilibrium superelevation, where, the value of superelevation is the sum of full amount of cant deficiency and the actual superelevation.

The above three methods are used for maximum speed determination when the length of transition curve can possibly be increased. But in case, length of transition curve cannot be changed, the following fourth method is also included.

(iv) Speed from the length of the transition curve. This is the lesser value of the speed given by following two formulae :

(a) For normal speeds upto 100 km. p.h.

$$V_{max} = \frac{134 \quad L}{e} \qquad \text{..... (i)}$$

$$Vmax = \frac{134 \quad L}{D} \qquad \text{..... (ii)}$$

Where L = length of transition curve based on rate of change of cant as 38 mm/sec for normal speeds and 55 mm/sec for high speeds.

e = superelevation in mm

D = cant deficiency in mm

(b) For high speeds above 100 km. p.h.

$$V_{max} = \frac{198 \quad L}{e} \qquad \text{...... (i)}$$

$$V_{max} = \frac{198 \quad L}{D} \qquad \text{..... (ii)}$$

Negative superelevation When the main line is on a curve and has a turnout of contrary flexture leading to a branch line (as shown in Fig. 15.4), the superelevation necessary for the average speeds of trains running over the main line cannot be provided.

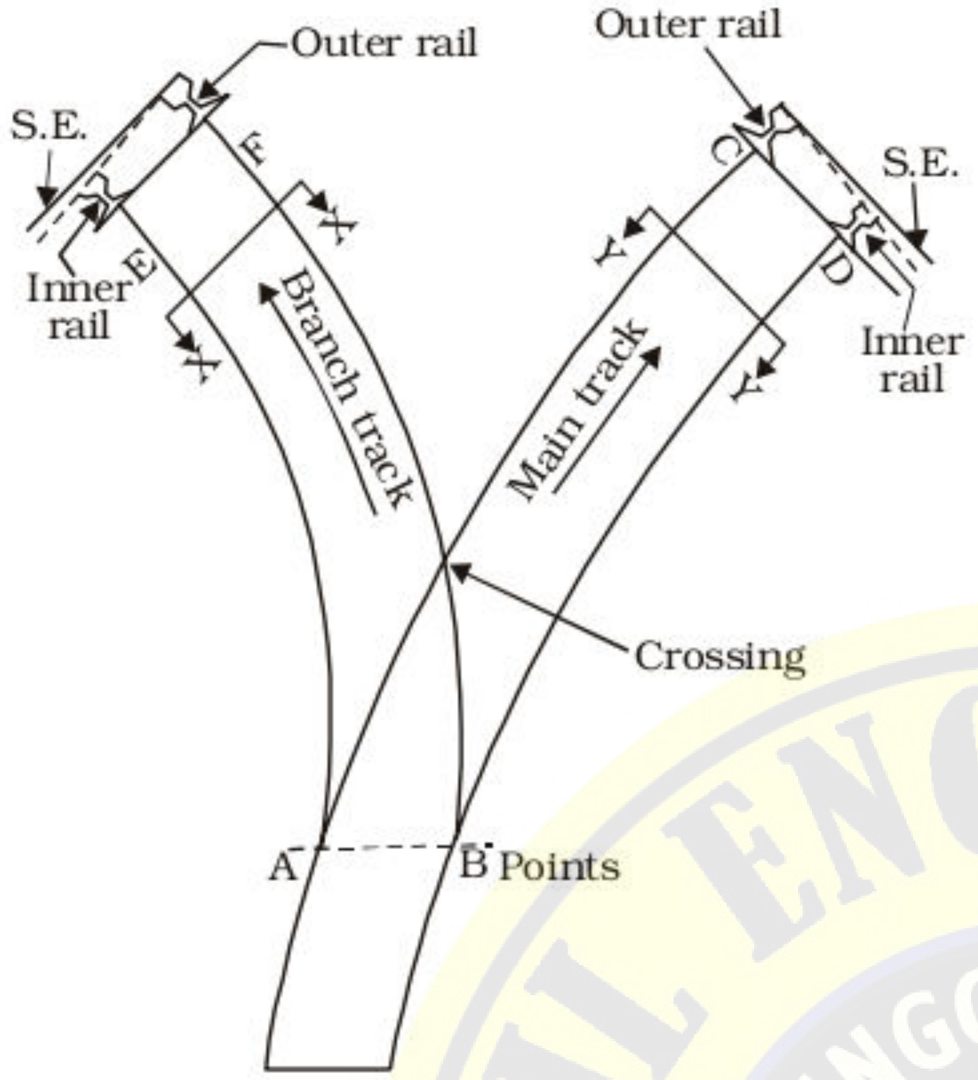


Fig. Negative Superelevation

Refer to the figure, which is the outer rail of the main line curve must be higher than inner rail BD or in other words, the point 'A' should be higher than point B

For the branch line however BF should be higher than AE or the point B should be higher than point A.

There two contradictory conditions can't be met at the same time within one layout. So instead of outer rail BF on branch line being higher, it is kept. lower than the inner rail AE. In such cases, the branch line curve has a negative superelevation and therefore speeds on both track must be restricted, particularly on branch line.

STATION AND YARDS :

A Railway station is the selected palce on a railway line where trains halt for one or more of the following purposes :

(i) For exchange of passengers.
(ii) For exchange of goods.
(iii) For control of train movements
(iv) To enable the trains on a single like track to cross form opposite directions.
(v) To enable the following exprees trains to overtake.
(vi) For taking disel or coal and water for locomotives.
(vii) For detaching engines and running staff.
(viii) For detaching or attaching of compartments and wasons.

CLASSIFICATION OF RAILWAY STATIONS

Stations can be classified according to operational and functional characteristics in the following categories :

(1) Operational classification : Indian Railway classify the stations in following classes :

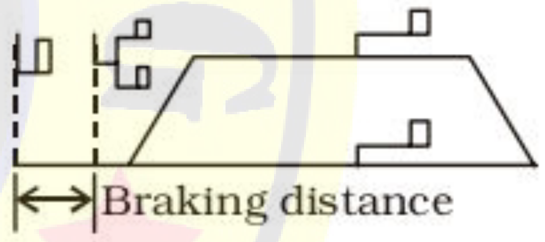
(i) **Block stations :** class 'A' class 'B' and class 'C' stations in descending order of importance
(ii) **Non-Block stations :** class 'D' stations and flag stations.
(iii) **Special class stations.**

Block Stations : 'Block sections' which are sort of compartments into which the railway line is divided are established so as to saftey space the trains behind each other. A block station is a place on the railway line at which "permission to approach"and "authority to proceed" are granted.

(a) **"A" class stations :** "A class" is a station where the line has to be cleared up to an adequate distance (400 m) beyond the home signal for giving permission to approach to a train. Its minimum sighal requirements are given in fig below :

(i) **Home Singal :** which is the first stop signal.

(ii) **Starter Signal :** Placed at an adequate distance from Home Signal. It marks the line upto which the line should be clear, for giving permission to approach.



(iii) **Warmer Signal :** Placed at a warning distance from the Home signal to indicate whether the section beyond is clear or not.

(b) **"B" class station :** 'A' "B class" station is one, where the line has to be cleared upto an adequate distance beyond the outer signal before giving permission to approach to train.

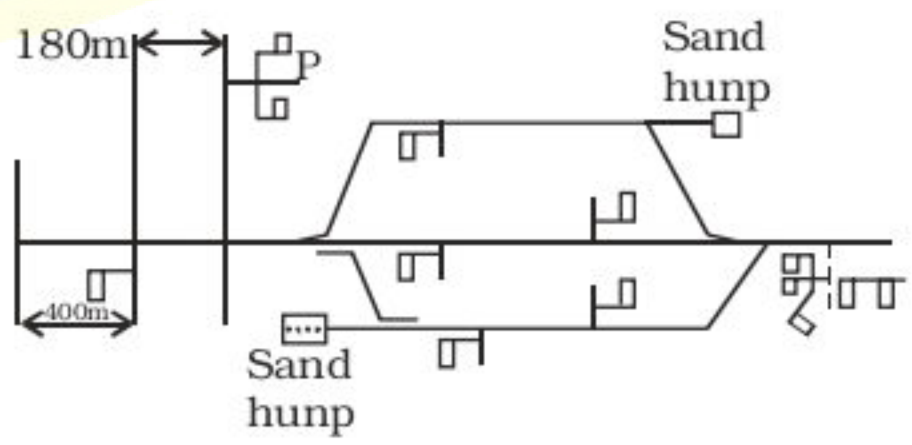


Fig: "B" Class Station (3 lines)

(i) **An Outer signal :** Which is first stop signal.

(ii) **A Home signal :** Placed at an adequate distance from the otuer signal. It is practise to place the otuer signal at a single line station at a distance of 580 meters from the home signal.

(c) 'C' class station : A "C class" station is only a "black hut" where no pessengers are boocked. It is used as mean to split a long back section so that the intervals between successive trains is reduced.

PLATFORMS : A raised level surface from wherer either pessengers boards and alight from train or loading and unloading of goods is done is known as a platform. Generally the following two types of platforms are provided at stations.

(1) Passenger platforms : As the name implies, this platfrom is meant for passenger who are using the railways. The platform should be covered for a minimum distance of 60m of their length. A minimum of 3.66 m of platform should be passed. The end of the raised platform should be in the form of a ramp with a maximum slope of 1 : 6. The length of platform is goverened by the length of longest train (excluding engine length) likely to use tee platform. However the minimum length prescribed or specified for passenger platform is 180 m for all the gauges. The deserable length of passenger platform in case of B.G. is 305 metres.

(2) Goods platform : As the name implies, there platmorms are used for looding and unloading of goods.

As per standards of Indian Railway Board, the passengers and goods platforms should be such that the minimum horizontal distance between centre of track and any structure of building line should be as below.

S.No	Type of platform	Minimum Horizontal distance between centre line of track and structure (D) in m.		
		B.G.	M.G.	N.G.
1.	Passenger platform	5.33 m	5.00 m	4.88 m
2.	Goods platform	4.72 m	3.18 m	3.05 m

STATION YARDS : A yard is defined as a system of tracks laid usually on a level within defined limits, for receiving, storing, sorting, making up new trains, despatch of vehicle and for other purpose over which movements are not authorised by a time table. The various movements on a system of tracks are governed by prescribed rules, regulations and signals.

