TRANSPORTATION ENGINEERING II

UNIT I COMPONENTS OD RAILWAY ENGINEERING

Permanent way: A permanent way is the combination of rails fitted to sleepers resting on ballasts and subgrade with the help of fixtures and fastenings, etc is called permanent way. This term is used to distinguish the finished and permanent track from a temporary track which is laid for temporary work, i.e. for transporting construction material etc on major construction sites.

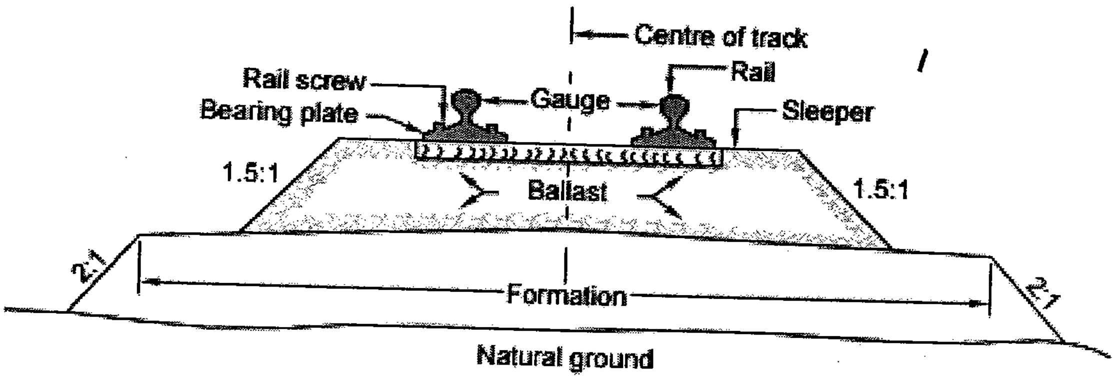


Fig. 5.1 Various components of a track

such a temporary track is removed as soon as the construction completed. the purpose of use of a permanent way is to provide the permanent facility for safety and quick movement of normal commercial traffic between the starting and destination stations. permanent way costs nearly 40% of the total investment to the railways.

COMPONENT PARTS OF A PERMANENT WAY
Following are the components of a permanent way.
(i) Subgrade
(ii) Ballast
(iii) Sleepers
(iv) Rails
(v) Fixture and Fastening
In a permanent way, rails are joined either by welding or by using fish plates and are fixed with sleepers by using different types of fastenings. Sleepers are properly placed and packed with ballast. Ballast is placed on the prepared subgrade called formation.

REQUIREMENTS OF AN IDEAL PERMANENT WAY Following are the basic requirements of a permanent way:
(i) The guage should be uniform and correct.
(ii) Both the rails should be at the same level in a straight track.
(iii) On curves proper superelevation should be provided to the outer rail.
(iv) The permanent way should be properly designed so that the load of the train is uniformly distributed over the two rails.

(v) The track should have enough lateral strength.
(vi) The radii and superelevation, provided on curves, should be properly designed.
(vii) The track must have certain amount of elasticity.
(viii) All joints, points and crossings should be properly designed.
(ix) Drainage system of permanent way should be perfect.
(x) All the components of permanent way should satisfy the design requirements.
(xi) It should have adequate provision for easy renewals and repairs.

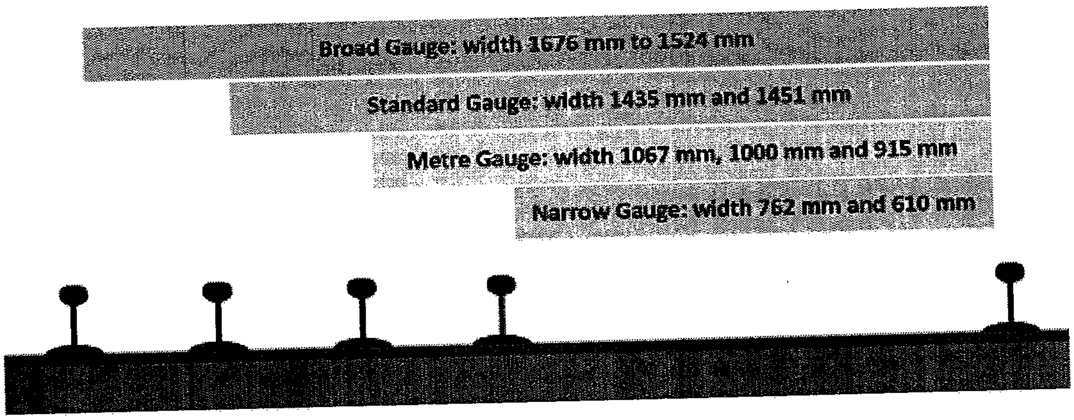
Rail : rails are the members of the track laid in two parallel lines to provide an unchanging, continuous, and level surface for the movement of trains. To be able to with stand stresses they are made of high-carbon steel.

Functions of Rail

1. Transmit the vertical load to sleepers and reduce pressure on ballast and formation level.
2. Provides unchanging hard surface for passengers travelling.
3. Bears stress developed due to heavy vertical load,lateral and breaking force.
4. Rail material should be of good quality to reduce regual replacement.

Rail Gauges : The gauge of a railway track is defined as the clear minimum perpendicular distance between the inner faces of the two rails. The different gauges can broadly be divided into the following four categories:

1. Broad Gauge: width 1676 mm to 1524 mm
2. Standard Gauge: width 1435 mm and 1451 mm
3. Metre Gauge: width 1067 mm, 1000 mm and 915 mm
4. Narrow Gauge: width 762 mm and 610



Choice of Gauge

The choice of gauge is very limited, as each country has a fixed gauge and all new railway lines are constructed to adhere to the standard gauge. However, the following factors theoretically influence the choice of the gauge.

Cost Considerations

There is only a marginal increase in the cost of the track if a wider gauge is adopted. In this connection, the following points are important.

(a) There is a proportional increase in the cost of acquisition of land, earthwork, rails, sleepers, ballast, and other track items when constructing a wider gauge.

(b) The cost of building bridges, culverts, and tunnels increases only marginally due to a wider gauge.
(c) The cost of constructing station buildings, platforms, staff quarters, level crossings, signals, etc. associated with the railway network is more or less the same for all gauges.
(d) The cost of rolling stock is independent of the gauge of the track for carrying the same volume of traffic.

Traffic Considerations

The volume of traffic depends upon the size of wagons and the speed and hauling capacity of the train.
(a) As a wider gauge can carry larger wagons and coaches, it can theoretically carry more traffic.
(b) A wider gauge has a greater potential at higher speeds, because speed is a function of the diameter of the wheel, which in turn is limited by the width of the gauge.
(c) The type of traction and signalling equipment required are independent of the gauge.

Physical Features of the Country

It is possible to adopt steeper gradients and sharper curves for a narrow gauge as compared to a wider gauge.

Uniformity of Gauge

The existence of a uniform gauge in a country enables smooth, speedy, and efficient operation of trains. Therefore a single gauge should be adopted irrespective of the minor advantages of a wider gauge and the few limitations of a narrower gauge.

Problems Caused by Change of Gauge

The need for uniformity of gauge has been recognized by all the advanced countries of the world. A number of problems have cropped up in the operation of Indian Railways because of the use of three gauges. The ill effects of change of gauge (more popularly known as *break of gauge*) are numerous; some of these are enumerated here.

Inconvenience to Passengers

Due to change of gauge, passengers have to change trains mid-journey alongwith their luggage, which causes inconvenience such as the following.
(a) Climbing stairs and crossing bridges
(b) Finding seats in the compartments of the later trains
(c) Missing connections with the later trains in case the earlier train is late
(d) Harassment caused by porters
(e) Transporting luggage
(f) Uncertainty and delay in reaching the destination

Difficulty in Trans-shipment of Goods

Goods have to be trans-shipped at the point where the change of gauge takes place. This causes the following problems.
(a) Damage to goods during trans-shipment.
(b) Considerable delay in receipt of goods at the destination.

(c) Theft or misplacement of goods during trans-shipment and the subsequent claims.
(d) Non-availability of adequate and specialized trans-shipment labour and staff, particularly during strikes.

Inefficient Use of Rolling Stock

As wagons have to move empty in the direction of the trans-shipment point, they are not fully utilized. Similarly, idle wagons of one gauge cannot be moved on another gauge.

Hindrance to Fast Movement of Goods and Passenger Traffic

Due to change in the gauge, traffic cannot move fast which becomes a major problem particularly during emergencies such as war, floods, and accidents.

Additional Facilities at Stations and Yards

(a) Costly sheds and additional facilities need to be provided for handling the large volume of goods at trans-shipment points.

(b) Duplicate equipment and facilities such as yards and platforms need to be provided for both gauges at trans-shipment points.

Difficulties in Balanced Economic Growth

The difference in gauge also leads unbalanced economic growth. This happens because industries set up near MG/NG stations cannot send their goods economically and efficiently to areas being served by BG stations.

Difficulties in Future Gauge Conversion Projects

(b) Gauge conversion is quite difficult, as it requires enormous effort to widen existing tracks. Widening the gauge involves heavy civil engineering work such as widening of the embankment, the bridges and tunnels, as well as the tracks; additionally, a wider rolling stock is also required. During the gauge conversion period, there are operational problems as well since the traffic has to be slowed down and even suspended for a certain period is order to execute the work.

Uni-gauge Policy of Indian Railways

The problems caused by a multi-gauge system in a country have been discussed in the previous section. The multi-gauge system is not only costly and cumbersome but also causes serious bottlenecks in the operation of the Railways and hinders the balanced development of the country. Indian Railways therefore took the bold decision in 1992 of getting rid of the multi-gauge system and following the uni-gauge policy of adopting the broad gauge (1676 mm) uniformly.

1 Benefits of Adopting BG (1676 mm) as the Uniform Gauge

The uni-gauge system will be highly beneficial to rail users, the railway administration, as well as to the nation as described below.

No Transport Bottlenecks

There will be no transport bottlenecks after a uniform gauge is adopted and this will lead to improved operational efficiency resulting in fast movement of goods and passengers.

No Trans-shipment Hazards

There will no hazards of trans-shipment and as such no delays, no damage to goods, no inconvenience to passengers of transfer from one train to another train.

Provisions of Alternate Routes

Through a uni-gauge policy, alternate routes will be available for free movement of traffic and there will be less pressure on the existing BG network. This is expected to result in long-haul road traffic reverting to the railways.

Better Turnround

There will be a better turnround of wagons and locomotives, and their usage will improve the operating ratio of the railway system as a whole. As a result the community will be benefited immensely.

Improved Utilization of Track

There will be improved utilization of tracks and reduction in the operating expenses of the railway.

Balanced Economic Growth

The areas presently served by the MG will receive an additional fillip, leading to the removal of regional disparities and balancing economic growth.

No Multiple Tracking Works

The uni-gauge project will eliminate the need for certain traffic facilities and multiple tracking works, which will offset the cost of gauge conversions to a certain extent.

Better Transport Infrastructure

Some of the areas served by the MG have the potential of becoming highly industrialized; skilled manpower is also available. The uni-gauge policy will help in providing these areas a better transportation infrastructure.

Boosting Investor's Confidence

With the liberalization of the economic policy, the uni-gauge projects of the Indian Railways have come to play a significant role. This will help in boosting the investors' confidence that their goods will be distributed throughout the country in time and without any hindrance. This will also help in setting up industries in areas not yet exploited because of the lack of infrastructure facilities.

2 Planning of Uni-gauge Projects

The gauge-conversion programme has been accelerated in Indian Railways since 1992. In the eight Plan (1993-97) itself, the progress achieved in gauge-conversion projects in 5 years was more than the total progress made in the last 45 years.

Requirements of an Ideal Alignment

The ideal alignment of a railway line should meet the following requirements.

Purpose of the New Railway Line

The alignment of a new railway line should serve the basic purpose for which the railway line is being constructed. As brought out earlier, the purpose may include strategic considerations, political considerations, developing of backward areas, connecting new trade centres, and shortening existing rail lines.

Integrated Development

The new railway line should fit in with the general planning and form a part of the integrated development of the country.

Economic Considerations

The construction of the railway line should be as economical as possible. The following aspects require special attention.

Shortest route It is desirable to have the shortest and most direct route between the connecting points. The shorter the length of the railway line, the lower the cost of its construction, maintenance, and operation. There can, however, be other practical considerations that can lead to deviation from the shortest route.

Construction and maintenance cost The alignment of the line should be so chosen that the construction cost is minimum. This can be achieved by a balanced cut and fill of earthwork, minimizing rock cutting and drainage crossings by locating the alignment on watershed lines, and such other technical considerations. Maintenance costs can be reduced by avoiding steep gradients and sharp curves, which cause heavy wear and tear of rails and rolling stock.

Minimum operational expenses The alignment should be such that the operational or transportation expenses are minimum. This can be done by maximizing the haulage of goods with the given power of the locomotive and traction mix. This can he achieved by providing easy gradients, avoiding sharp curves, and adopting a direct route.