TYPES OF YARDS :

The yards are classified into four categories.

(i) **Passenger Bogic Yards :** The main function of passenger bogic yards is to provide facilities for the safe movement of passengers and vehicle for the use of passengers

(ii) **Goods yards :** The main function of a good yard is to provide facilities for receiving, loading and unloading, delivery of goods and the movement of good vehicles. Practically, all the stations except flag stations are provided with goods yards.

(iii) **Marshalling yards :** Marshalling yard is said to be a "Machine to receive, break-up, re-form and despatch tains onwards". In other words a marshalling yard is one where trains and other loads are received sorted out and new trains formed, and despatched ownwards to their destinations.

MAINTENANCE OF TRACK :

The maintenance of railway track can be carried out either manually or by use of mechanical appliances or by a combination of both i.e., machines and labours.

In India conventional maintenance is carried out by means of manual labour and hand tools.

The maintenance of Track can be divided into two parts :

(a) Daily maintenance : Daily maintenance is carried out by the full time staff maintained throughout the year. The railway track is divided into 5 to 6 km length. One gang is attached to each section for maintaining that section in good condition.

(b) Periodic maintenance : Periodic maintenance is carried out after an interval of two or three years. During periodic maintenance the gauge, levels, alignments, points and crossing etc. are thoroughly checked, the defects are detected, the causes are determined and finally remedial remidial measures taken. The track is made in perfect condition by removing all its measure and minor defects. The subject of maintenance is very wide. The maintenance of track includes the following items of maintenance in good conditions.

(i) Surface of rails (ii) Track-Alignment (iii) Gauge (iv) Proper Drainage (v) Track component (vi) Bridge and its Approaches (vii) Rolling stock (viii) Points and crossings (ix) Level crossings (x) Tunnels

BRIDGE ENGINEERING :

Introduction : A bridge is a structure facilitating a communication route for carrying road traffic or other moving loads over a depression or obstruction such as river. Stream, channel, road or railway. The communication route may be a railway track a tramway, a road way, a foothpath, a cycle track or a combination of them

Bridge Site Investigation and Planning :

Detailed ground reconnaisance, collection of adequate hydraulic/ground data and subsoil investigation from an essential part of engineering survey for deciding the best possible and type of bridge. The side for a bridge is usually governed by engineering economic social and aesthetic considerations. In case of old alignments, the bridge site may be governed by existing roadway or railway alignments. On the other hand in case of new alignments, the bridge site so choosen as to give the maximum commercial benefits. In order to select a least objectionable bridge site one must know the following characteristics of an ideal site.

Idea Bridge Site characteristies :

(i) Suitable, unyielding and non-erodable material for foundation should be available at a short depth for the abutments and piers of a bridge. The bearing starts should be free from the tendency to slip or slide or sink under loads and away from fault zone. In other word it should be geologically suitable.

(ii) The stream at the bridge site should be well defined and as narrow as possible.

(iii) There should be a straight reach of stream at bridge site.

(iv) The site should have firm, permanent, straight and high banks.

(v) The flow of water in the stream at the bridge site should be in steady regime condition. It should be free from whirls and craes currents.

(vi) There should be no confluence of large tributaries in the vicnity of bridge site.

(vii) It should be feasible to have straight approach roads and square allignment i.e., right angled crossing.

(viii) There should be no need for costly river training works in the vicinity of bridge site.

(ix) There should be minimum obstruction of natural waterway so as to have minimum flux.

(x) In order to achieve economy there should be easily available of labour, construction material, transport facility in the vicinity of bridge site.

(xi) In order to have minimum foundation cost, the bridge site should be such that work is to be carried inside the water.

CLASSIFICATION OF BRIDGES

Bridges may be classified into various types which depend upon the following factors :

1. **The Relative Position of Bridge Floor :** In this category, the bridge can be classified as
   - (a) Deck bridge
   - (b) Semi through bridge, and
   - (c) Through bridge

Deck Bridges are the bridges whose floorings are supported at the top of the super structure.

Through Bridges are the bridges whose floorings are supported at the bottom of the super structure. Semi-through bridges are the bridges whose floorings are supported at some intermediate level of the super structure.

2. **Life :** In this, the bridges may be classified as
   - (a) Permanent bridges
   - (b) Temporary bridges

3. **Materials used for Construction :** Here in this category bridges may be classified as :
   - (a) Timber bridges
   - (b) Masonry bridges
   - (c) Steel bridges
   - (d) Reinforced cement concrete bridges
   - (e) Pre-stressed concrete bridges
   - (f) Composite bridges

4. **Span length :** In this category, the bridges can be classified as
   - (a) Culverts (Span less than 6m)
   - (b) Minor bridges (Span between 6 to 30m)
   - (c) Major bridges (Span above 30m)
   - (d) Long span bridges (Span above 120m)

5. **Position of High floor Level :** In this, the bridges may be classified as
   - (a) Submersible bridge and,
   - (b) Non-submersible bridge,

Submersible Bridges are the bridges whose floor levels are below the High flood level. During flood seasons, it allows the water to pass over the bridge submerging the communication route. In economic point of view, these bridges are constructed.

Non-submergible bridges are the bridges whose floor levels are above the High flood level.

6. **Alignment :** In this category, the bridge may classified as
   - (a) Straight or square bridges and
   - (b) Skew bridges

Straight or square bridges are the bridges which are at right angles to the axis of the river.

Skew bridges are not at right angles to the axis of the river.

7. **Loading :** Road bridges and culverts have been classified by Indian Road Congress into
   - (a) Class AA bridges
   - (b) Class A bridges
   - (c) Class B bridges according to the loadings they are designed to carry.

8. **Function of Purpose :** In this category the bridge can be classified as
   - (a) Highway bridge
   - (b) Railway bridge
   - (c) Foot bridge
   - (d) Viaduct and
   - (e) Aqueduct etc.

9. **Type of Superstructure :** In this, the bridges may be classified as
   - (a) Arch bridges P
   - (b) Truss bridges
   - (c) Portal frame bridges
   - (d) Balanced cantilever bridges
   - (e) Suspension bridges etc.,

COMPONENT PARTS OF A BRIDGE

A Bridge can be divided into two major parts which are,

1. Sub Structure, 2. Super structure

1. Sub Structure : The function of the sub structure is similar to that of foundations, columns and walls of a building, as it supports the super structure of the bridges and transmits the load safely to the ground.

The substructure consists of the following parts,

1. Wing walls : These are the walls provided at both ends of the abutments to retain the earth filling of the approach road. They are constructed of the same material as those of the main abutment.

2. Approaches : The portion of the road constructed to reach the bridge from their general route or height is known as approach of the bridge. The alignment and the level of the approaches mainly depend on the design and layout of the bridge.

3. Abutments : The end of the superstructure of a bridge is calld abutments.

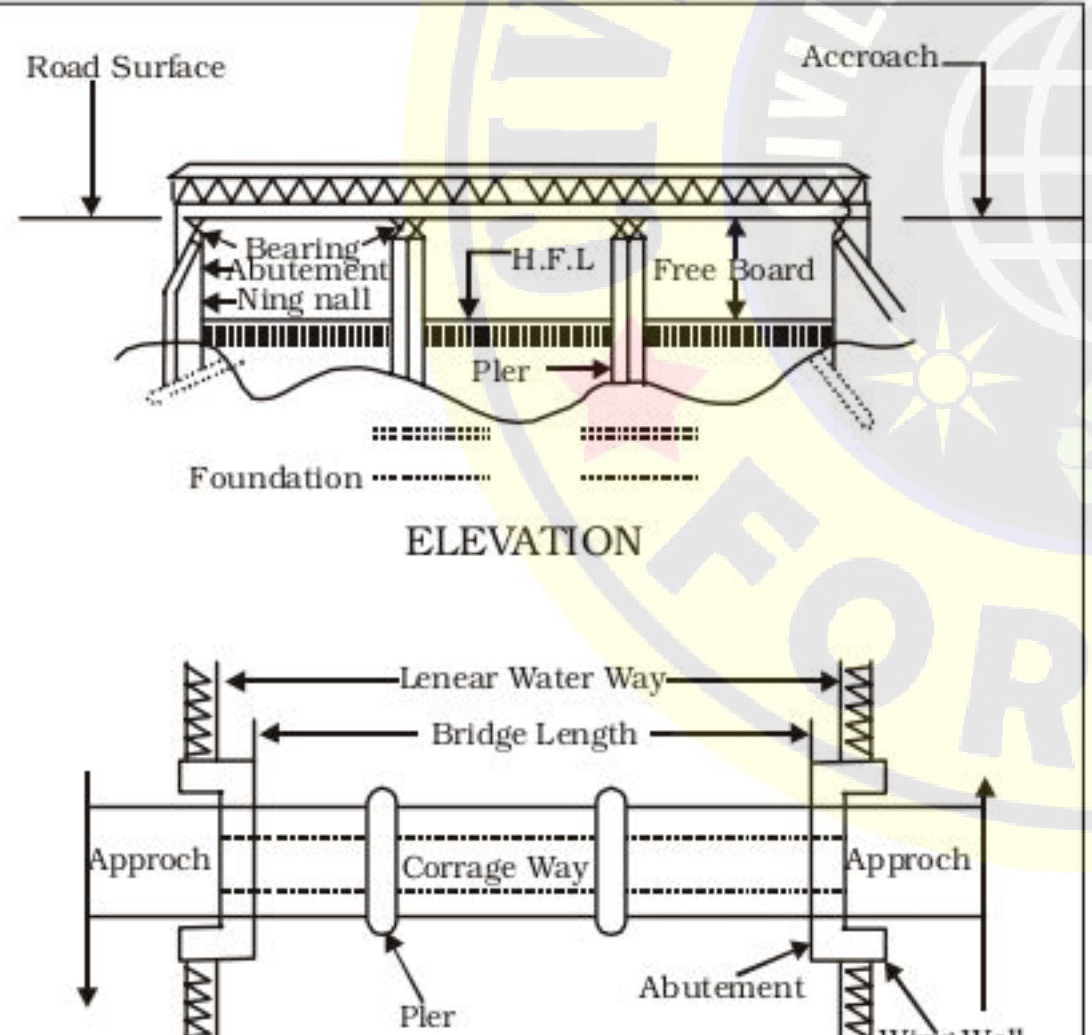


Fig.1 COMPONENY PARTS OF A BRIDGE

Its main functions are,

1. To give final formation level to the bridge.
2. To transmit the load from the bridge superstructure.
3. To laterally support the earth work of the embankment of the approaches.

Bridge abutments can be made of brick masonry, stone masonry, plain concrete or reinforced concrete.

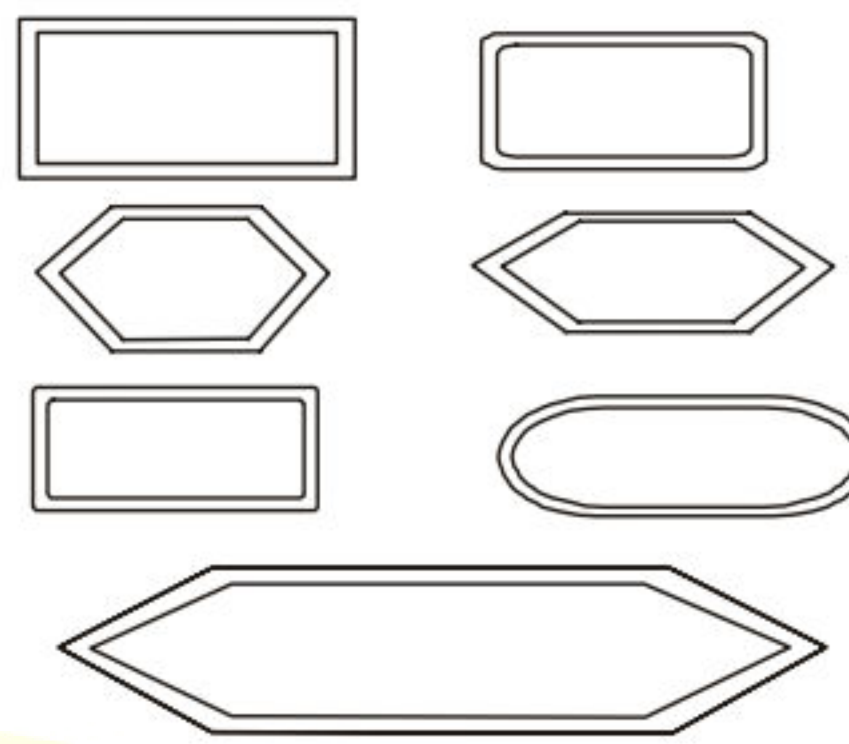


Fig. 2.SHAPES OF BRIDGE PIERS

4. Piers : For the superstructure, piers are the intermediate supports. Piers transmit the loads from the superstructure of the bridge to the foundations. A pier essentially consists of a column or shaft and a foundation. As shown in figure 2, they may have different configurations. These piers may be constructed with stone-masonry or concrete.

CULVERTS

Culvert may be defined as a small bridge which is totally enclosed and used for carrying water from one side to another side in the embankment of road or railway.

The different types of culverts which are commonly used in practice are,

(1) Box culvert
(2) Steel Girder culvert
(3) Pipe culvert
(4) Arch culvert
(5) Slab culvert

(1) Box Culvert : (Shown in Figure 6), these type of culverts mainly consist of one or more number of square or rectangular openings for passing the water from one side to the other. These culverts are constructed in masonry or reinforced cement concrete. But R.C.C. box culverts are very common. They may be of percast or cast-in-situ construction. These culverts are used where the bed has soft soils and there is possibility of scour.

(2) Steel girder Culvert : (Shown in figure 7), steel girder culvert is provided only in railways. Two main girders are laid just below the rails. Wooden sleepers are provided between these girders and the rails.

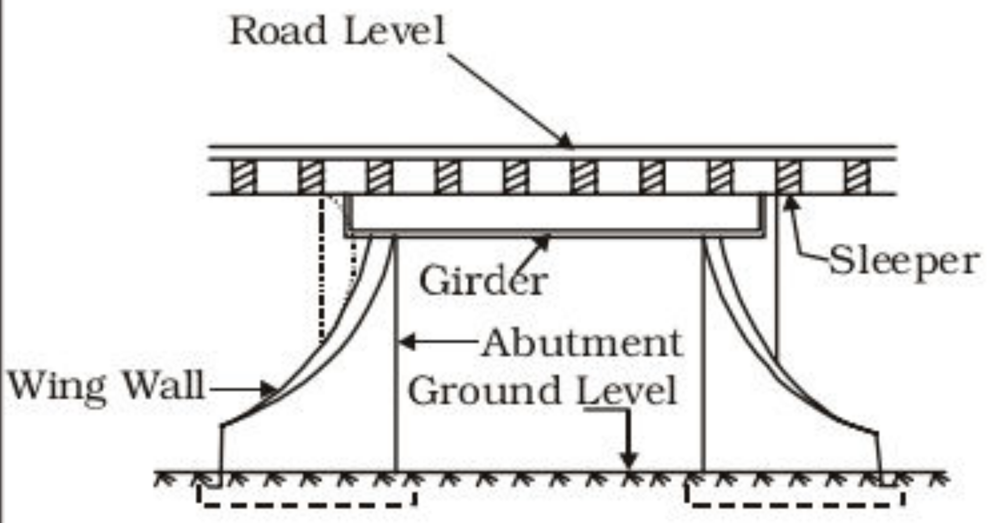


Fig. STEEL GIRDER CULVERT

(3) Pipe Culvert : (Fig. 5) Pipe culvert are used where depth of flow and discharge are small. These are easily constructed. The roads may be provided with pipe culvert by simply laying the R.C.C. or hume pipe in the position and filling the soil, compacting it and constructing the road over it. The exact number and the diameter of the pipes are determined by the maximum discharge which will pass through this culvert and height of the embankment of the road.

Figure

(4) Arch Culvert : Arch culverts are constructed economically for short spans of 2 to 3 m. The arch culverts may be constructed in stone masonry or Brick masonry. These culverts mainly consist of foundation, abutments, wing walls, arch and the parapet as shown in fig. 3. If the soil is poor and there is likelyhood of scouring, floor and curtain walls are provided. Spandrel filling is done with lime concrete.

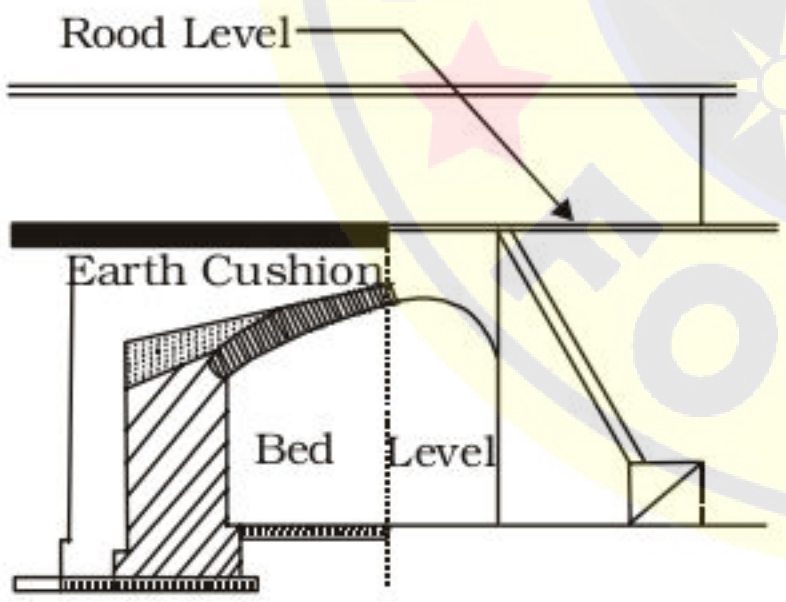


Fig.3 MASONARY ARCH CULVERT

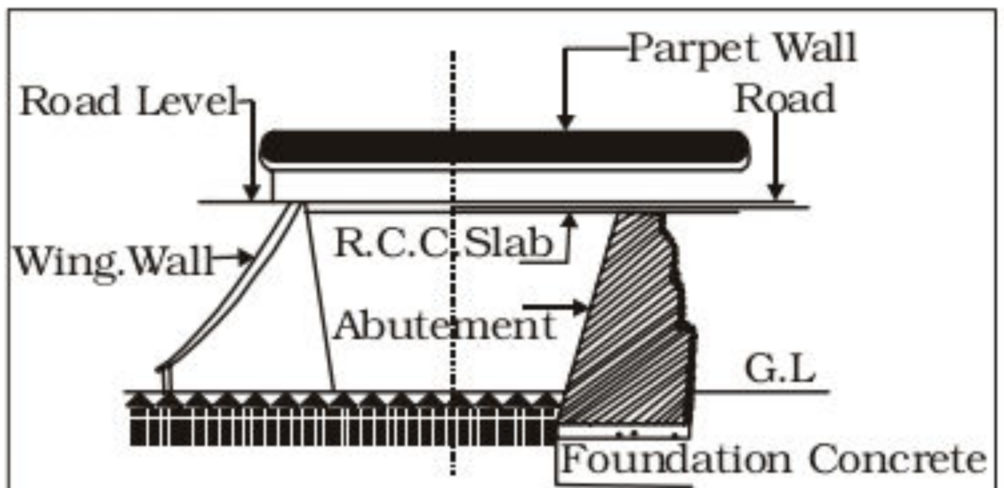


Fig. 4 SLAB CULVERT

(5) Slab Culvert : This type of culvert consists of stone slab or R.C. Slab suitably supported on masonry walls on either side as shown in fig. 4. The stone slab culverts are suitable for span upto 2.5m. R.C. Slab culverts are suitable for span upto 6 m. R.C. Slab culverts are used for highway or railway bridge.