Maximum Safety and Comfort

The alignment should be such that it provides maximum safety and comfort to the travelling public. This can be achieved by designing curves with proper transition lengths, providing vertical curves for gradients, and incorporating other such technical features.

Aesthetic Considerations

While deciding the alignment, aesthetic aspects should also be given due weightage. A journey by rail should be visually pleasing. This can be done by avoiding views of borrow pits and passing the alignment through natural and beautiful surroundings with scenic beauty.

TYPES OF RAILS

The rails used in the construction of railway track are of following types:

1. Double headed rails(D.H. Rails)
2. Bull headed rails(B.H.Rails)
3. Flat footed rails(F.F.Rails)

DOUBLE HEADED RAILS

The rail sections, whose foot and head are of same dimensions, are called Double headed or Dumb-bell rails. In the beginning, these rails were widely used in the railway track. The idea behind using these rails was that when the head had worn out due to rubbing action of wheels, the rails could be inverted and reused. But by experience it was found that their foot could not be used as running surface because it also got corrugated under the impact of wheel loads. This type of rail is not in use in Indian Railways now-a days.

BULL HEADED RAILS

The rail section whose head dimensions are more than that of their foot are called bull headed rails. In this type of rail the head is made little thicker and stronger than the lower part by adding more metal to it. These rails also require chairs for holding them in position. Bull headed rails are especially used for making points and crossings.

MERITS

(i) B.H. Rails keep better alignment and provide more smoother and stronger track.

(ii) These rails provide longer life to wooden sleepers and greater stability to the track.

(iii) These rails are easily removed from sleepers and hence renewal of track is easy.

DEMERITS

(i) B.H. rails require additional cost of iron chairs.

(ii) These rails require heavy maintenance cost.

(iii) B.H. rails are of less strength and stiffness.

FLAT FOOTED RAILS

The rail sections having their foot rolled to flat are called flat footed or vignole`s rails. This type of rail was invented by Charles Vignole in 1836. It was initially thought that the flat footed rails could by fixed directly to wooden sleepers and would eliminate chairs and keys required for the B.H. rails. But later on, it was observed that heavy train loads caused the foot of the rail to sink into the sleepers and making the spikes loose. To remove this defect, steelbearing plates were used in between flat footed rails and the wooden sleeper. These rails are most commonly used in India. Fig.4.3 shows flat footed rail.

MERITS

(i) F.F. rails have more strength and stiffness.

(ii) No chairs are required for holding them in position.

(iii) These rails require less number of fastenings.

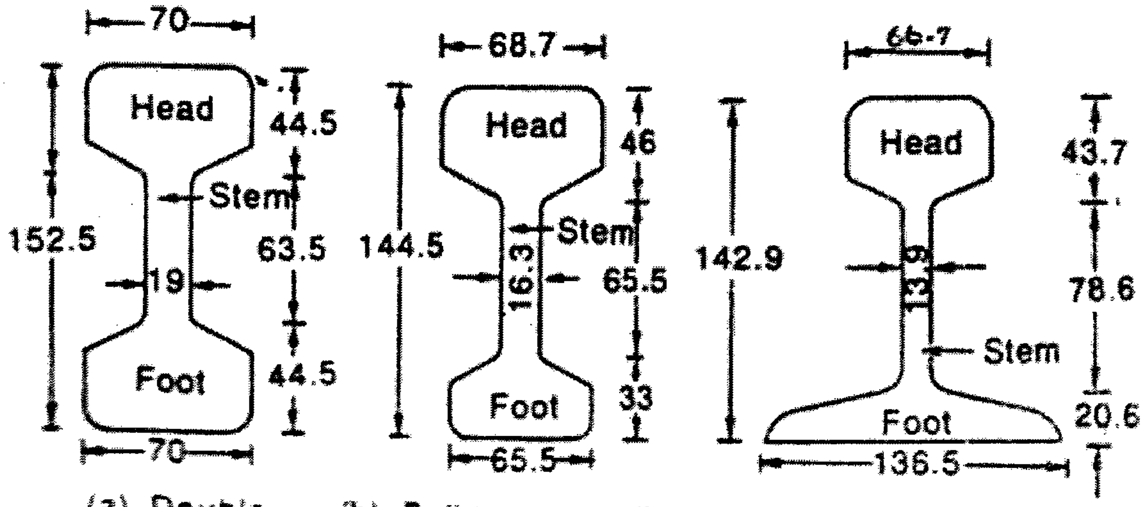
(iv) The maintenance cost of track formed with F.F. rails is less.

DEMERITS

(i) The fittings get loosened more frequently.

(ii) These rails are not easily removed and hence renewal of track becomes difficult.

(iii) It is difficult to manufacture points and crossings by using these rails.



(a) Double-headed rail (b) Bull headed rail (c) Flat footed rail

(All dimensions are in mm)

Creep of rails : Creep in rail is defined as the longitudinal movement of the rails in the track in the direction of motion of locomotives. Creep is common to all railways and its value varies from almost nothing to about 6 inches or 16cm.

Theories for the Development of Creep

Various theories have been put forward to explain the phenomenon of creep and its causes, but none of them have proved to be satisfactory. The important theories are briefly discussed in the following subsections.

1 Wave Motion Theory

According to wave motion theory, wave motion is set up in the resilient track because of moving loads, causing a deflection in the rail under the load. The portion of the rail immediately under the wheel gets slightly depressed due to the wheel load.

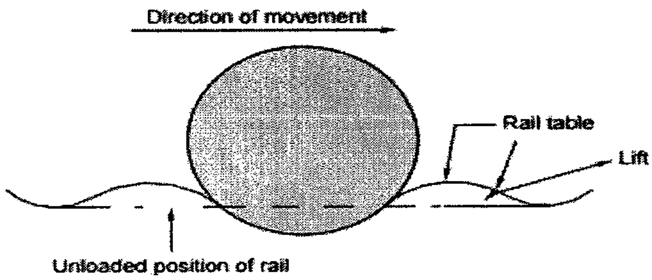


Fig. 11.1 Wave motion theory for development of creep

Therefore, the rails generally have a wavy formation. As the wheels of the train move forward, the depressions also move with them and the previously depressed portion springs back to the original level. This wave motion tends to move the rail forward with the train. The ironing effect of the moving wheels on the wave formed in the rail causes a longitudinal movement of the rail in the direction of traffic resulting in the creep of the rail

2.Percussion Theory

According to percussion theory, creep is developed due to the impact of wheels at the rail end ahead of a joint. As the wheels of the moving train leave the trailing rail at the joint, the rail gets pushed, forward causing it to move longitudinally in the direction of traffic, and that is how creep develops.

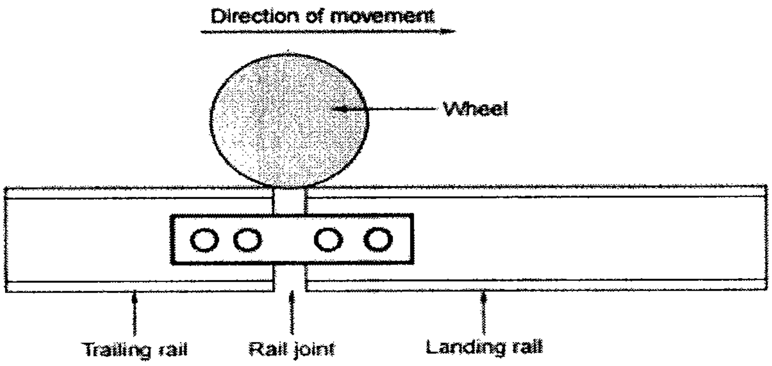


Fig. 11.2 Percussion theory for development of creep

Though the impact of a single wheel may be nominal, the continuous movement of several of wheels passing over thc joint pushes the facing or landing rail forward, thereby causing creep

3.Drag Theory

According to drag theory, the backward thrust of the driving wheels of a locomotive has the tendency to push the rail backwards, while the thrust of the other wheels of the locomotive pushes the rail in the direction in which the locomotive is moving. This results in the longitudinal movement of the rail in the direction of traffic, thereby causing creep.

Measurement of Creep

Creep can be measured with the help of a device called creep indicator. It consists of two creep posts, which are generally rail pieces that are driven at 1-km intervals on either side of the track.

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Creep can be measured with the help of a device called creep indicator. It consists of two creep posts, which are generally rail pieces that are driven at 1-km intervals on either side of the track. For the purpose of easy measurement, their top level is generally at the same level as the rail. Using a chisel, a mark is made at the side of the bottom flange of the rail on either side of the track. A fishing string is then stretched between the two creep posts and the distance between the chisel mark and the string is taken as the amount of creep.

According to the prescribed stipulations, creep should be measured at intervals of about three months and noted in a prescribed register, which is to be maintained by the the permanent way inspector (PWI). Creep in excess of 150 mm (6 in.) should not be permitted on any track and not more than six consecutive rails should be found jammed in a single-rail track at one location. There should be no creep in approaches to points and crossings.

Adjustment of Creep

When creep is in excess of 150 mm resulting in maintenance problems, the same should be adjusted by pulling the rails back. This work is carried out after the required engineering signals have been put up and the necessary caution orders given. The various steps involved in the adjustment of creep are follows.

1. A careful survey of the expansion gaps and of the present position of rail joints is carried out
2. The total creep that has been proposed to be adjusted and the correct expansion gap that is to be kept are decided in advance.
3. The fish plates at one end are loosened and those at the other end are removed. Sleeper fittings, i.e., spikes or keys, are also loosened or removed.
4. The rails are then pulled back one by one with the help of a rope attached to a hook. The pulling back should be regulated in such a way that the rail joints remain central and suspended on the joint sleepers.
5. The pulling back of rails is a slow process since only one rail is dealt with at a time and can be done only for short isolated lengths of a track. Normally, about 40-50 men are required per kilometre for adjusting creep.
6. When creep is required to be adjusted for longer lengths, five rail lengths are tackled at a time. The procedure is almost the same as the preceding steps except that instead of pulling the rails with a rope, a blow is given to them using a cut rail piece of a length of about 5 m.

Creep Adjuster

A creep adjuster is normally used when extensive work is involved. The creep adjuster is set at the centre of the length of the track, to be tackled, with the wide joints behind it and the jammed joints ahead of it. The following steps are adopted.

1. Expansion liners of the correct size are put in all the expansion gaps.
2. All the keys on this side of the creep adjuster are removed and all fish bolts loosened.
3. The creep adjuster is then used to close up the gaps to the required extent by pushing the rails forward. A gap of a few inches is left behind between the rail ends opposite the adjuster.
4. The corrected rails are then fastened with keys. After that, the rails on the other side of the adjuster are tackled.
5. The operation leaves some of the expansion gaps too wide which are tackled by the creep adjuster when it is set in the next position.
6. The corrected rails are then fastened and the adjuster is shifted to the new position.
7. The whole process is repeated again and again till the requisite attention has been paid to the entire length of the rail. In the end it may be necessary to use a rail with the correct size of closure (bigger or smaller) to complete the work.

Portions of Track Susceptible to Creep

The following locations of a track are normally more susceptible to creep.

(a) The point where a steel sleeper track or CST-9 sleeper track meets a wooden sleeper track
(b) Dips in stretches with long gradients
(c) Approaches to major girder bridges or other stable structures
(d) Approaches to level crossings and points and crossings

Measures to Reduce Creep

To reduce creep in a track, it should be ensured that the rails are held firmly to the sleepers and that adequate ballast resistance is available. All spikes, screws, and keys should be driven home. The toe load of fastenings should always be slightly more than the ballast resistance. Creep anchors can effectively reduce the creep in a track. At least eight of these must be provided per panel. Out of the large number of creep anchors tried on Indian Railways, the 'fair T' and 'fair V' anchors, have been standardized for use. The fair 'V' anchor, which is more popular, is shown in Fig. 11.3. The creep anchor should fit snugly against the sleeper for it to be fully effective. The following measures are also helpful in reducing creep.

(a) The track should be well maintained-sleepers should be properly packed and the crib and shoulder ballast should be well compacted.
(b) A careful lookout should be kept for jammed joints that exist in series. In the case of a fish-plated track, more than six consecutive continuously jammed joints should not be permitted. In the case of SWR tracks, more than two consecutive jammed joints should not be permitted at rail temperatures lower than the maximum daily temperature (tm) in the case of zones I and II and lower than (tm - 5 o C) in the case of zones III and IV. Regular adjustment may be necessitated on girder bridges.