REINFORCED CEMENT CONCRETE BRIDGES

Concrete is very suitable for taking compressive loads and steel is more suitable for tensile loads. So the combination of these two will be an ideal material for the construction of Engineering structures.

The different types of R.C.C. bridges, which are commonly used under different conditions are,

(1) Arch bridges
(2) Balanced cantilever bridges
(3) T.Beam and slab bridges
(4) Bow string girder bridges
(5) R.C.C. bridges.
(6) Slab bridges
(7) Continuous bridges

(1) Arch Bridges : These type of bridges can be economically used upto spans of about 200m. The arches may be of barrel type of tib type.

i. Barrel type of filled spandrel arches : In this type, the spandrel i.e., the portion between the curved arch slab and the checking is filled with earth.

ii. Rib type or open spandrel Ribbed Arches : In this type, the deck is supported on columns which are in turn supported on the arch ribs.

The arches used in these type of bridges may be three hinged, two hinged or fixed barrel type.

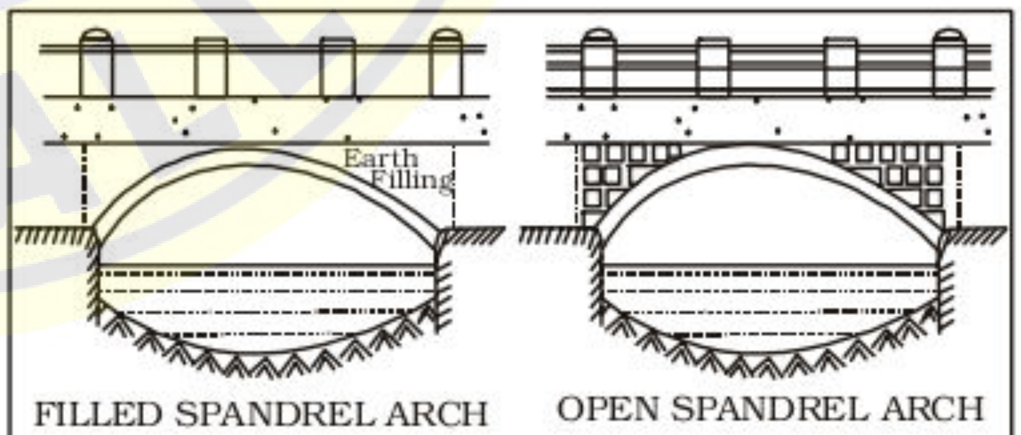


Fig. RCC ARCH BRIDGE

(2) Balanced Cantilever Bridge : It is shown in figure 10. It is suitable where the bridges have many spans. The main feature of it is the construction of alternate spans with projecting cantilevers, the ends of which are used as supports for freely supported slabs constructed between them. This type of construction can be used upto 70 metres span. In yielding river beds, where foundations are expensive and small spans are uneconomical, it can be used with advantage.

This junction between the suspended span and the edge of the cantilever is called as articulation.

The bearings at articulations should be of fixed and expansion type alternately. The length of the cantilever is about 20 to 25 percentage of the supported span. The cross section of a balanced cantilever bridge can be of Tee beam and slab.

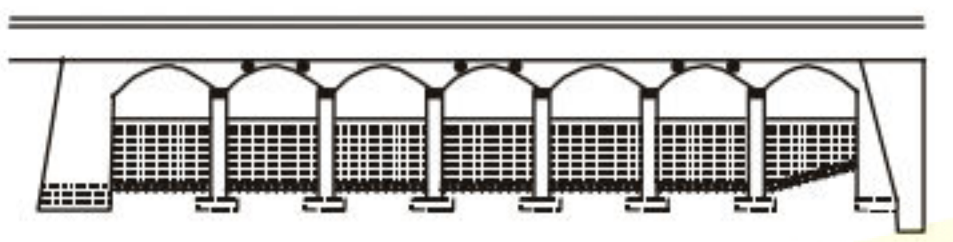


Fig. BALANCED CANTI LEVEL BRIDGE

(3) T-Beam and Slab Bridges : It is used for spans upto 20 metres. In these type of bridges, the Tee beam longitudinal functions as main girders. The roadway is supported on a number of Tee beams as longitudinal girders with or without transverse beams. The Tee Beam is simply supported over abutments and piers. The typical cross-section of floor arrangement for deck girder bridges is shown in figure.

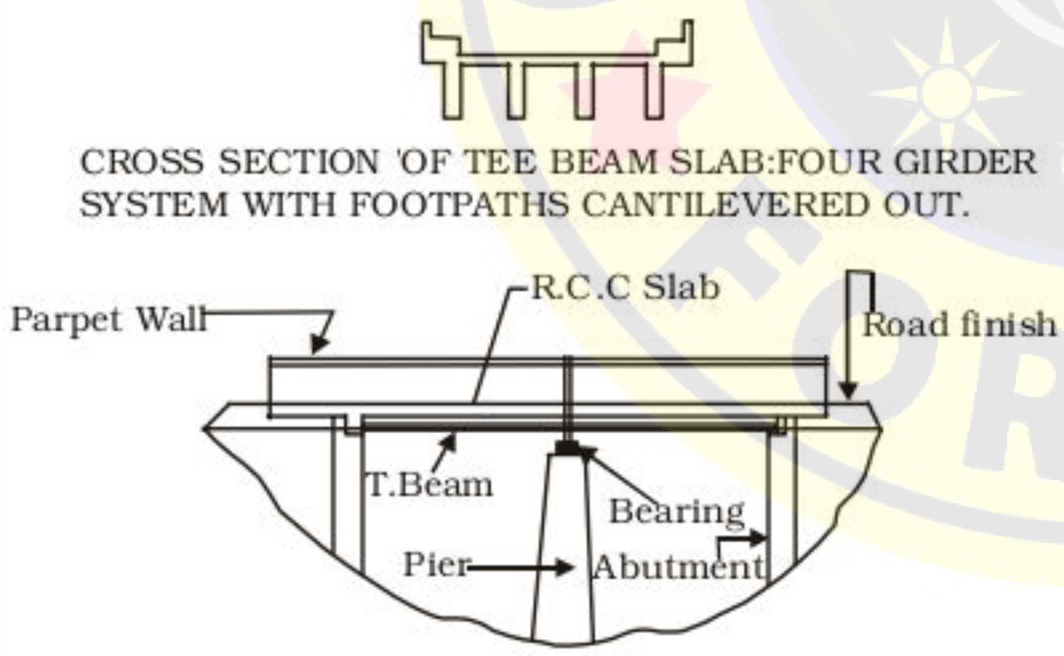


Fig. TEE BEAM RCC BRIDGE

(4) Bow string girder bridges : These types of bridges are more economical where more head room is required under the bridge. The floor beams are suspended from the arches by means of vertical suspenders. The main supporting system is known as bow string girder, due to resemblance of its arch with the bow and the tie beam with that of string of the bow. A bow string girder is unaffected by small displacement of the abutment.

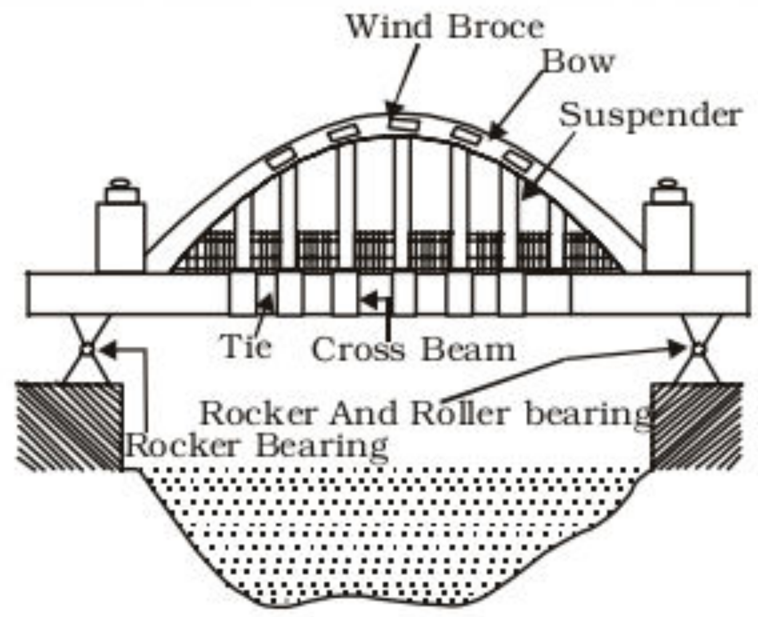


Fig. RCC BOWS-STRING BRIDGE

(6) Slab Bridges : These type of bridges are the simplest type of reinforced cement concrete bridges and is very easy to construct. It consists of simply a slab of uniform thickness on two abutments. It is suitable for spans upto 8 metres.

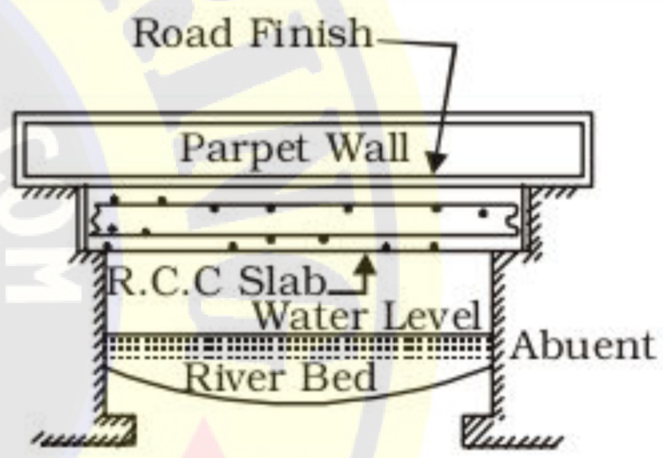


Fig.SLAB RCC BRIDGE

(7) Continuous Bridges : In these type of bridges, the slab continues unbroken over more than one span. These type of bridges are also used with large spans. These type of bridges are adopted where unyielding foundations are available. Because even slight settlement of piers and abutments introduces a high stresses in the slab. Usually the end spans are made about 16 to 20 percentage smaller than the intermediate spans. The deck can be in the form of slab or T.Beam Section.

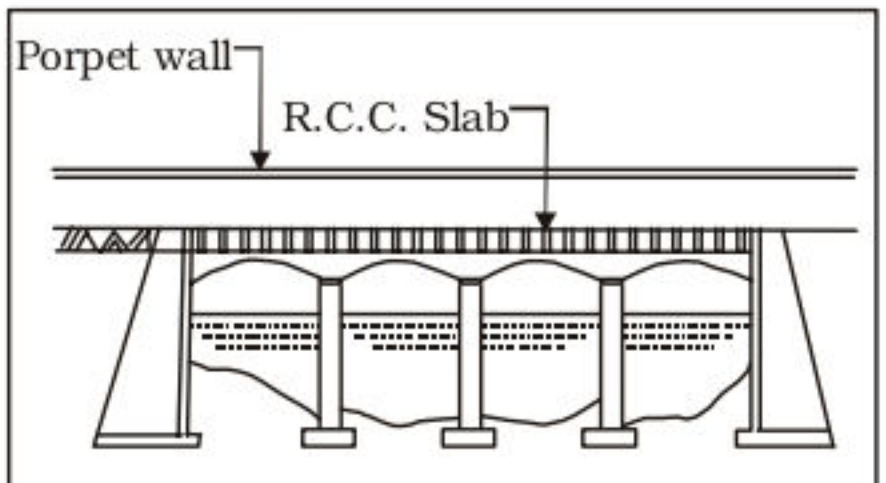


Fig. CONTINUOUS BRIDGE

(5) Rigid frame R.C.C Bridges : These bridges have high stability against lateral forces such as wind and earthquake. In this type the horizontal deck slab is made monolithic with the vertical abutment walls. These bridges are suitable upto 20meter span only.

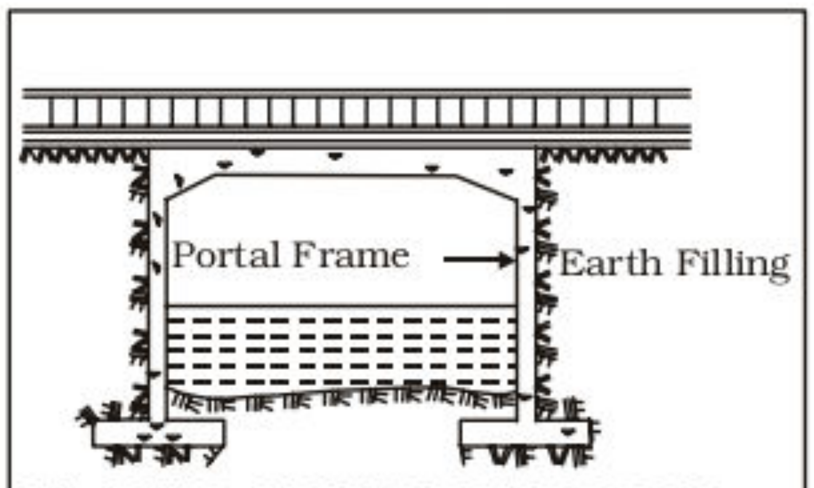


Fig RIGID FRAME RCC BRIDGE

IRON AND STEEL BRIDGES

Steel bridges are built for many purposes like carrying a highway, a railway track, for support of water pipes, gas or oil pipes etc. In India for railway bridges steel is used for very small spans to very large spans. Steel bridges can be classified as,

(1) Steel Bow string girder bridges
(2) Steel Arch bridges
(3) Steel truss bridges
(4) Plate girder bridges
(5) Movable bridges
(6) Suspension bridges
(7) Steel rigid frame bridges

(1) Steel Bow String girder bridges : In these type of bridges, steel girder, steel tie is provided for joining the two ends of an arch to bear horizontal thrust. The roadway is suspended from the arch-ribs by suspenders.

(2) Steel Arch Bridges : Bridges of very long single spans are constructed with steel arches where it is not possible to construct intermediate pier. Steel arches may be of two hinged or three hinged type which in turn may be either of the spandrel braced or trussed arch type. These bridges are adopted upto 150m span.

(3) Steel truss bridges : In the case of very long bridges of railway, generally trussed steel girders are provided because they are less affected by wind pressure. The primary forces in its members are axial forces. Its erection is considerably simple because of the relative lightness of the component members. These bridges are used upto 80m span. The different trusses used in bridges are shown in figure. These trusses generally have depth of about $\frac{1}{6}$ of the span.

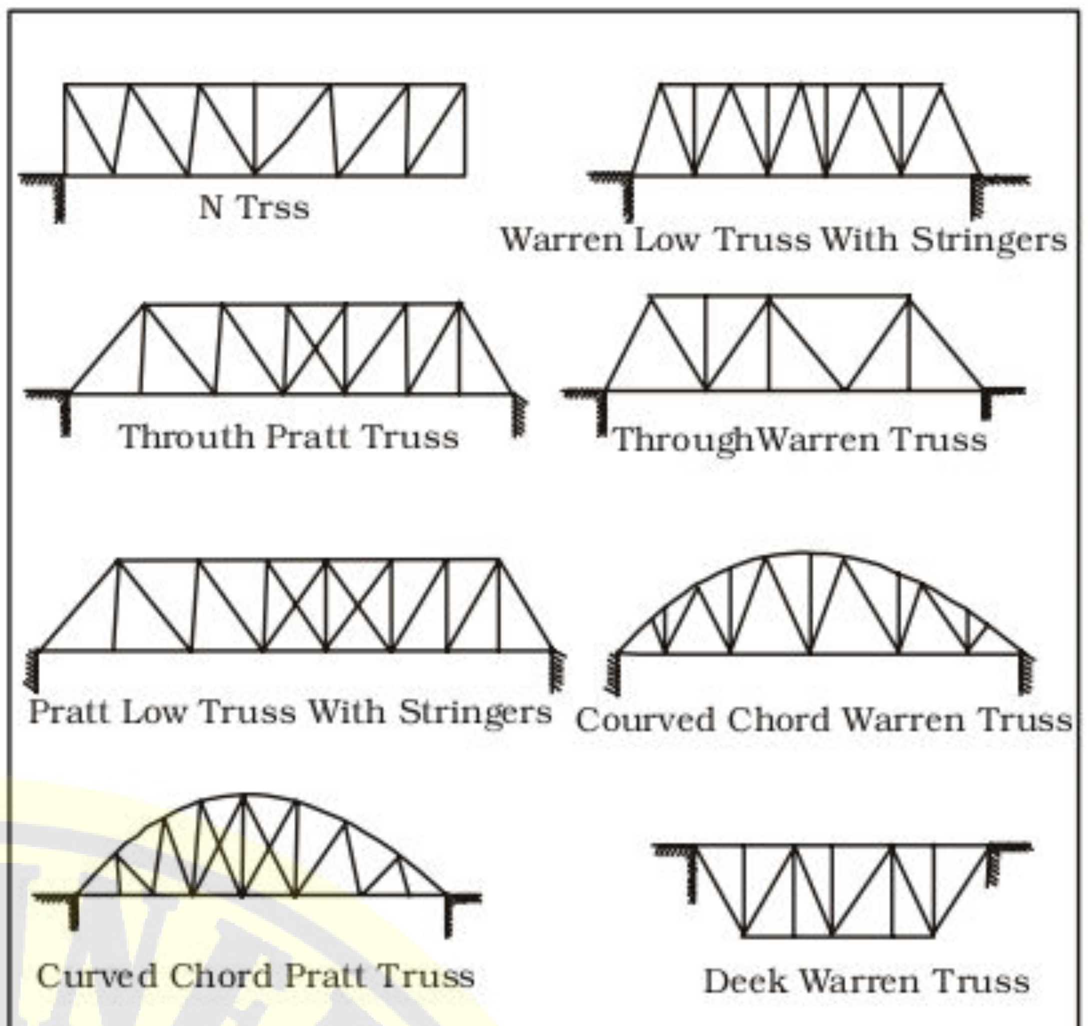


Fig DIFFERENT TYPES OF STEEL TRUSSES

(4) Plate Girder Bridges : These type of bridges are mainly used for railway bridges. Essentially a plate girder is a built up beam to carry heavier load over longer spans. The simplest form of riveted plate girder consists of pair angles connected to solid web plate. For carrying larges loads, the flange area can be increased by reverting additional cover plates as shown in figure. Sometimes box girders which consists of four plates connected by angles are also used to increase lateral stability. Steel bearings are provided below the girders which transfer the load to abutment.

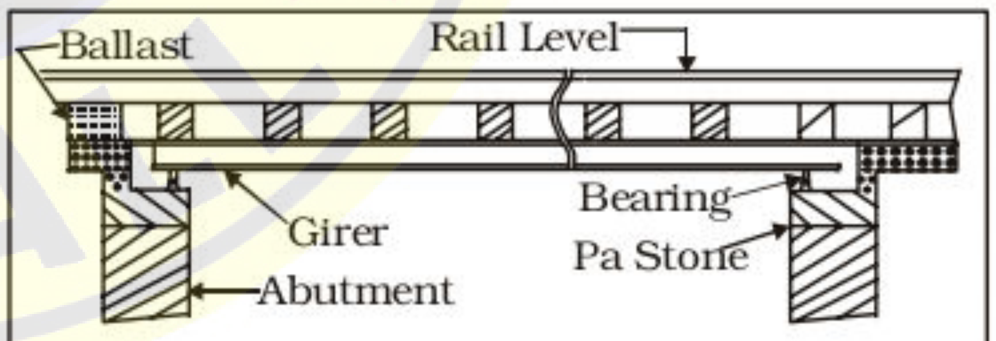


Fig. PLATE GIRDER BRIDGE

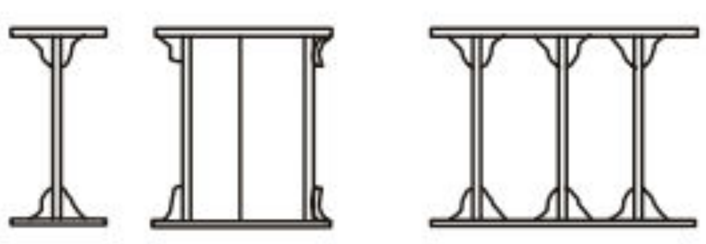


PLATE GIRDERS

(5) Movable bridges : In case of the navigation canals, it is not possible to construct the bridge superstructure at such a level that navigation ships can pass below the bridges even in high floods.