Coning of Wheels : The tread of the wheels of a railway vehicle is not made flat, but sloped like a cone in order to enable the vehicle to move smoothly on curves as well as on straight tracks. The wheels are generally centrally aligned on a straight and level surface with uniform gauge, and the circumference of the treads of the inner and outer wheels are equal

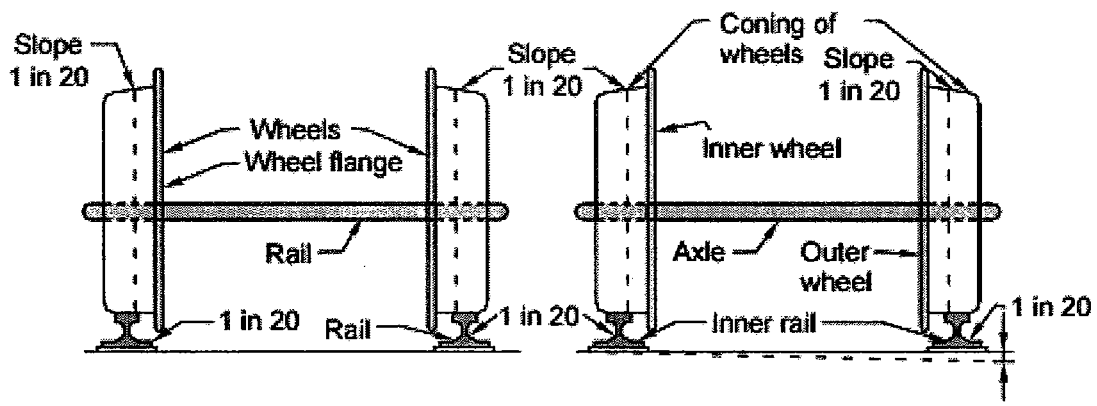

Fig. 5.6 Coning of wheels

The problem, however, arises in the case of a curve, when the outer wheel has to negotiate more distance on the curve as compared to the inner wheel. Due to the action of centrifugal force on a curve, the vehicle tends to move out. To avoid this the circumference of the tread of the outer wheel is made greater than that of the inner wheel. This helps the outer wheel to travel a longer distance than the inner wheel.The wheels of a railway vehicle are connected by an axle, which in turn is fixed on a rigid frame. Due to the rigidity of the frame, the rear axle has a tendency to move inward, which does not permit the leading axle to take full advantage of the coning. The rigidity of the frame, however, helps to bring the vehicle back into central alignment and thus works as a balancing factor.

The coning of wheels helps to keep the vehicle centrally aligned on a straight and level track also. Slight irregularities in the track do occur as a result of moving loads and the vagaries of the weather. The wheels, therefore, move from side to side and therefore the vehicles sway. Due to the coning of wheels, this side movement results in the tread circumference of one wheel increasing over the other. As both the wheels have to traverse the same distance, this causes one wheel to slide. Due to the resistance caused by the sliding, any further side movement is prevented. If there was no coning, the side movement would have continued and the flange of the wheel would have come in contact with the side of the rail, causing jerks and making the ride uncomfortable.

Coning of wheels causes wear and tear due to the slipping action. It is, however, useful as

(a) it helps the vehicle to negotiate a curve smoothly,

(b) it provides a smooth ride, and

(c) it reduces the wear and tear of the wheel flanges.

As far as the slip is concerned, it can be mathematically calculated as follows.

$$\text{Slip} = \frac{2\pi\theta}{360} G \qquad (5.10)$$

the angle at the centre of the curve fixed by the rigid wheel box and G is the gauge in metres.The approximate value of the slip for broad gauge is 0.029 metre per degree of the curve.

Tilting of Rails : Rails are tilted inward at an angle of 1 in 20 to reduce wear and tear on the rails as well as on the tread of the wheels. As the pressure of the wheel acts near the inner edge of the rail, there is heavy wear and tear of the rail. Lateral bending stresses are also created due to eccentric loading of rails. Uneven loading on the sleepers is also likely to cause them damage. To reduce wear and tear as well as lateral stresses, rails are titled at a slope of 1 in 20, which is also the slope of the wheel cone. The rail is tilted by 'adzing' the wooden sleeper or by providing canted bearing plates.

Standard Rail Section: The rail is designated by its weight per unit length. In FPS units, it is the weight in lbs per yard and in metric units it is in kg per metre. A 52 kg/m rail denotes that it has a weight of 52 kg per metre. The weight of a rail and its section is decided after considerations such as the following:

(a) Heaviest axle load

(b) Maximum permissible speed

(c) Depth of ballast cushion

(d) Type and spacing of sleepers

(e) Other miscellaneous factors

The standard rail sections in use on Indian Railways are 60 kg, 52 kg, 90 R, 75 R, 60 R and 50 R. The two heavier rail sections, 60 kg and 52 kg, were recently introduced and are designated in metric units. Other rails are designed as per the revised British Standard specifications and are designated in FPS units though their dimensions and weight are now in metric units. In the nomenclature 90 R, 75 R, etc., R stands for revised British specifications.

Every rail rolled has a brand on its web, which is repeated at intervals. As per IRS-T-12-88, the brand marks are as follows:

IRS-52 kg - 710 - TISCO - II 1991 OB

The definitions for the various abbreviations are as follows:

(a) IRS-52-kg: Number of IRS rail section, i.e., 52 kg

(b) 710: Grade of rail section, i.e., 710 or 880

(c) TISCO: Manufacturer's name, e.g., Tata Iron and Steel Co.

(d) II 1991: Month and year of manufacture (February 1991)

(e) -> : An arrow showing the direction of the top of the ingot

(f) OB: Process of steel making, e.g., open hearth basic (OB)

Table 6.1 Standard rail sections

Gauge	*Rail section*	*Type of section*	*Rail length*
Broad gauge	60 kg/m	UIC	13 m (42 ft as per old standards)
	52 kg/m	IRS	
	90 lb/yd	RBS	
Metre gauge	90 lb/yd	RBS	12 m (39 ft as per old standards), except 90-lb rails, which are of 13 m length
	75 lb/yd	RBS	
	60 lb/yd	RBS	
Narrow gauge	50 lb/yd	RBS	12 m (39 ft as per old standards)

UIC-International Union of Railways, IRS-Indian Railway Standard, RBS-Revised British Standard. Detailed dimensions of standard rail sections are shown in Fig. 6.4 and Table 6.2.

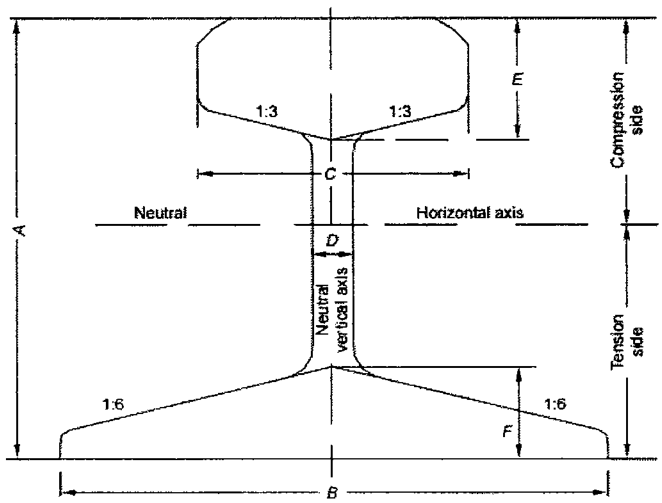

Fig. 6.4 Standard flat-footed rail section

Table 6.2 Details of standard rail sections

Rail section	*Wt/ metre (kg)*	*Area of section (mm^2)*	*Dimensions (mm)*					
			A	*B*	*C*	*D*	*E*	*F*
50 R	24.80	3168	104.8	100.0	52.4	9.9	32.9	15.1
60 R	29.76	3800	114.3	109.5	57.2	11.1	35.7	16.7
75 R	37.13	4737	128.6	122.2	61.9	13.1	39.7	18.7
90 R	44.61	5895	142.9	136.5	66.7	13.9	43.7	20.6
52 kg (IRS)	51.89	6615	156.0	136.0	67.0	15.5	51.0	29.0
60 kg (UIC)	60.34	7686	172.0	150.0	74.3	16.5	51.0	31.5

Weight of rails

Maximum axle load = 560 * sectional weight of rail in lbs per yard or kg per metre

For rails of 90 lbs per yard,

Maximum axle load = 560 * 90 lbs = 50,400 lbs or 22.5 t For rails of 52 kg per m,

Maximum axle load = 560 * 52 kg = 29.12 t

The length of a rail is, however, restricted due to the following factors.

(a) Lack of facilities for transport of longer rails, particularly on curves.

(b) Difficulties in manufacturing very long rails.

(c) Difficulties in acquiring bigger expansion joints for long rails.

(d) Heavy internal thermal stresses in long rails.

Taking the above factors into consideration, Indian Railways has standardized a rail length of 13 m (previously 42 ft) for broad gauge and 12 m (previously 39 ft) for MG and NG tracks. Indian Railways is also planning to use 26 m, and even longer, rails in its track system.

90 UTS Rails: Indian Railways has mostly been using medium manganese rails with an ultimate tensile strength (UTS) of 72 kg/mm^2 manufactured by the Bhilai steel plant. The service life of 52 kg (72 UTS) rails is only about 350 GMT. On a section with an annual traffic density of about 20 GMT, the renewal cycle is just about 17-18 years, which is rather short as compared to the service life of 50 years of a concrete sleeper. Moreover, such rails wear faster on curves and gradient sections.In view of the above considerations, Indian Railways has been importing 52-kg and 90 R, 90 UTS rails for some time. These rails have the following main advantages.

1. The service life of 90 UTS rails is about 50% more than that of conventional medium manganese 72 UTS rails.

2. The total GMT that 72 and 90 UTS rails can carry during their primary service life is as follows:

52 kg (72 UTS): 350 GMT

52 kg (90 UTS): 525 GMT

60 kg (90 UTS): 900 GMT

3. 90 UTS rails are more resilient against wear and have a hardness of about 270 BHN (Brinell hardness number) as against that of 220 BHN of medium manganese rails with 72 UTS. The allowable shear stress of 90 UTS rails is much higher, as can be seen from the comparative figures given below:

Rails Allowable shear stress

Medium manganese rails (72 UTS) 18.0 kg/mm^2

Wear-resistant rails (90 UTS) 22.5 kg/mm^2

Studies have shown that the maximum shear stress due to BOX N wagons could be of the order of 20.0 kg/mm^2, which is in excess of the permissible shear stress for medium manganese 72 UTS rails. Therefore, for routes on which BOX N wagons are running, it is desirable to have 90 UTS rails.

End-hardened rails These are rails with ends that are hardened by oil or water quenching. The wear and tear and end batter of such rails is considerably less.

Head-hardened rails These are rails with heads that have been hardened by passing them through a thermal treatment plant. The head is hardened for a depth of about 12 mm from the surface. Head hardened rails have a longer service life that extends up to 2-3 times more compared to as ordinary medium manganese rails.

The chemical composition of head-hardened steel (grade 1080) is prescribed as given in Table 6.9 **Table 6.9** Chemical composition of head-hardened rail

Table 6.9 Chemical composition of head-hardened rail

Item	*Carbon*	*Manganese*	*Silicon*	*Sulphur*	*Phosphorus*
Limit of values	0.72–0.82	0.75–1.05	0.05–0.30	0.035 max.	0.035 max.

Rail Wear

Due to the passage of moving loads and friction between the rail and the wheel, the rail head gets worn out in the course of service. The impact of moving loads, the effect of the forces of acceleration, deceleration, and braking of wheels, the abrasion due to rail-wheel interaction, the effects of weather conditions such as changes in temperature, snow, and rains, the presence of materials such as sand, the standard of maintenance of the track, and such allied factors cause considerable wear and tear of the vertical and lateral planes of the rail head. Lateral wear occurs more on curves because of the lateral thrust exerted on the outer rail by centrifugal force. A lot of the metal of the rail head gets worn out, causing the weight of the rail to decrease. This loss of weight of the rail section should not be such that the stresses exceed their permissible values. When such a stage is reached, rail renewal is called for.

In addition, the rail head should not wear to such an extent that there is the possibility of a worn flange of the wheel hiting the fish plate.

1 Type of Wear on Rails

A rail may face wear and tear in the following positions:

(a) on top of the rail head (*vertical wear*)
(b) on the sides of the rail head (*lateral wear*)
(c) on the ends of the rail (*battering of rail ends*)

Wear is more prominent at some special locations of the track. These locations are normally the following:

(a) on sharp curves, due to centrifugal forces
(b) on steep gradients, due to the extra force applied by the engine
(c) on approaches to railway stations, possibly due to acceleration and deceleration
(d) in tunnels and coastal areas, due to humidity and weather effects

2 Measurement of Wear

Wear on rails can be measured using any of the following methods.

(a) By weighing the rail
(b) By profiling the rail section with the help of lead strips
(c) By profiling the rail section with the help of needles
(d) By using special instruments designed to measure the profile of the rail and record it simultaneously on graph paper

3 Methods to Reduce Wear

Based on field experience, some of the methods adopted to reduce vertical wear and lateral wear on straight paths and curves are indicated below.

(a) Better maintenance of the track to ensure good packing as well as proper alignment and use of the correct gauge
(b) Reduction in the number of joints by welding
(c) Use of heavier and higher UTS rails, which are more wear resistant
(d) Use of bearing plates and proper adzing in case of wooden sleepers
(e) Lubricating the gauge face of the outer rail in case of curves
(f) Providing check rails in the case of sharp curves
(g) Interchanging the inner and outer rails
(h) Changing the rail by carrying out track renewal

4 Rail End Batter

The hammering action of moving loads on rail joints batters the rail ends in due course of time. Due to the impact of the blows, the contact surfaces between the rails and sleepers also get worn out, the ballast at places where the sleepers are

joined gets shaken up, the fish bolts become loose, and all these factors further worsen the situation, thereby increasing rail end batter.