In these type of cases, the bridge is constructed at the required level. The design of bridge super structure is done in such a way that it can be moved so as to allow necessary width and clearance for the passing of ships.

(6) Suspension bridges : There are two main cables on each side of the roadway in this type of bridges. They are carried over solid piers and are securely anchored to the banks. The road way is suspended from two main cables by means of suspenders. For heavy loads suffering is required to prevent vertical distortions. This is achieved by providing stiffening trusses at the roadway or by bracing the chain.

These bridges are adopted with spans upto 1000m.

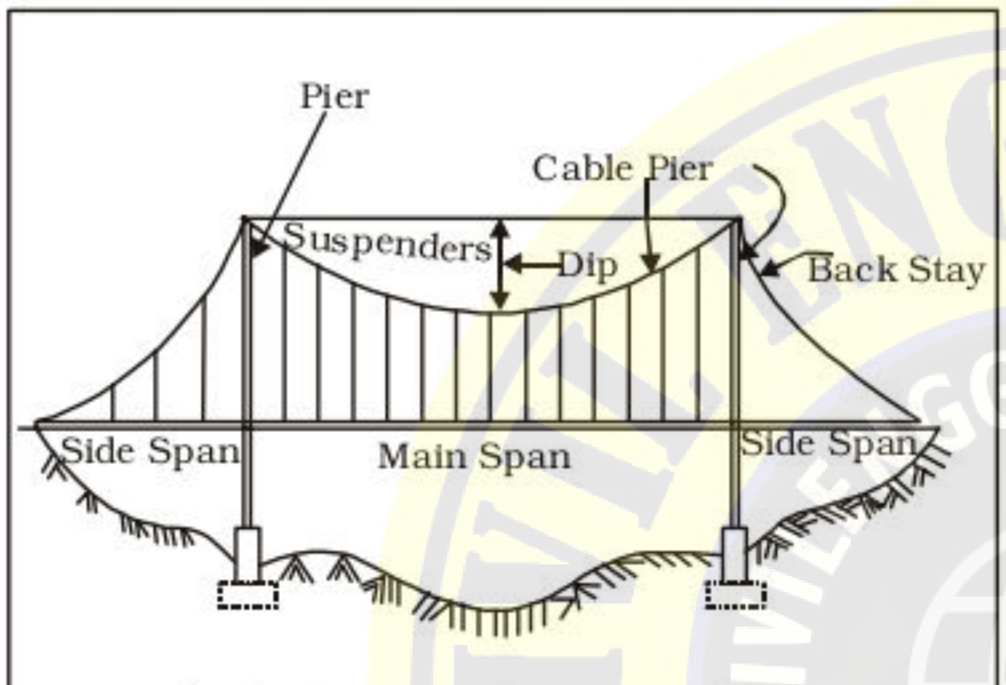


Fig SUSPENSION BRIDGE

(7) Steel Rigid Frame bridges : In this type of bridges, steel portal frames are used for the construction of bridges. The roadway is provided on the top of the portal frames. These bridges provide more clearance below the bridges and no heavy abutments are required. It does not require bearing and fixtures over the piers.

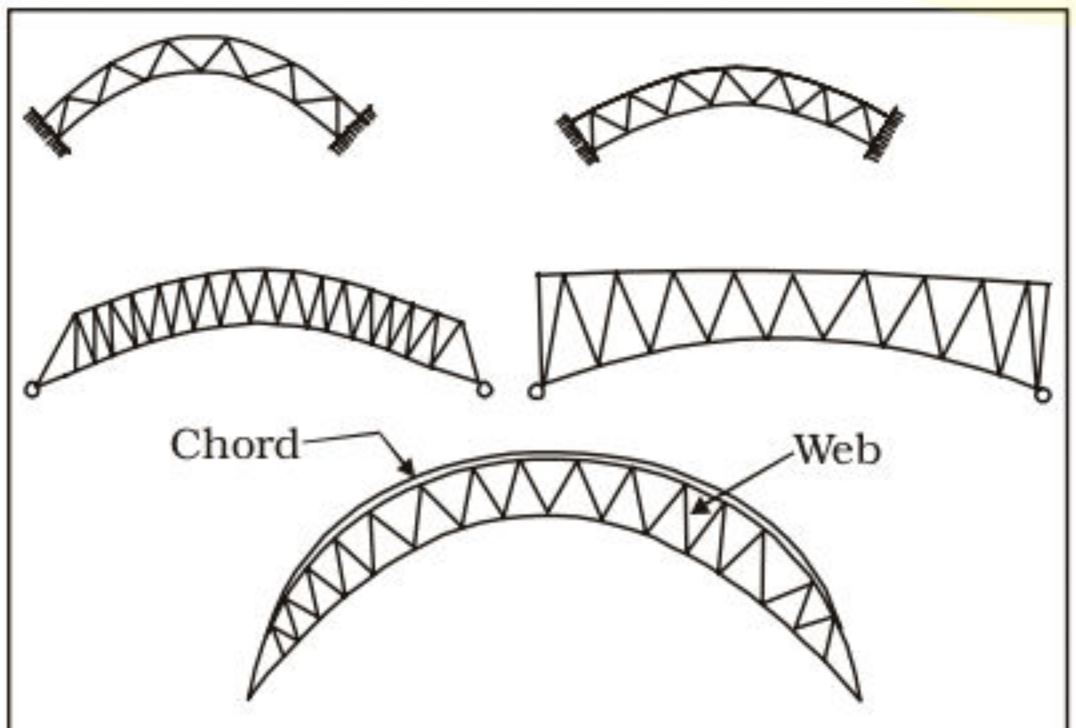


Fig DIFFERENT TYPES OF STEELARCHES

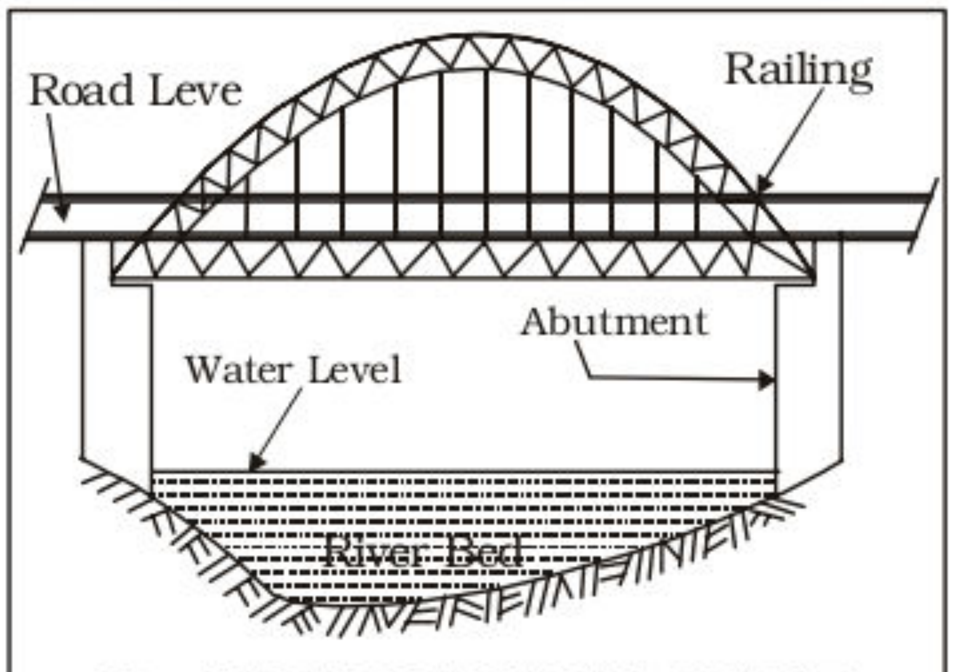


Fig. STEEL BOW STRING BRIDGE

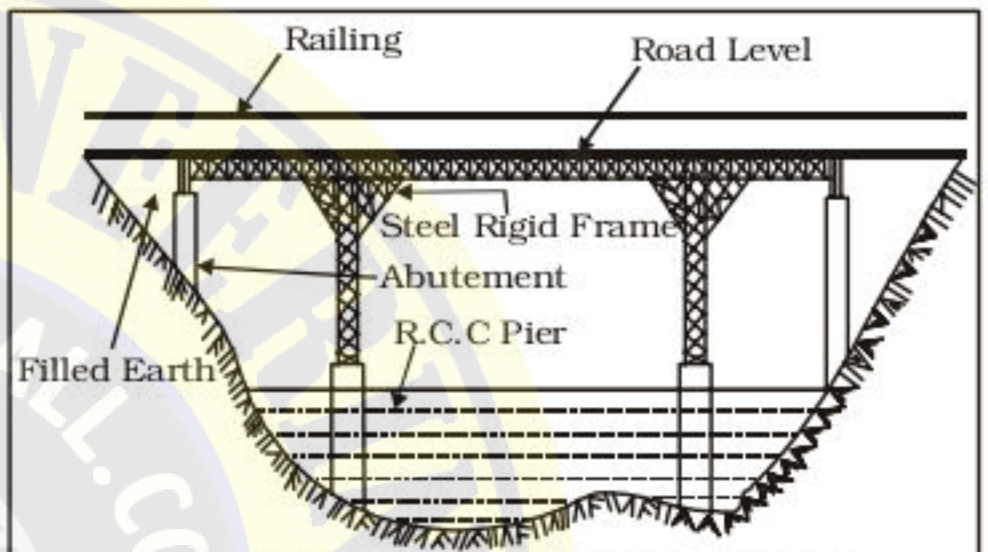


Fig. STEEL RIGID FRAME BRIDGE

CAUSEWAYS

A causeway is a temporary bridge which is situated across waterway designed to permit passage of traffic during dry periods.

Causeways are constructed under the following circumstances.

1. The road surface is closer to the bed level and below the High Flood Level (H.F.L)
2. There is high flood discharge for a short period of time.
3. The river carries very little water and the water is spread over a wide area.
4. If there is no water in the river during a substantial part of the year.

CLASSIFICATION OF CAUSEWAYS

Causeways may be classified as

1. High level causeways or submersible bridges.
2. Vented causeways
3. Flush causeways

1. High level causeways or submersible bridges : These type of bridge structures constructed are with vents. They will submerge only during occasional high floods. Since this structure is similar to a bridge and is submerged during high floods, it is called as a submersible bridge.

2. Vented causeways : It is designed and built in such a way that during dry weather, the river water flows through a number of box type or circular openings or vents provided below the road surface.

3. Flush causeways : A flush causeway is a low level causeway. In this type, the pavement for the traffic may be at the bed level of the stream itself. There is no vent or opening underneath.

BRIDGE TERMINOLOGIES

Highest Flood Level (HFL) : This is the level of highest flood ever recorded of the calculated level for the highest possible flood.

Low Water Level (LWL) : This is the minimum water level in the dry weather.

Ordinary Flood Level (OFL) : This is the flood level which normally occur every years.

Bed Level : The level of river bed below a bridge is called the Bed level.

Scour : If the velocity of stream exceeds the limiting velocity which the erodable particle of bed material can stand, the water erode the river bed which is known as scour.

Measures should be taken to prevent the scouring of the river bed are,

1. The river bed below the bridges should be properly pitched with heavy long stones.
2. To prevent scouring piles can be driven in the river bed.
3. The slope of the pier should be designed in such a way that it may not cause eddies and currents in the water.
4. Sufficient water – way should be provided below the bridge.

In order to find the depth of scour the following formula is adopted which is based on Lacey's regime equation.

$$D = 0.473 \frac{Q^{\frac{1}{3}}}{f} \times R$$

Where D = Scour depth in metres

Q = Designed discharge in m^3/Sec.

f = Lacey's silt factor.

R = Constant varying from 1.27 to 2.0 depending on the water course.

Afflux or Back Water : If a bridge is constructed then the structure such as abutment and piers cause the reduction of the natural water way area. Due to this obstruction, there is a rise in the level of the water above the normal level on the upstream side of a bridge. The rise in water level or the difference in levels of water surface between the upstream and the downstream sides of the bridge is known as Afflux.

Water way : The area through which the water flows under a bridge superstructure is called the water way of the bridge. The linear measurement of this area along the bridge is called as the linear water - way. The linear water way is equal to the sum of all the clear spans. It is may be called as artificial linear waterway. The natural waterway is the unobstructed area of the river stream through which the water flows at the bridge site.

INSPECTION AND DATA COLLECTION

In view of the great number of structures arressment of individual structure is not easy. Further to account for many other factos like age factors and conditions of the structure, it is necessary to inspect all there structures and collect all relevant particulars, repairs necessary and possibility of alternative arrangements for traffic during repairs.

Method for Assessment of fafe carrying capacity of Bridge.

The assesment of safe carrying capacity of bridge may be done by any of the following methods.

(i) **Theoretical method :** After collecting all relevant data, the theoretical safe load on the bridge can be determined by theoretical calculations. Charts and tables have been prepared by I.R.C giving allowable loadsfor various types of loads bridges with various types of loads bridges with various dimensions of the structures are known the safe load cna be read off from the charts and tables.

(ii) **Correclation method :** In certain case of bridge structure, it is possible to ascertain the safe carrying capacity of the structure by correclating the sectional details of the structure with those of idential specifications and sectional details whose safe carrying capacity are known.

(iii) **Load testing :** In case of bridges where it is not possible to ascertain their safe carrying capacity by any of the first two mehods the load testing method is restored to Load test can be either proof test or tests to failure. Test where loads exceed the usual working limits but do nt cause any damage to the structure are called proof tests.

Rating by proof testing is recommended only for arches and simply supported reinfored concrete girder bridge and not for any other types of bridge for the reasons that,

(a) These can be conveniently rated by theoretical analysis, and

(b) It is difficult to lay down a precise aceeptance criteria for load testing of these bridges.

The test vehicle choosen should be the next heavier vehicle than the predominant heavy loads presently passing over the bridge.

The test vehicle for rating should be specified by I.R.C. load should be placed in such a way as to produce the wrost effect in the girders. The load test should be done during such period of the day when the varication the variation in temperature is the loast. Preferobly this should be done during the early hours of mrning. The load increment in stages should be $\frac{W}{4}$, $\frac{W}{2}$, $3\frac{W}{4}$ and W, here 'W' is the gross laden weight of the test vehicle. Observation should be made for any cracks in the structure before the testing and cracks if any observed should be marked and their behavior observed during the test.

TUNNEL ENGINEERING :

Introduction : A tunnel is an underground structure beneath the ground, under the bodies of water or through mountain. It is wed for transporting freignt, passengers, goods, water, swage, oil gas, etc. The various purposes of tunnels are :-

(i) They provide passage ways for rail roads and automotive vehicles through mountains and under bodies of water.

(ii) They provide accesses to mines.

(iii) They act like conduits for water.

(iv) They relieve congestion on surface roads.

Modern developments have contributed towards solving the problems of tunnelling. Preumatic drills, improved drill bits, high quality modern explosives have greatly increased speed of tunnding. THe use of shield, electric power and compressed air have resulted in speed and certainty in tunnelling.

Classification of Tunnels :

The tunnels can be classified in the following wasy :-

Classification leased on the purpose of tunnels

(1) **Traffic tumers :** They are (a) Highway tunnes (b) Railway tunnds, (c) Pedestrian tunnels, (d) Navigation tunnels, and (e) Subway tunnels

(2) **Conveyance tunnels :** they are (a) water supply tunnels, (b) Hydroelectric power tunnels (c) Sewer tunnels, (d) Tunnels for carrying public utility services and (e) Tunnels for serving industry. classification based on type of material used for construction of tunnels, they are :-

(1) Tunnels in hard rock, (2) Tunnels in soft rock, (3) open cut tunnels, (4) Tunnels underneath the river bed or sub-marine tunnels, and (5) Tunnel in quick sand

Classification based on alignment or position of tunnels : they are :-

(1) Saddle and lore tunnel, (2) Spiral tunnels, (3) off spurtunnels, and (4) Slope tunnels.

A brief discussion of the above - emntioned runnels is given below :-

(1) **Saddle and base runnels : -** On these runnels the track is led through valleys as long as natural slope of the valley does not become steeper than ruling grodients of the route. This technique minimises the length of actual tunnel.

(2) **Spiral tunnel :** These tunnels are provided in narrow valleys. In these tunnels the initial length for minimum permissible radius is obtained by forming a loop into the interior of maintain.

(3) **Off-spur tunnels :** These are short length tunnels which are constructed to short cut minor local obstacles.

(4) **Slope tunnels :** These tunnels are constructed in steep moantance to ensure saftey in operation and protection to railway or highway

SHAPE OF TUNNELS :

The shope of the cross-section of a tunnd depends upon the pressure of the ground which the tunnel lineing can resist and the purpose for which the tunnel is constructed. The most common cross-sections are :

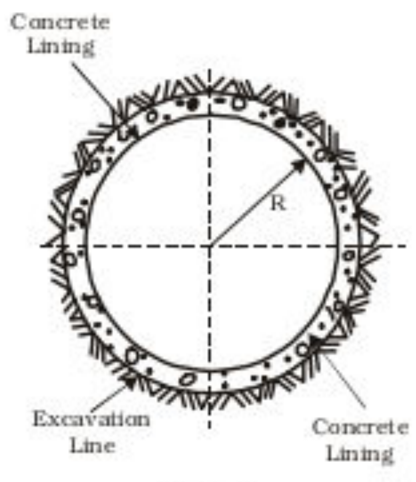
(a) **Circular Section :** This type of section offers greater resistance to external pressure. Hence if the ground is highly constable, such as soft clay or sand, it is necessary to use circular section. For carrying water and sweerage under pressure eg. aqueduct the tunnel section may be circular. Circular section if used for road or railway route, require more filling to form the flat base. Hence they are not preferred as traffic tunnedl. The lining of these tunnels is alvodifficult. These tunnels are the best for relisting external and internal presures caused ly water, water bearing soil or soft grounds.

(b) **Elliptical section :** They are used in grounds softer than rock. In order to have better resistance to external pressure, the major axis of these tunnels is kept vertical. These tunnels sewes as water and sweage conduit. They can't be used as traffic tunnels because of their narrow base.

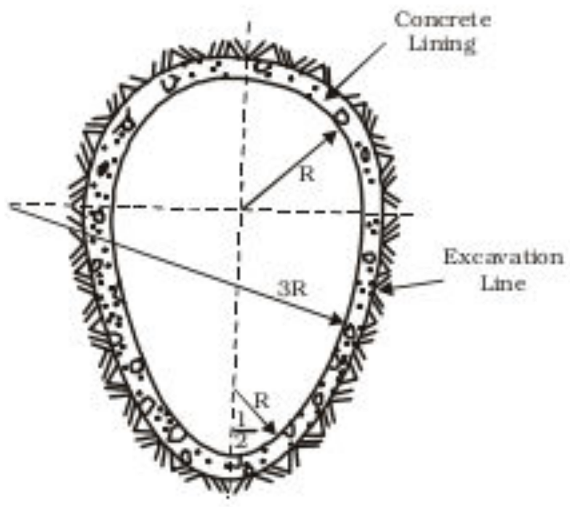
(c) **Egg shaped section :** These sections have narrower croess-sections at bottem. They are best suited for carrying sewage.

(b) **Horse shoe section :** This form consists of a semi-circular roof together with arched sides and a curved invert. They are suitable in soft rock grounds. They are most popular as traffic tunnels for road and railway routes. they have enough flat base to provide working space during its construction. They resist the external pressuee by axis acton also at their bottom These tunnels combine the advantages of circular section and that of arched with straight sides. These tunnels also are difficult to construct.