Rail end batter is measured as the difference between the height of the rail at the end and at a point 30 cm away from the end. If the batter is up to 2 mm, it is classified 'average', and if it is between 2 and 3 mm, it is classified as 'severe'. When rail end batter is excessive and the rail is otherwise alright, the ends can be cropped and the rail reused.

Rail wear and the battering of rail ends are the two major defects in rails. However, some other types of defects may also develop in a rail and necessitate its removal in extreme cases. These are described below.

Hogging of rails

Rail ends get hogged due to poor maintenance of the rail joint, yielding formation, loose and faulty fastenings, and other such reasons. Hogging of rails causes the quality of the track to deteriorate. This defect can be remedied by measured shovel packing. (For details, refer to Chapter 20.)

Scabbing of rails

the scabbing of rails occurs due to the falling of patches or chunks of metal from the rail table. Scabbing is generally seen in the shape of an elliptical depression, whose surface reveals a progressive fracture with numerous cracks around it.

Wheel burns

Wheel burns are caused by the slipping of the driving wheel of locomotives on the rail surface. As a consequence, extra heat is generated and the surface of the rail gets affected, resulting in a depression on the rail table. Wheel burns are generally noticed on steep gradients or where there are heavy incidences of braking or near water columns.

Shelling and black spots

Shelling is the progressive horizontal separation of metal that occurs on the gauge side, generally at the upper gauge corner. It is primarily caused by heavy bearing pressure on a small area of contact, which produces heavy internal shear stresses.

Corrugation of rails

Corrugation consists of minute depressions on the surface of rails, varying in shape and size and occurring at irregular intervals. The exact cause of corrugation is not yet known, though many theories have been put forward. The factors which help in the formation of rail corrugation, however, are briefly enumerated here.

(a) Metallurgy and age of rails

(i) High nitrogen content of the rails

(ii) Effect of oscillation at the time of rolling and straightening of rails.

(b) Physical and environment conditions of track

(i) Steep gradients
(ii) Yielding formation
(iii) Long tunnels
(iv) Electrified sections
(c) Train operations
(i) High speeds and high axle loads
(ii) Starting locations of trains
(iii) Locations where brakes are applied to stop the train
(d) Atmospheric effects
(i) High moisture content in the air particularly in coastal areas
(ii) Presence of sand

Functions and Requirements of Sleepers

The main functions of sleepers are as follows.

(a) Holding the rails in their correct gauge and alignment
(b) Giving a firm and even support to the rails
(c) Transferring the load evenly from the rails to a wider area of the ballast
(d) Acting as an elastic medium between the rails and the ballast to absorb the blows and vibrations caused by moving loads
(e) Providing longitudinal and lateral stability to the permanent way
(f) Providing the means to rectify the track geometry during their service life. Apart from performing these functions the ideal sleeper should normally fulfil the following requirements.

(a) The initial as well as maintenance cost should be minimum.
(b) The weight of the sleeper should be moderate so that it is convenient to handle.
(c) The designs of the sleeper and the fastenings should be such that it is possible to fix and remove the rails easily.
(d) The sleeper should have sufficient bearing area so that the ballast under it is not crushed.
(e) The sleeper should be such that it is possible to maintain and adjust the gauge properly.
(f) The material of the sleeper and its design should be such that it does not break or get damaged during packing.
(g) The design of the sleeper should be such that it is possible to have track circuiting.
(h) The sleeper should be capable of resisting vibrations and shocks caused by the passage of fast moving trains.

(i) The sleeper should have anti-sabotage and anti-theft features.
(ii) Sleeper Density and Spacing of Sleepers

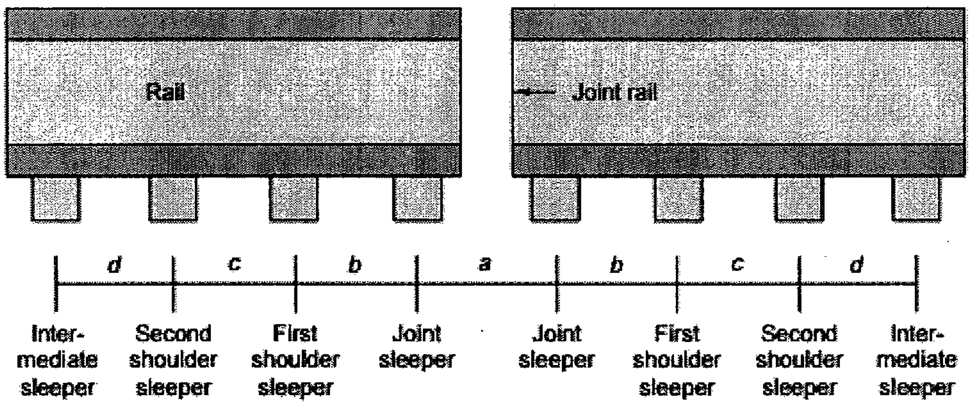

Fig. 7.1 Spacing of sleepers on a fish-plated track

Sleeper density is the number of sleepers per rail length. It is specified as M + x or N + x, where M or N is the length of the rail in metres and x is a number that varies according to factors such as (a) axle load and speed, (b) type and section of rails, (c) type and strength of the sleepers, (d) type of ballast and ballast cushion, and (e) nature of formation.

Sleeper Density and Spacing of Sleepers : Sleeper density is the number of sleepers per rail length. It is specified as $M + x$ or $N + x$, where M or N is the length of the rail in metres and x is a number that varies according to factors such as (a) axle load and speed,

(b) type and section of rails,

(c) type and strength of the sleepers,

(d) type of ballast and ballast cushion, and

(e) nature of formation.

If the sleeper density is $M + 7$ on a broad gauge route and the length of the rail is 13 m, it means that 13 + 7 = 20 sleepers will be used per rail on that route. The number of sleepers in a track can also be specified by indicating the number of sleepers per kilometre of the track. For example, 1540 sleepers/km. This specification becomes more relevant particularly in cases where rails are welded and the length of the rail does not have much bearing on the number of sleepers required. This system of specifying the number of sleepers per kilometre exists in many foreign countries and is now being adopted by Indian Railways as well. The spacing of sleepers is fixed depending upon the sleeper density. Spacing is not kept uniform throughout the rail length. It is closer near the joints because of the weakness of the joints and impact of moving loads on them. There is, however, a limitation to the close spacing of the sleepers, as enough space is required for working the beaters that are used to pack the joint

Table 5.1 Track structure for BG system of IR (W—wooden sleeper, ST—steel sleeper, SD—sleeper density, PRC—prestressed concrete)

*Traffic density (GMT)**	*Route*						
	A	*B*	*C*	*D spl*	*D*	*E spl*	*E*
Rail section							
> 20†	60 kg	60 kg	60 kg	60 kg	60 kg	60 kg	60 kg
10–20	60 kg	60 kg	60 kg	60 kg	52 kg/90	60 kg	52 kg/90‡
5–10	60 kg	52/90¶	52/90	52/90	52/90	52/90	52/90
Under 5	52/90	52/90	52/90	52/90 or 60 kg (SH)	52/90 or 60 kg (SH)	52/90 or 60 kg (SH)	52/90§ (SH) or 60 kg (SH)
Number of sleepers per km							
>20**	1660	1660	1660	1660	1660	1660	1540
10–20	1660	1540	1540	1660	1540	1660	1540
< 10	1660	1540	1540	1660	1540	1660	1310††
Sleeper, fastening, and ballast							
Type of sleeper fastening	PRC, W and ST EF‡‡	PRC, W and ST EF	PRC and W EF	PRC EF	PRC, W, ST¶¶ existing standard	PRC EF	PRC, W, ST¶¶ existing standard
Loop lines and sidings							
Loop	Rails§§	52 kg	(SH)	Sleepers	PRC, ST and W	SD 1310	
	Rails	52 kg	(SH and T-18)	Sleepers	PRC and ST	SD 1310	
Ballast	300	300/250	300	300	300/200	300	300/200

* GMT stands for gross million tonnes per km/annum.

† 60-kg rails are to be used on all routes identified for carrying 22 t axle load wagons.

‡ The existing 90 R rails may be allowed to remain for speeds not exceeding 110 km/h.

¶ 52/90 represents 52 kg/90 UTS (ultimate tensile strength) rail section.

§ Second-hand 52-kg rails may be used on a case-to-case basis, with the prior approval of the Railway Board, depending upon the quality of released rails available.

** For routes identified for running 22.1 t axle load wagons, a sleeper density of 1660 per km should be maintained.

†† Where primary renewals are undertaken and there is potential for LWR tracks, sleeper density may be kept as 1540.

‡‡ EF stands for elastic fastening.

¶¶ CST-9 sleepers can also be provided as an interim measure.

§§ Head-hardened rails should be used for (i) local lines where there is an EMU stock running, (ii) sections with gradients steeper than 1 in 150 and/or curves sharper than 2°, and (iii) locations where the rate of wear of rails necessitates rail renewal at a frequency of 10 years or so. These rails should be laid on continuous and long stretches.

sleepers. The standard spacing specifications adopted for a fish-plated track on Indian Railways are given in Table 7.1. The notations used in this table are explained in Fig. 7.1.

Now-a-days sleeper density is also indicated in terms of the number of sleepers/km. The sleeper spacing required for various sleeper densities is given in Table 7.2.

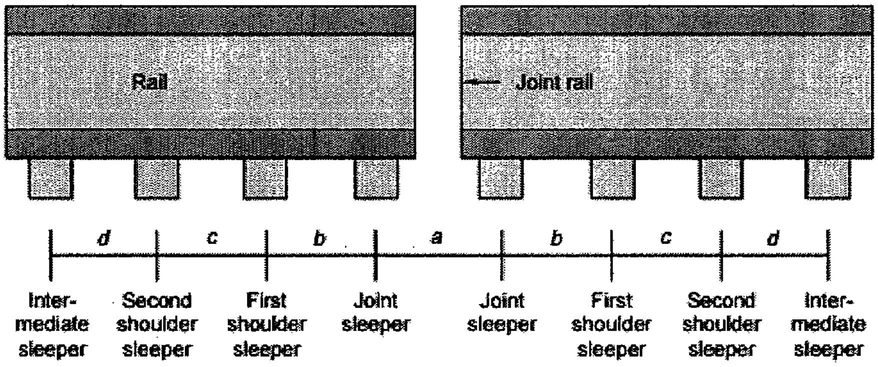

Fig. 7.1 Spacing of sleepers on a fish-plated track

Table 7.2 Spacing of sleepers for welded track

No. of sleepers per km	*Exact centre-to-centre spacing required as per calculation (mm)*	*Centre-to-centre spacing to be provided in the field (mm)*	
		LWR track	*SWR track*
1660	602.4	600	-
1540	649.3	650	660
1310	763.3	-	780

Types of Sleepers

The sleepers mostly used on Indian Railways are (i) wooden sleepers, (ii) cast iron (CI) sleepers, (ii) steel sleepers, and (iv) concrete sleepers. Table 7.3 compares the important characteristics of these types.

Wooden

Characteristics

Service life (years) : 12-15

Weight of sleeper for BG (kg) : 83

Handling : Manual handling; no damage to sleeper while handling

Type of maintenance : Manual or mechanized

Cost of maintenance : High

Gauge adjustment : Difficult

SteelCharacteristics

Service life (years) : 40-50

Weight of sleeper for BG (kg) : 79

Handling : Manual handling; no damage to sleeper while handling

Type of maintenance : Manual or mechanized

Cost of maintenance : Medium
Gauge adjustment : Easy

ClCharacteristics

Service life (years) : 40-50
Weight of sleeper for BG (kg) : 87
Handling : Manual handling; liable to break by rough handling
Type of maintenance : Manual
Cost of maintenance : Medium
Gauge adjustment : Easy

ConcreteCharacteristics

Service life (years) : 50-60
Weight of sleeper for BG (kg) : 267
Handling : No manual handling; gets damaged by rough handling
Type of maintenance : Mechanized only
Cost of maintenance : Low
Gauge adjustment : No gauge

Wooden Sleepers : The wooden sleeper is the most ideal type of sleeper, and its utility has not decreased with the passage of time. The wooden sleeper has the following features.

Specifications The size of a wooden sleeper should be economical. It should provide the desired strength to the sleeper as a beam as well as adequate bearing area. The depth of a sleeper governs its stiffness as a beam and its length and width control the necessary bearing area. The bearing length under each rail seat is 92 cm (3 ft) for a BG wooden sleeper, thereby giving an area of 2325 cm^2 under each rail seat. The sizes of sleepers used for BG, MG, and NG as well as the bearing area per sleeper are given in Table 7.4.

Table 7.4 Sizes of wooden sleepers and bearing areas

Table 7.4 Sizes of wooden sleepers and bearing areas

Gauge	*Size (cm)*	*Bearing area per sleeper (m^2)*
BG	275 × 25 × 13	0.465
MG	180 × 20 × 11.5	0.3098
NG	150 × 18 × 11.5	0.209

Wooden sleepers required for bridges, points, and crossings are of a thicker section-25 cm 15 cm or 25 cm , 18 cm.