(e) **Vertical wall with Arch Roof type :** This shope is commonly used in Subways or for navigotional purposes the section has its roofs as segmental in shope with vertical sides and flat floors. They are coly to construct However these tunned require comparatively thick lining.

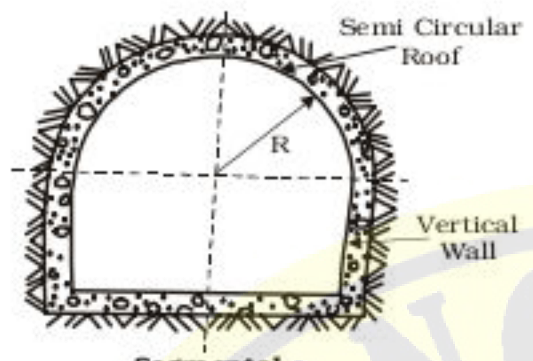


Circular



Egg Shapeo

Horse Shoe



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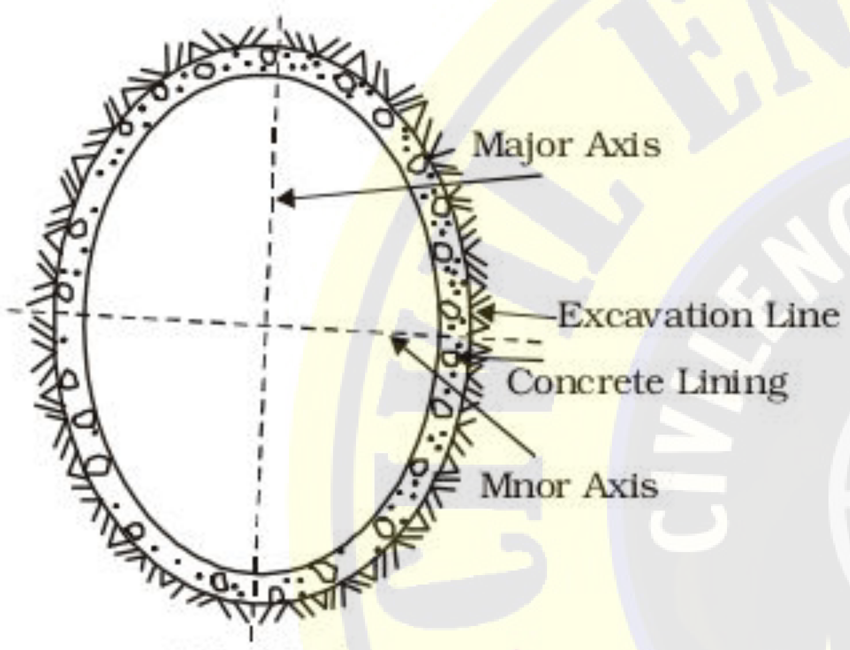

Eluptical

SIZE OF TUNNEL : The size which indicates dimensions of the cross-section of a tunnel depends mainly upon :-

(i) Purpose of tunnel

(ii) A layout to fit the topography and

(iii) Aesthetics

The purpose of tunnel is to transport passengess, freight, water, sewage or gas etc. Passengers and freight is transported by means of railways or highways. the size of tunned is determined based upon :-

(i) Type and volume of traffic : The vehicle size, magnitude speed and tonnage influence the tunnel size requirements. More the traffic volume, larger shall be the tunnel size requirement.

(ii) **Size of clearances Required :** The horizontal and vertical clearance required depend upon the maximum dimension of moving vehicle. In case of highway traffic the maximum dimension of vehicle is taken as 3300 × 4500 mm. For a single lane tunnd, the minimum horizontal clearance is assumed as 3800 mm and vertical clearance as 5000 mm.

FIELD SURVEYS FOR TUNNELLING :

The surveying in tunnel means to mark the centre line of the tunnd on the ground and then to transfer the same to inside of the tunnel. The alignment of tunnel should be straight, short; eassy, safe and economical. The gradient should be appreciably less than that the open cut. However 0.2% gradient may be given to-provide drainage in the tunnel. In case of long tunned it is better to give two grodes rising from each end towards the centre. It has been found that for proper ventilation the gradient should be provided in one direction only.

Surveying work operations can be briefly listed as eblow :

(i) **Centre line location on ground :** In order to determine centre are tried on plans. The alternative which is more suited from economic and other considerations is finally chosen. Final location survey consists in fixing up the centre line of the proposed tunnel on the ground with necessary horizontal and vertical central.

The main operation inveIved in the final location survey are :-

(a) Staking out the final centre line to the field.

(b) Detailed levelling.

(ii) Shaft construction over the centre line :- Shafts are intermediated openings constructed along the centre line of the tunnel. Each shoft provides two additional face to wrok.

Hence in case of long tunneds the construction of shoft helpsinincreasing the rate of driving a tunnel. they facilitate in :-

(a) Removal of muck (b) Removal of water (c) Delivery of materials (d) Delivery of supplies (e) Natural ventilation and (f) Passegeway for workman, constructed tools, machinery, compressed air, water and other utilities.

Thus shoft are necessary for transferring centre line and on early completion of construction.

TUNNELING METHODS :

(1) **Methods of Tunneling in soft grounds :** Soft ground is excavated with tools like picks, showed, axe etc. It does not require use of explosives. When a tunnel is driven, it may be necessary to support the ground adjacent to the trunnel untill a permanent concrete lining can be installed. the temporary support must be strong enough to resist the pressures transmitted to them by the ground. These pressure are caused ly faulted, folded or fractured rock masses or the swelling of the surroundings earth following the removal of the material from a tunnel.

The differnt operations involved in soft ground tunnelling are :

(i) Setting up, mining or excavation.

(ii) Ground support or timbering

(iii) sucking, and

(iv) Lining

(2) **Method of Tunnelling in Rock :** The operations to drive tunnel through rock can be listed as below :

(i) Setting up and drilling

(ii) Loading holes and blasting the explosives.

(iii) Ventilating and removing the dust.

(iv) Loading and hauling muck.

(v) Removing ground water.

(vi) Timebring and support errestion for the roof and sides

(vii) Placement of reenforcing steel.

(viii) Placing the concrete lining.

CONSTRUCTION EQUIPMENTS :

The different equipments used for construction of tunnel are :

(i) Drilling equipments like wagon, chern, rotaly, drifter, drill mounted on base or columns, drill jumbo, jumbo mounted on skids, on wheel travelling on roads or on pnellmatic tires. They are used for drilling holes.

(ii) Electical detonators and delay detonators are used for firing dirlled holes loaded with explosives.

(iii) Trench jacks are used for centring and framework of tunnds.

(iv) Mechanical moles for driving tunnels through both earth and rock.

(v) Powel shovels, mucking machines, clusters or tractor loadersscere used for mucking.

(vi) Trollay, battery and combination trolley and battery are three types of electric locomofives which are used for tunnel howage

(vii) Plumbing sets are used for dranage of tunnels.

Precautions in censtruction of Tunnel :

(i) Tunnel design should serve the intended purpose in a most efficient and economic manner.

(ii) Size and shope of tunnel should be such that it is economically and easy to construct.

(iii) Design for the use of cost-sawing equipment and mthods.

(iv) Unnecessary special construction requirement should be elimenated.

(v) Tunnel design should be such that required labour is minimu.

TUNNEL LINING :

Lining means to give a benisheng touch to the tunnel cross section. Generally a laryer of timber, iron, mororoy or concrete is provided the inside of a tunnel. Lining can be both temperay and permanent. Temporay lining is provided for supporting the roof and wall of a tunnel diring construction. Tunnel in soft ground are provided with a permanent lining becasue soft ground is always liable to disintegrate.

The cost of lining is generally one third the total cost of construction. Hence it is desirable for tunned lining to be as thin as practical. the thicknees of lining can be determined by :-

(i) The condition of ground surrounding the tunnel.

(ii) The size and shope of the x-section.

(iii) The requirements of construction conditions.

(iv) Internal pressure.

An ideal lining should be :

(i) Economical (ii) Stable (iii) Desbale (iv) Simple to construct, and (v) easy to maintain.

Object of lining :-

The tunnel lining is provided to achieve the following purposes :

(i) It withstands soil bressure when driven into soft ground.

(ii) It supports the loosered rock piece during blosting.

(iii) It gives proper section of tunnel.

(iv) It strenthens the weak locotions in the tunnel.

(v) It protects rock susceptible to air sloking.

VENTILATION OF TUNNEL :

Ventilation means techniques of providing freshnees of air inside the tunnel during and after construction.

The ventilation of tunnel is neceeary due to following reasons :-

(i) To furnish fresh air for the workers.

(ii) To remove obnoxious gases and to fumes produced ly explosives.

(iii) To remove the dust caused by drilling, blasting, mucking and other operations.

Methods of Tunnel ventilation :

Tunnel ventilation can be carried out by following methods :

(i) **Natural method :** Natural ventilation is due to difference of temperature inside and outside the tunnels. This type of ventilation can be achieved by providing shofts at a suitable interval along the alignment of a tunnel during its construction. This along the alignment of a tunnel during its construction. This method is suitable under the following conditions :-

(a) If a drift is driven through a tunnel from protal to portal, it may provide sufficient natural ventilation for the nelarging operations.

(b) When diameter of tunnel is large but its length is small.

(c) When tunnel orientation is along wind direction.

(ii) **Mechanical Methods :** Mechanical ventilation is achevedly bone or more electric-motor driven fands which may blow fresh air into a tunnel or exhaust the dust and foul air from the tunnel.

Thus mechanical ventilation can be provided by :-

(a) Blowing (b) Exhausting, and (c) Combination of both.

Air is blown into a tunnel through a light weight pipe or a fabric duct. If fresh air is blown into a tunnel, it is rleased near the working face and as it flows to the portal through the tunnel it carries the dust and gases with it.

Dust control :

(i) In order to remove cutting from drilled holes water should be used instead of air.

(ii) By allowing muck pile to remain wet during loading operation

(iii) Complete ventilation of space near the face following blasting.

(iv) Use of vaccem hood around the drill steel at the rock face during drilling operation. ❐❐❐