Composite sleeper index The composite sleeper index (CSI), which evolved from a combination of the properties of strength and hardness, is an index used to determine the suitability of a particular timber for use as a sleeper from the point of view of mechanical strength.

The CSI is given by the formula

$$CSI = \frac{S + 10H}{20} \quad (7.1)$$

where S is the figure for the general strength for both green and dry timber at 12% moisture content and H is the figure for the general hardness for both green and dry timber at 12% moisture content. The minimum CSI prescribed on Indian Railways are the following.

Type of sleeper	Minimum CSI
Track sleeper	783
Crossing sleeper	1352
Bridge sleeper	1455

Bearing plates are invariably used on sleepers with a CSI value of 82 or less. The CSI values for some of the timber species recommended by Indian Railways for making sleepers are as follows.

Sal	112
Teak	82
Deodar	63
Chir	54

Wooden sleepers have the following main advantages and disadvantages.

Advantages

(a) Cheap and easy to manufacture
(b) Absorbs shocks and bears a good capacity to dampen vibrations; therefore, retains the packing well
(c) Easy handling without damage
(d) Suitable for track-circuited sections
e) Suitable for areas with yielding formations
(f) Alignment can be easily corrected
(g) More suitable for modern methods of maintenance
(h) Can be used with or without stone ballast
(i) Can be used on bridges and ashpits also
(j) Can be used for gauntleted track

Disadvantages

(a) Lesser life due to wear, decay, and attack by vermin
(b) Liable to mechanical wear due to beater packing
(c) Difficult to maintain the gauge
(d) Susceptible to fire hazards
(e) Negligible scrap value

At present wooden sleepers are being procured from the State Forest Departments. A detailed inspection of sleepers is done at the time of procurement to ensure that the sleepers accepted are of good quality and free from defects. The main defects normally found in sleepers are

(a) Centre heart
(b) Presence of knots, warps, wanes, and shakes
(c) Split ends
(d) Twisted or cross grains

The normal service life of wooden sleepers in India is only about 15 years as against a much longer service life obtained on other advanced railways. The weather conditions, particularly the rains, humidity, etc., are responsible for the shorter life-span of these sleepers in India. A committee was appointed by the Railway Board in the year 1972 to examine the measures for increasing service life and improving the utilization of wooden sleepers. The main recommendations of this committee are as follows.

(a) Sleepers should be procured in nominated sleeper depots of the Railways. The inspection of sleepers should also be done by the Railways in addition to the Forest Department.

(b) The net retention of creosote and fuel oil (in the ratio of 1:1) for the sleeper should be a minimum of 8 lb/ft^3.

(c) Bearing plates and elastic fastenings as well as modern methods of maintenance such as measured shovel packing (MSP) and mechanical tamping should be progressively used with wooden sleepers to avoid damage to the sleepers and ensure a longer life for them. Bearing plates should be compulsorily used when traffic density exceeds 20 GMT on BG routes and 5 GMT on MG routes as well as on joint sleepers and on curves of radius 1,500 metre and sharper curves.

(d) Spike-killed sleepers should be systematically reconditioned.

(e) Track depots should be organized in each railway to undertake the operations of end-binding, adzing, and pre-boring of sleepers.

1 Durable and Non-durable Types of Sleepers

Wooden sleepers may be classified into two categories, durable and non-durable.

Durable type

Durable sleepers do not require any treatment and can be laid directly on the track. The Indian Railway Board has classified particular categories of sleepers as the durable type. These are sleepers produced from timbers such as teak, sal, nahor, rosewood, anjan, kongu, crumbogam kong, vengai, padauk, lakooch, wonta, milla, and crul.

Non-durable type

Non-durable sleepers require treatment before being put on the track. Non-durable sleepers are made of wood of trees such as chir, deodar, kail, gunjan, and jamun.

If a non-durable type of sleeper is put onto the track directly without any preservative treatment, the sleeper will decay in a very short time. If, however, such sleepers are treated before use, they last longer and their life is comparable to that of durable sleepers. Fir sleepers, however, have not provided good service and their use has been restricted to only those trunk routes and main lines where traffic density is not more than 10 GMT [gross million tonne(s) per km/annum]. The primary service life of a wooden sleeper is approximately as follows

Durable BG : 19 years MG : 31 years

Non-durable BG : 12.5 years MG : 15.5 years

2 Treated and Untreated Sleepers

Wooden sleepers are also sometimes classified as hard wood and soft wood sleepers depending upon the origin or species of the wood of which these are made. Broadly speaking, timber produced from trees with broad leaves is known as *hard wood* and that obtained from trees bearing long leaves is considered *soft wood.* Some of the hard wood varieties also require treatment before being used in the track. As per the recommendations of the committee, the use of the terms 'durable' and 'non-durable' as well as 'hard' and 'soft' should be done away with to avoid confusion. The committee recommended that for simplification and rationalization, wooden sleepers should be classified in two categories:

(a) 'U' or *Untreated sleepers* comprising of all the sleepers made of wood from naturally durable species.

(b) 'T' or *Treated sleepers* consisting of the rest of the sleepers.

Treatment of sleepers

Indian Railways has set up four sleeper treatment plants at the locations given below for treating non-durable sleepers:

Dhilwan (Punjab) in Northern Railways 1923

Naharkatia (Assam) in North Frontier 1928

Clutterbuckganj (UP) in North East 1955

Olvakot (Kerala) in Southern Railways 1957

All these plants utilize the pressure treatment process and the preservative is forced into the wood under pressure using any one of the following three methods.

Full cell (Bethell) process In the Bethell process, a cylinder loaded with the charge for about 300-400 sleepers is first subjected to a vacuum of 55-60 cm of mercury for 20-30 minutes by means of a vacuum pump. Hot creosote oil is then forced into the cylinder at a pressure of 150-180 psi at a temperature of 180 o F. This pressure is maintained for a period of 50-70 minutes till the desired amount of absorption is obtained. Thereafter, the pressure is reduced and the cylinder is drained off the creosote oil. A final vacuum of 55 cm of mercury is applied to free the timber of excess preservative. The whole process takes about 2-3 hours. This process is normally used when maximum retention of creosote oil is required for a particular type of sleeper such as that made of kail, deodar, fir, etc. At present this method is in use in Olvakot, Clutterbuckganj, and Dhilwan plants for various types of wood.

Empty cell (Rueping) process In the Rueping process, wooden sleepers loaded into the cylinder are first subjected to an initial air pressure of 3.5 to 5.25 kg/cm^2 for about 20-30 minutes. Afterwards, without reducing the pressure, hot creosote oil is forced into the cylinder at a temperature of 180 o C to 210 o C. The pressure is then raised to a value of 10.5-19.6 kg/cm^2 and maintained for a period of 20-30 minutes till the desired absorption is achieved. Finally, the pressure is released, the cylinder is drained off the creosote, and a final vacuum of 55 cm of mercury is created to drain off the excess preservative. The whole process of treatment takes about 2-3 hours per charge. This process is generally employed for treating porous timbers and is used in Dhilwan and Clutterbuckganj depots for chir sleepers. In this process, air in the cell is entrapped, thereby limiting the preservative to be absorbed by the sleeper to a certain extent.

Empty cell (Lowry) process In the Lowry process, the cylinder loaded with timber charge is filled and then subjected to a pressure of 180 lb, which is sufficient to ensure proper impregnation. The cylinder is then drained off and the timber subjected to a final vacuum of 55 cm of mercury for a period of 45 minutes or so. The air entrapped in the timber cells forces the excess preservative out. Preservative recovery is greater in this case than in the full cell process but is less than in the Rueping process. This process is used in the Naharkatia plant for very green species of timber.

Prophylactic treatment of sleepers Prophylactic treatment is given to the sleepers by using patent chemicals such as arsenic pentaoxide, copper sulphate, and potassium dichromate solution in water 1:3:4 wt (60%) to prevent infection at the forest head and in the treatment plant. This is necessary an as appreciable amount of time elapses in transferring the sleepers from the forest depots to the treatment plant.

Seasoning of sleepers

Wooden sleepers are seasoned to reduce the moisture content so that their treatment is effective. The Indian Standard code of practice for preservation of timber lays down that the moisture content in the case of sleepers to be treated by pressure treatment should not be more than 25%.

The seasoning of sleepers can be done by any one of the following processes.

Artificial seasoning in kiln This is a controlled method of seasoning the timber, normally used in the USA and other advanced countries, under conditions of temperature and relative humidity, which are in the range of natural air seasoning.

Boulton or boiling under vacuum process This is a process in which unseasoned wood is treated with hot preservative to remove the moisture content. This is adopted in the Naharkatia depot

Air seasoning This is the method adopted extensively for the seasoning of wooden sleepers in India. The sleepers are stacked in the timber yard and a provision is made for enough space for the circulation of air in between the sleepers. The sleepers are stacked in any one of the following ways:

(a) One and nine method (Fig. 7.2)
(b) Close crib method
(c) Open crib method (Fig. 7.3)

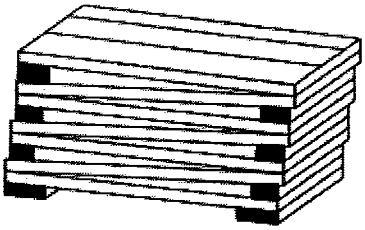

Fig.7.2 One and nine method

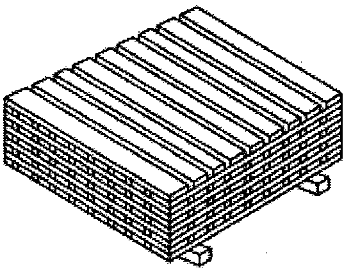

Fig. 7.3 Open crib method

Normally, the one and nine method is adopted on Indian Railways for stacking the sleepers. About 6 months are required to air season the timber fully by this method.

3 Laying of Wooden Sleepers

Great care should be taken in laying wooden sleepers. Untreated wooden sleepers should be laid with the sapwood side upwards and the heartwood side downwards so as to ensure minimum decay due to fungus, etc., attacking from below. More moisture would also percolate into the sleepers if laid otherwise. In the case of treated sleepers, however, the heartwood side is kept upwards and the sapwood side downwards. This is done because the sapwood side contains more creosote and is liable to less damage from vermin and fungus.

4 Adzing of Wooden Sleepers

In order to enable the rails to be slightly tilted inwards at a cant of 1 in 20, wooden sleepers are required to be cut to this slope at the rail seat before laying. This process of cutting the wooden sleeper at a slope of 1 in 20 is known as 'adzing of the wooden sleeper'.

It may be pointed out that adzing or cutting of a wooden sleeper at a slope of 1 in 20 is done with great care, otherwise the slope will vary from sleeper to sleeper resulting in a rough ride. The adzed surface of a wooden sleeper is treated with coal tar or creosote to ensure proper protection of the surface. Normally, adzing of a wooden sleeper is done only when bearing plates are not provided.

Steel Channel Sleepers

In view of the great shortage of wooden sleepers, steel channel sleepers have been developed by Indian Railways particularly for use on girder bridges. Steel channel sleepers can be used for welded plates, riveted plates, as well as open web girders.

Composite sleepers have been developed indigenously in India as a replacement for wooden sleepers. These are made from waste products such as used rubber tyres, and the manufacturers claim a lifespan of about 40 years for these sleepers. The Patel Group of Industries is one such firm that has developed these composite sleepers.

Composite sleepers are similar to wooden sleepers and use similar fittings. These sleepers are under trial and the results so far have been quite encouraging.

Steel Trough Sleeper

About 27% of the track on Indian Railways is laid on steel sleepers (Fig. 7.4). The increasing shortage of timber in the country and other economical factors are mainly responsible for the use of steel sleepers in India. Steel sleepers have the following main advantages/disadvantages over wooden sleepers.

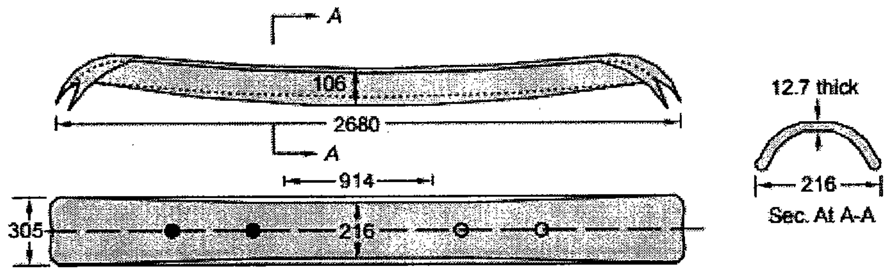

Fig. 7.4 Steel trough sleeper (BG 90 R)

Advantages

(a) Long life
(b) Easy to maintain gauge and less maintenance problems
(c) Good lateral rigidity
(d) Less damage during handling and transport
(e) Simple manufacturing process
(f) Very good scrap value
(g) Free from decay and attack by vermin
(h) Not susceptible to fire hazards

Disadvantages

(a) Liable to corrode
(b) Unsuitable for track-circuited areas
(c) Liable to become centre-bound because of slopes at the two ends
(d) Develops cracks on rail seats during service
(e) Design is rail specific

1 Design Features

The steel trough sleeper essentially consists of a rolled steel plate of about 2 mm thickness pressed into a suitable trough shape and the rail seat canted to 1 in 20. The ends of the rolled section are flattened out in the shape of a spade to retain the ballast. Two alternative types of sleepers have been designed for each rail section as per the following details.

1. In one type, the lugs or jaws are pressed out of the plate itself to accommodate the foot of the rail and the key (Fig. 7.5). There are several maintenance problems with these pressed up lugs, as they give way due to the movement of the keys as well as due to the vibrations and impact of the moving loads.

2. In order to obviate this defect, another sleeper design has been adopted. In this design, two holes are punched into either side of the plate to accommodate specially designed 'loose jaws' (Fig. 7.6). The rails are held with the help of two standard keys driven either into the pressed up lugs or into the loose jaws.

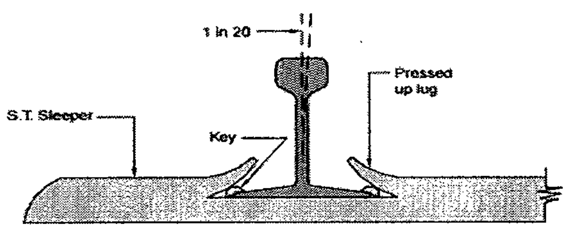

Fig. 7.5 ST sleeper with pressed up lugs

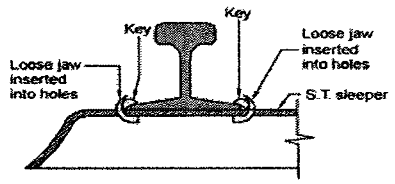

Fig. 7.6 Sleeper with losse jaws inserted into holes

The adjustment of the gauge to the extent of 3 mm is done by properly driving in the keys. In the double-line section, the keys are driven in the direction of the traffic. The approximate weight of a standard BG trough sleeper is 81 kg and that of an MG sleeper is 35 kg. The steel trough (ST) sleeper has an average life of about 50 years. It is an acceptable type of sleeper for use with long welded rails because of its lateral stability and its adaptability for use along with elastic fastenings.

2 Classification

All steel sleepers conforming to Indian Railways specifications T-9 are classified as first quality sleepers. The sleepers not accepted as first quality but free from the following defects are termed second quality steel trough sleepers.

(a) Inward tilt at rail seat beyond the limits of 1 in 15 to 1 in 25
(b) Sleepers with a twist
(c) Heavy scale fitting or deep grooves or cuts
(d) Deep guide marks at heads, blisters, etc.

All first quality sleepers are normally marked by a green dot. Sleepers that have been rejected as first quality sleepers on account of pipes, seams, and laps but are free from the defects indicated above are marked with a cross in yellow paint at the centre. All other second quality steel trough sleepers are marked distinctly with a 15-cm-wide strip of yellow paint at one end. Sleepers that are unfit as second quality are given a distinct red paint mark to avoid mixing them up with first and second quality sleepers during loading.

3 Maintenance Problems

It has been noticed that the keys used to fix rails on steel sleepers tend to become loose due to the bending of the pressed up lugs or due to wear at the rail seat. The holes also get elongated during service. Special types of shims and liners are provided in these cases to hold the gauge well. Mota Singh Liner is a very effective type of liner used for holding the correct gauge for oblong holes with loose jaws. Another maintenance problem with steel trough sleepers is that these tend to become centre-bound if due care is not taken while packing. The ballast is normally removed from the centre of the sleepers after packing so as to ensure that centre binding of the sleepers does not take place. Sometimes the alignment of steel sleeper tracks also gets affected by the overdriving of the keys.

Cast Iron Sleepers

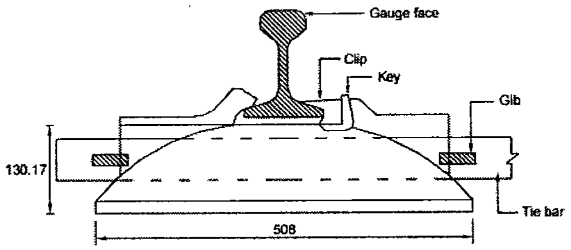

Fig. 7.7 CI pot sleeper (dimensions in mm)

Table 7.5 Details of CST-9 sleeper (Fig. 7.9)

Rail	*Gauge*	*RDSO drawing number*	*Wt (kg)*	*A (mm)*	*B (mm)*	*C (mm)*	*D (mm)*
52 kg	BG	T-478 (M)	43.55	800	330	140	89
90 R	BG	T-478 (M)	43.55	800	330	140	89
90 R	MG	T-2366	–	700	300	132	85
75 R	MG	T-498 (M)	24.50	650	270	114	77
60 R	MG	T-10257	20.07	650	270	114	77
50 R	NG	T-438	–	533	228	108	69

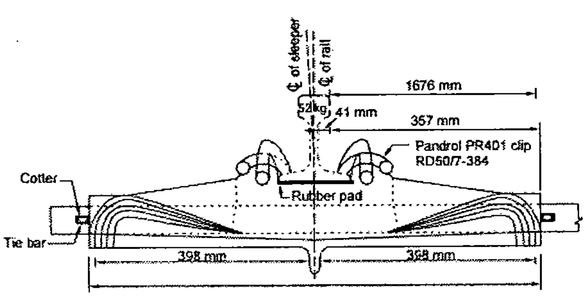

Fig. 7.10 CST-11 sleeper

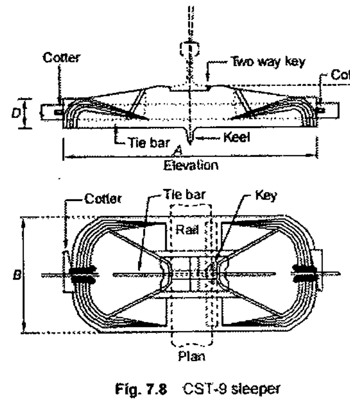

Fig. 7.8 CST-9 sleeper

Cast iron sleepers are being extensively used on Indian Railways and about 45% of the track at present consists of CI sleepers, which may be either pot type or plate type.

Cast Iron Sleepers: Cast iron sleepers are being extensively used on Indian Railways and about 45% of the track at present consists of CI sleepers, which may be either pot type or plate type. The main advantages and disadvantages of CI sleepers over steel trough sleepers are the following.

Advantages

(a) Less corrosion

(b) Less probability of cracking at rail seat

(c) Easy to manufacture

(d) Higher scrap value

Disadvantages

(a) Gauge maintenance is difficult as tie bars get bent

(b) Provides less lateral stability

(c) Unsuitable for track-circuited lines

(d) Not very suitable for mechanical maintenance and/or MSP because of rounded bottom

(e) Susceptible to breakage

CI pot sleepers : Cast iron pot sleepers (Fig. 7.7) consist of two hollow bowls or pots of circular or elliptical shape placed inverted on the ballast section. The two pots are connected by a tie bar with the help of cotters and gibs; the gauge can be adjusted slightly 3 mm (1/8″)] by changing their positions. The rail is placed on top of the pots in a rail seat provided with a cant of 1 in 20 and is held in position with the help of a key. The pot sleeper suffers from the drawback that it cannot be used on curves sharper than 4 o on BG. Most of the fittings are hidden and their inspection and maintenance is quite difficult. These sleepers have become obsolete now and are not being procured by the Indian Railways any more.

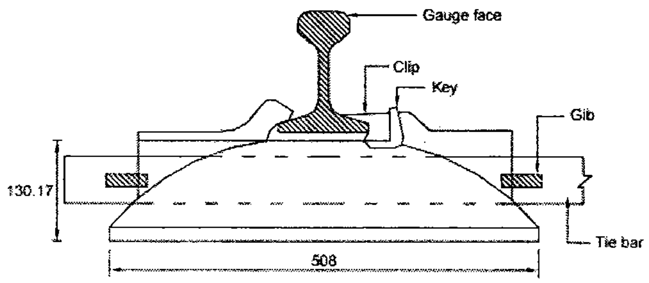

Fig. 7.7 CI pot sleeper (dimensions in mm)

CST-9 sleepers : The CST-9 sleeper is a standard sleeper and is being most extensively used on Indian Railways (IR). It is called CST-9 (Central Standard Trial-9) (Fig. 7.8) because it is the ninth of the series produced by the Central Standard Office. The sleeper is a combination of pot, plate, and box sleepers. It consists of two triangular inverted pots on either side of the rail seat, a central plate with a projected keel, and a box on top of the plate. The two CI plates are connected by a tie bar with the help of four cotters. The rails are held to the sleeper by two-way keys provided at each rail seat on the side of the gauge face. The gauge is adjusted to a value of 5 mm by altering the relative positions of the four cotters.

Table 7.5 Details of CST-9 sleeper (Fig. 7.9)

Rail	*Gauge*	*RDSO drawing number*	*Wt (kg)*	*A (mm)*	*B (mm)*	*C (mm)*	*D (mm)*
52 kg	BG	T-478 (M)	43.55	800	330	140	89
90 R	BG	T-478 (M)	43.55	800	330	140	89
90 R	MG	T-2366	-	700	300	132	85
75 R	MG	T-498 (M)	24.50	650	270	114	77
60 R	MG	T-10257	20.07	650	270	114	77
50 R	NG	T-438	-	533	228	108	69

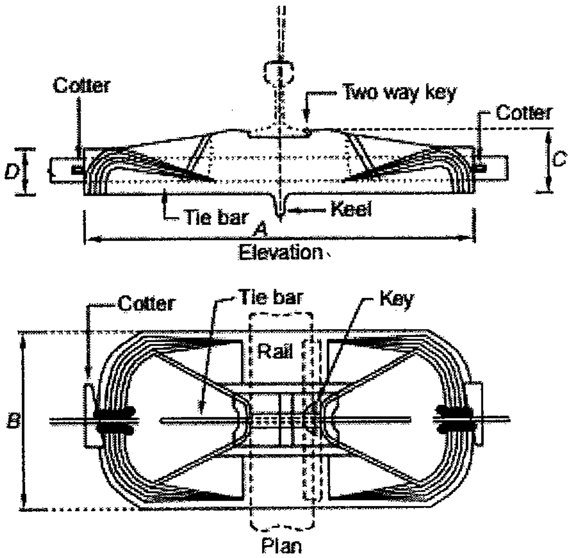

Fig. 7.8 CST-9 sleeper

The rail seat of a CST-9 sleeper is 115 mm wide along the length, and this narrow bearing tends to reduce the rocking of the sleeper under the wave motion of the rail. The sleeper is designed to provide a firm support to the rail and provides fairly good lateral and longitudinal stability to the rails. The dimensions of CST sleepers in use on IR are given in Table 7.5. The sleeper provides a bearing area approximately equal to the effective bearing area of a standard BG wooden sleeper, i.e., 5 sq. ft, for both the plates. CST-9 plates are also available with reverse jaws (T-443 type) to serve as an anti-sabotage measure; a few of these are provided in each rail length. Normally, three reverse jaw CST-9 sleepers are provided per rail to serve anti-sabotage purposes. The weight of a CST-9 sleeper assembly along with fastenings for BG is 102 kg and for MG is 58 kg. The CST-9 sleeper is one of the most popular sleepers on Indian Railways at present. The sleeper has, however, certain limitations when combined with the modern track as mentioned in the following.

(a) As the sleeper does not have a flat bottom, it is not quite suitable for MSP and mechanical maintenance with tie tamers.

(b) The suitability of a CST-9 sleeper on LWRs, particularly on the breathing lengths, is doubtful because of rigid fastenings and the inability of the fastenings to hold the rail with a constant toe load.

(c) The rail seat wears out quickly causing the keys to come loose.

(d) The sleeper has only limited longitudinal and lateral strength to hold LWRs, particularly in the breathing length.

(e) Due to the use of less metal under rail seat, the shocks and vibrations are directly transmitted to the ballast, resulting in poor retention of packing (loose packing) and hence an increased frequency of attention.

CST-9 sleeper for MGA new design of the CST-9 sleeper has recently been developed by Indian Railways for 90 R rails on MG lines as shown in Fig. 7.9.

CST-10 sleepers The CST-10 sleeper is an improvement on the design of the CST-9 sleeper to suit the requirements of a modern track. The basic design feature of this sleeper is the same as that of a CST-9 sleeper except the following improvements.

(a) The rail is held with clips and double-coil spring washers instead of a fixed lug and key.

(b) An insulating liner is provided between the rail and the sleeper.

(c) A rubber pad is provided below the rail seat.

A CST-10 sleeper gives certain amount of elasticity to the track by virtue of its double-coil spring washer. The sleeper, however, has the limitation that it cannot be used with elastic fastenings

CST-11 sleeper : The CST-11 sleeper is an improvement over the CST-10 sleeper. A special shoulder is provided to accommodate the Pandrol clip instead of clips and double-coil spring washers. An elastic rubber pad is provided between the sleeper and the rail seat instead of the rail resting directly on the sleeper. The CST-11 sleeper has the potential of being used on the modern track. The sleeper, however, is still in the experimental stage and the results are not very encouraging at present. Its design details are shown in Fig. 7.10.

CST-12 sleepersCST-12 sleepers are designed to suit the IRN-202 clip, instead of the Pandrol clip. In this case the casting is quite complicated due to the shape of the clip. No firm has undertaken the manufacture of this sleeper as yet.

CST-13 sleepers : The purpose of the CST-13 sleeper is to use the existing CST-9 sleeper with certain additions and alternations made in the local workshop. It consists of the CST-9.

Concrete Sleepers

The need for concrete sleepers has been felt mainly due to economic considerations coupled with changing traffic patterns. In the early days of Indian Railways, wood was the only material used for making sleepers in Europe. Even in those days, the occasional shortage of wooden sleepers and their increasing price posed certain problems and this gave a fillip to the quest for an alternative material for sleepers. With the development of concrete technology in the nineteenth century, cement concrete had established its place as a versatile building material and could be adopted suitably to meet the requirements of a railway sleeper. In the year 1877, Mr Monnier, a French gardener and inventor of reinforced concrete, suggested that cement concrete could be used for making sleepers for railway tracks. Monnier in fact designed a concrete sleeper and obtained a patent for it, but his design did not work successfully. The design was further developed and the railways of Austria and Italy produced the first concrete sleepers with a promising design around the turn of the nineteenth century. This was closely followed by other European railways, where large-scale trials of concrete sleepers were done mostly due to economic considerations.

Development

The development of concrete sleepers that took place on various railway systems was mainly based on the following concepts of design.

(a) RCC or prestressed sleepers similar in shape and size to wooden sleepers

(b) Block-type RCC sleepers connected by a steel tie bar

(c) Prestressed concrete blocks and a steel or an articulated concrete tie bar

(d) Prestressed (pre-tensioned or post-tensioned) type of concrete sleepers These four concepts of design are the basis of the development of present-day concrete sleepers.

Advantages and disadvantages

Concrete sleepers have the following advantages and disadvantages.

Advantages

(a) Concrete sleepers, being heavy, lend more strength and stability to the track and are specially suited to LWR due to their great resistance to buckling of the track.

(b) Concrete sleepers with elastic fastenings allow a track to maintain better gauge, cross level, and alignment. They also retain packing very well.

(c) Concrete sleepers, because of their flat bottom, are best suited for modern methods of track maintenance such as MSP and mechanical maintenance, which have their own advantages.

(d) Concrete sleepers can be used in track-circuited areas, as they are poor conductors of electricity

(e) Concrete sleepers are neither inflammable nor subjected to damage by pests or corrosion under normal circumstances.

(f) Concrete sleepers have a very long lifespan, probably 40-50 years. As such rail and sleeper renewals can be matched, which is a major economic advantage.

(g) Concrete sleepers can generally be mass produced using local resources.

Disadvantages

(a) Handling and laying concrete sleepers is difficult due to their large weights. Mechanical methods, which involve considerable initial expenditure, have to be adopted for handling them.

(b) Concrete sleepers are heavily damaged at the time of derailment.

(c) Concrete sleepers have no scrap value.

(d) Concrete sleepers are not suitable for beater packing.

(e) Concrete sleepers should preferably be maintained by heavy 'on track' tampers.

Design considerations: The forces and factors considered in the design of concrete sleepers are the following.

(a) Forces acting on a sleeper

(b) Effects of the geometric form including shape, size, and weight

(c) Effect of the characteristics of fastenings used

(d) Provision of failure against derailments

Loading conditions adopted by Indian Railways

Concrete sleepers have been designed by the Research Design and Standard Organization (RDSO) wing of Indian Railways for the following different loading conditions.

BG sleeper

(a) 15 t vertical loads at the rail seat.

(b) Vertical load of 15 t at rail seats plus a reaction at the centre of the sleeper equal to half of the load under the rail seat.

(c) A vertical load of 13 t and a lateral load of 7 t directed towards the outside of one rail only.

The sleeper is designed to resist a bending moment of 1.33 t m at the rail seat and 0.52 t m at the centre of the sleeper.

MG sleeper

(a) Vertical loads of 10 t at the rail seats plus a reaction at the centre of sleeper equal to half of that under the rail seat.

(b) Vertical loads of 8 t at the rail seats with 4.5 t lateral force directed towards the outside of one rail only.

Mono-block prestressed concrete sleepers with pandrol clips

The mono-block prestressed concrete sleeper (Fig. 7.11), which is similar to the German B-58 type of sleeper, has an overall length of 2750 mm and a weight of 270 kg approximately. The sleeper has a trapezoidal cross section with a width of 154 mm at the top and 250 mm at the bottom and a height of 210 mm at the rail seat. A cant of 1 in 20 is provided on the top surface of the sleeper for a distance of 175 mm on either side of the centre line of the rail to cover the area of rail fittings. The sleeper is prestressed with 18 high tensile steel (HTS) strands of 3 , 3 mm diameter and 12 6-mm-diameter mild steel links. The initial prestressing of the steel is 100 kg/cm^2. The 28-day crushing strength of the concrete is normally not less than 525 kg/cm^2.

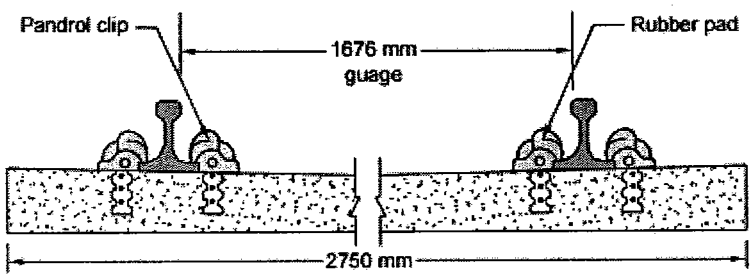

Fig. 7.11 Mono-block prestressed concrete sleeper

The rail rests on a grooved 130 , 130 mm rubber pad, with the grooves lying parallel to the axis of the rail. The fastenings provided for the 52-kg rail are Pandrol clips, which are held in malleable cast iron inserts as shown in Fig. 7.12.

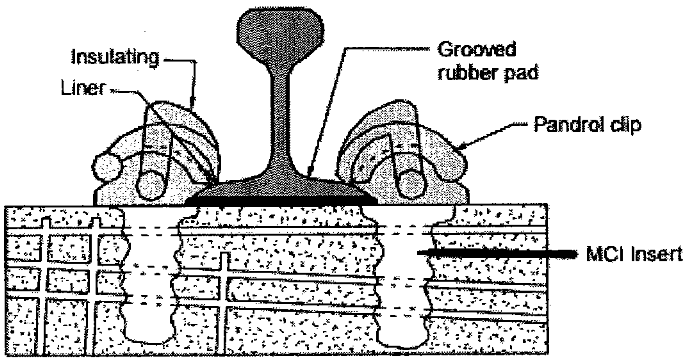

Fig. 7.12 Details at rail seat of a prestressed concrete sleeper

PCS-12 and PCS-14

PCS-12 is the latest type of prestressed concrete (PRC) sleeper for use on BG routes with 52-kg rails and elastic rail clips. For use with 60-kg rails and elastic rail clips, the PCS-14 sleeper has been standardized on Indian Railways.

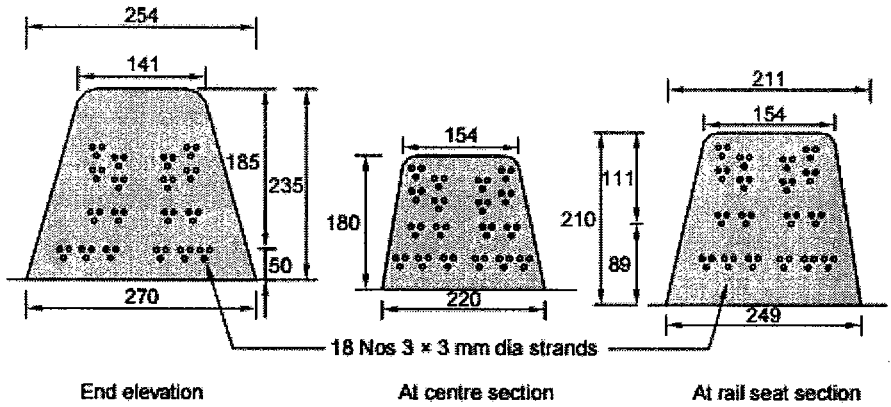

Fig. 7.13 PCS-12 mono-block concrete sleeper (units in mm)

The important dimensions of both of these types of sleepers are shown in Fig. 7.13 and listed as follows.

- Length = 2750 mm
- Weight = 267 kg
- Reinforcement: Eighteen 3 * 3 mm diameter strands
- Concrete is to be of controlled quality with a minimum 28-day crushing strength of 525 kg/cm^2
- Each strand to be tensioned with an initial tensile force of 2730 kg

Mono-block post-tension type of concrete sleepers for BG

The first factory in India for the manufacture of post-tension type of mono-block concrete sleepers was set up by Northern Railways at Allahabad in collaboration with M/s Dyckerhoff and Widmann (D&W) of West Germany. The factory, which started production in 1981, has a planned capacity of manufacturing 300,000 concrete sleepers per year. The salient feature of post-tension type of concrete sleepers are the following.

Size of sleeper

- Length = 2750 mm
- Width at centre = 160 mm (top)
  200 mm (bottom)
- Depth at centre = 180 mm
- Weight = 295 kg

Design features

- Initial prestressing force = 37 t
- Final prestressing force = 31 t
- Minimum concrete strength in 28 days = 550 kg/cm^2
- Minimum strength of concrete at the time of applying prestress = 450 kg/cm^2

The use of concrete sleepers using the post-tension method has not been successful on Indian Railways and its manufacture has since been stopped.

Mono-block PRC sleepers for MG (PCS-17)

A design for mono-block PRC sleepers (PCS-17) has recently been standardized for MG. The sleeper has a trapezoidal cross section similar to that of a BG sleeper. The concrete should have a 28-day compressive strength of 525 kg/cm^2. The salient features of this sleeper are the following (Fig. 7.14).

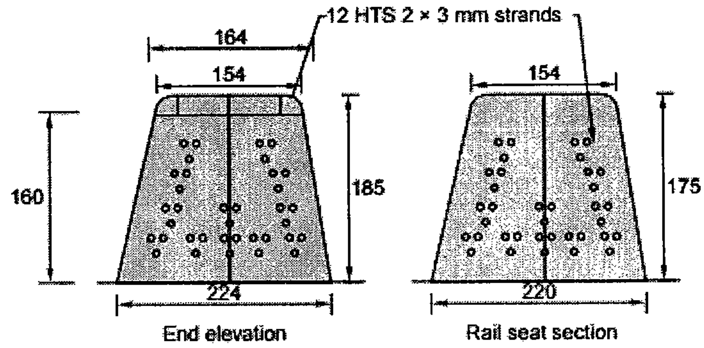

Fig. 7.14 PCS-17 concrete sleeper for MG (units in mm)

- Length = 2000 mm
- Weight = 158.5 kg

Reinforcement: Twelve 3 * 3 mm diameter strand of HTS wire tensioned to initial force of 2730 kg

PRC sleepers can be used for 90 R rails with elastic rail clips and glass filled nylon liners (GFN 66) and on sole plates.

Two-block RCC sleeper for BG yards

A design for a two-block RCC sleeper for BG yards has been standardized by RDSO as per drawing number RDSO/T-2521 for extensive trials on Indian Railways. There is a general scarcity of wooden and CST-9 sleepers for use in BG yards and the new RCC sleepers will ease the situation in a big way. Some of the salient features of this sleeper are as follows.

- Considering low speeds in yard lines and less impact effect, the rail seat design load has been taken only as 10 t without any lateral thrust.
- Size at rail seat (top width bottom width depth) = 22 cm * 30 cm * 17 cm
- Overall length of the sleeper = 247.5 cm
- Weight of the sleeper = 170 kg
- Main reinforcement in each block
  - At top: Five 8-mm-diameter steel bars
  - At bottom: Two 8-mm-diameter steel bars
- The fastenings used are steel clips and a spring washer with screw fitted to a polythene dowel

Two-block concrete sleeper for MG yards

Two-block concrete sleepers for use in MG yards have recently been developed. The sleeper consists of two cement concrete blocks, each weighting about 36 kg and consisting of an MS reinforcement of about 7 kg. The two RCC sleeper blocks are connected by an angle tie bar of 55 * 50 * 6 mm section and 1.5 m length. The rail is fixed to the sleeper block either by a clip and bolt arrangement or by polythene dowels and rail screws. A pad is provided below the rail seat to provide cushioning.

Mono-block versus two-block concrete sleepers

There are relative advantages and disadvantages of mono-block and two-block concrete sleepers. Some of these are enumerated below.

(a) Mono-block sleepers give better longitudinal and lateral stability to the track compared to two-block concrete sleepers.

(b) The mono-block concrete sleeper, being a monolithic concrete mass, is likely to have a longer working life compared to the two-block concrete sleeper connected with a tie bar. In the latter case, a tie bar is weak and has a comparatively shorter life due to corrosion, etc.

(c) The mono-block concrete sleeper requires heavy capital expenditure for its manufacture, being a prestressed reinforced concrete unit, compared to the two-block sleeper, which is an ordinary reinforced concrete sleeper.

(d) In a mono-block prestressed concrete sleeper, a crack that develops because of overstressing is likely to close down upon return to normal condition, whereas in a two-block sleeper, such a crack will continue to remain open.

(e) Mono-block sleepers are likely to become centre-bound unlike two-block sleepers.

(f) During derailments and rough handling the tie bars of two-block sleeper get deformed, thereby affecting the gauge.

(g) In a two-block sleeper, the two blocks are not likely to rest on the ballast in a way that each rail is properly inclined to the vertical, a feature which could affect the alignment and gauge of the track.

Sleepers for Turnouts

A railroad turnout is a mechanical installation that enables trains to be guided from one line of rail tracks to another. In this section we discuss sleepers and sleeper designs for turnouts.

Prestressed concrete sleepers for turnouts

Due to the acute shortage of wood, especially of long timbers required for points and crossings, it was felt necessary to develop PRC sleepers for use on turnouts in track-circuited areas. RDSO developed a PRC sleeper design with a rectangular cross section in July 1986 for 1 in 12 left-hand turnouts with a 7730-mm curved switch for use with 52-kg rails. These PRC sleepers for turnouts have been manufactured in the PRC sleeper factory at Khalispur, and these sleepers are on trial on Northern Railways at present. The salient features of these sleepers are the following.

(a) The sleepers have a rectangular cross section.

(b) There are 74 sleepers comprising 21 sleepers in switch assembly, 3 in intermediate sub-assembly and 18 in crossing sub-assembly.

(c) The sleepers are of varying lengths and design. There are 16 different turnout sleeper designs.

(d) These sleepers require the use of a number of fittings different from the existing standard fittings. The grooved rubber pads are of a standard 4.5 mm thickness, but of varying size.

New fan-type concrete sleeper for turnouts

The prestressed concrete sleepers discussed above are suitable only for 1 in 12 turnouts. RDSO has developed a new fan-type sleeper that can be used for 1 in 8.5 as well as 1 in 12 turnouts.

The new design of concrete sleepers has the following characteristics.

(a) The cross section of the sleeper in the new design is trapezoidal instead of rectangular as in the earlier design.

(b) The layout of the sleepers is fan shaped and the same design of sleepers can be used for right-hand as well as left-hand turnouts by rotating them 10 o in a horizontal plane.

(c) Apart from approach sleepers, 54 concrete sleepers are used for 1 in 8.5 turnouts and 83 concrete sleepers are used for 1 in 12 turnouts.

(d) The concrete used has a 28-day crushing strength of 600 kg/cm^2.

(a) The sleepers are laid perpendicular to the main line on the switch portion. In the lead portion, sleepers are laid equally inclined to the straight and turnout tracks. In the crossing portion, the sleepers are laid perpendicular to the bisecting line of the crossing.

(f) The sleepers under the switch portion have dowels for fixing slide chairs with the help of screws. These sleepers are laid perpendicular to the main line and, therefore, can be used for both left-hand and right-hand turnouts.

(g) The mark 'RE' is provided on the fan-shaped PRC turnout sleepers at one end. The sleepers should be so laid that the end with the RE mark is always laid on the right-hand side.

Laying of the concrete sleepers on turnouts

Turnouts with concrete sleepers can be maintained in any one of the following ways:

(a) using points and crossing tamper,

(b) using off-track tampers with lifting jacks, or

(c) measured shovel packing.

In the case of emergencies such as derailments, when the sleepers may be damaged, temporary repairs should be carried out by interlacing wooden sleepers for permitting traffic with restricted speed. The damaged concrete sleepers are replaced by a fresh lot of turnout concrete sleepers as a permanent measure as early as possible. The wooden sleepers and any other damaged sleepers are replaced one by one with new turnout sleepers.

Manufacture of concrete sleepers

Prestressed concrete sleepers can be of the pre-tensioned or post-tensioned type. In the case of pre-tensioned sleepers, the force is transferred to the concrete through bonds or through a combination of bonds and positive anchors. Bond transmission lengths and the losses in prestress vitally affect the design and determine the quality of manufacture. In the post-tensioned type of sleeper, the force is transferred only through positive anchors.

Mono-block prestressed

Mono-block concrete sleepers are generally manufactured by the 'long line method'. In this method, at a time, 30-40 moulds for casting concrete sleepers are kept in about 100-120-m-long casting beds. High tensile steel wires with diameters of 5 mm are anchored at the end block between the tension towers and moulds, and stretched by a specially designed tensioning method. The tensile stress in the wires should not exceed 70% of the specified minimum UTS

Testing of concrete sleepers

In addition to the control checks exercised on the material and manufacturing process, the concrete and the finished sleepers are subjected to the following periodical checks and tests.

(a) The minimum 28-day compressive strength of the test cube should not be less than 525 kg/cm^2. Sleepers from occasional batches in which the minimum crushing strength falls below 525 kg/cm^2 but not below 490 kg/cm^2 may be accepted subject to their passing the increased frequency of testing for static bending strength.

(b) The minimum compressive strength of the test cube of concrete at detensioning should not be less than 370 kg/cm^2.

(c) The modulus of rupture should be as specified in the Concrete Bridge Code.

(d) The dimensional tolerance and surface finish of the sleepers should be checked using suitable templates and gauges.

(e) The cracking and failure moments of the sleepers should be tested at the following sections by applying suitable loads:

(a) Positive cracking moment at rail seat bottom

(b) Negative cracking moment at centre section top

(c) Positive cracking moment at centre section bottom

(d) Failure moment at rail seat bottom

(f) For the abrasion resistance test, the concrete sleeper is subjected to a vibrating load under specified conditions. After 300 hours of operating time, the loss in weight due to abrasion should not be more than 3%.

(i) With fish-plated tracks. Should be used only with long welded rails. Fish-plated joints on concrete sleeper tracks, where unavoidable, should have wooden sleepers at joints.

Maintenance of Concrete sleepers

The following points need attention in the maintenance of concrete sleepers.

i) Concrete sleepers should normally be maintained with heavy on-track tampers. For spot attention, MSP or off-track tampers may be used. The size of chips for MSP should be 8 mm-30 mm as required

(b) Only 30 sleeper spaces are to be opened out at a time between two fully boxed track stretches of 30 sleepers length each in case a LWR track exists.

(c) Concrete sleepers should be compacted well and uniformly to give a good riding surface. Centre binding of mono-block concrete sleepers should be avoided, for which the central 800 mm of the sleeper should not be hard packed.

(d) Both ends of the concrete sleepers should be periodically painted with anticorrosive paint to prevent corrosion of the exposed ends of prestressing wires. In the case of two-block sleepers, the tie bars should be examined every year, and if any sign of corrosion is noticed, the affected portion should be painted with an approved paint.

(e) Mechanical equipment should be used for laying and maintaining concrete sleepers as far as possible.

(f) Wherever casual renewal of concrete sleepers is to be done, the normal precautions followed for LWR tracks should be taken.

(g) The elastic rail clip should be driven properly to ensure that the leg of the clip is flush with the end face of the insert. Overdriving and underdriving should be guarded against, as these cause eccentric loading on the insulations, resulting in their displacement and in the variation of load.

(h) A vigilant watch should be kept to ensure that no creep occurs in any portion of the concrete sleeper track or there is no excessive movement near the switch expansion joint (SEJ).

(i) It must be ensured that the rubber pads are in their correct positions. Whenever it is found that the rubber pads have developed a permanent set, these should be replaced by new ones. Such examinations can be done at the time of destressing. Toe load can also be lost due to ineffective pads.

(j) Nylon or composite insulating liners used with Pandrol clips should be examined periodically for signs of cracking and breakage. Adequate care should be exercised when driving the clip at the time of installation to prevent damage.

Treated and Untreated Sleepers

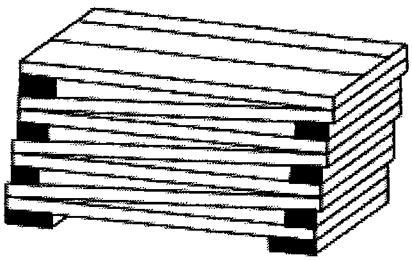

Fig.7.2 One and nine method

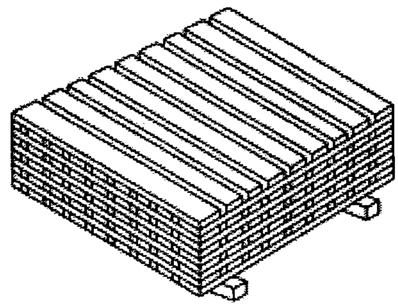

Fig. 7.3 Open crib method

Wooden sleepers are also sometimes classified as hard wood and soft wood sleepers depending upon the origin or species of the wood of which these are made

Treated and Untreated Sleepers: Wooden sleepers are also sometimes classified as hard wood and soft wood sleepers depending upon the origin or species of the wood of which these are made. Broadly speaking, timber produced from trees with broad leaves is known as *hard wood* and that obtained from trees bearing long leaves is considered *soft wood.* Some of the hard wood varieties also require treatment before being used in the track. As per the recommendations of the committee, the use of the terms 'durable' and 'non-durable' as well as 'hard' and 'soft' should be done away with to avoid confusion. The committee recommended that for simplification and rationalization, wooden sleepers should be classified in two categories:

(a) 'U' or *Untreated sleepers* comprising of all the sleepers made of wood from naturally durable species.

(b) 'T' or *Treated sleepers* consisting of the rest of the sleepers

Treatment of sleepers : Indian Railways has set up four sleeper treatment plants at the locations given below for treating non-durable sleepers:

Dhilwan (Punjab) in Northern Railways 1923

Naharkatia (Assam) in North Frontier 1928

Clutterbuckganj (UP) in North East 1955

Olvakot (Kerala) in Southern Railways 1957

All these plants utilize the pressure treatment process and the preservative is forced into the wood under pressure using any one of the following three methods.

Full cell (Bethell) process In the Bethell process, a cylinder loaded with the charge for about 300-400 sleepers is first subjected to a vacuum of 55-60 cm of mercury for 20-30 minutes by means of a vacuum pump. Hot creosote oil is then forced into the cylinder at a pressure of 150-180 psi at a temperature of 180 o F. This pressure is maintained for a period of 50-70 minutes till the desired amount of absorption is obtained. Thereafter, the pressure is reduced and the cylinder is drained off the creosote oil. A final vacuum of 55 cm of mercury is applied to free the timber of excess preservative. The whole process takes about 2-3 hours. This process is normally used when maximum retention of creosote oil is required for a particular type of sleeper such as that made of kail, deodar, fir, etc. At present this method is in use in Olvakot, Clutterbuckganj, and Dhilwan plants for various types of wood.

Empty cell (Rueping) process In the Rueping process, wooden sleepers loaded into the cylinder are first subjected to an initial air pressure of 3.5 to 5.25 kg/cm^2 for about 20-30 minutes. Afterwards, without reducing the pressure, hot creosote oil is forced into the cylinder at a temperature of 180 o C to 210 o C. The pressure is then raised to a value of 10.5-19.6 kg/cm^2 and maintained for a period of 20-30 minutes till the desired absorption is achieved. Finally, the pressure is released, the cylinder is drained off the creosote, and a final vacuum of 55 cm of mercury is created to drain off the excess preservative. The whole process of treatment takes about 2-3 hours per charge. This process is generally employed for treating porous timbers and is used in Dhilwan and Clutterbuckganj depots for chir sleepers. In this process, air in the cell is entrapped, thereby limiting the preservative to be absorbed by the sleeper to a certain extent.

Empty cell (Lowry) process In the Lowry process, the cylinder loaded with timber charge is filled and then subjected to a pressure of 180 lb, which is sufficient to ensure proper impregnation. The cylinder is then drained off and the timber subjected to a final vacuum of 55 cm of mercury for a period of 45 minutes or so. The air entrapped in the timber cells forces the excess preservative out. Preservative recovery is greater in this case than in the full cell process but is less than in the Rueping process. This process is used in the Naharkatia plant for very green species of timber

Prophylactic treatment of sleepers Prophylactic treatment is given to the sleepers by using patent chemicals such as arsenic pentaoxide, copper sulphate, and potassium dichromate solution in water 1:3:4 wt (60%) to prevent infection at the forest head and in the treatment plant. This is necessary an as appreciable amount of time elapses in transferring the sleepers from the forest depots to the treatment plant.

Seasoning of sleepers: Wooden sleepers are seasoned to reduce the moisture content so that their treatment is effective. The Indian Standard code of practice for preservation of timber lays down that the moisture content in the case of sleepers to be treated by pressure treatment should not be more than 25%. The seasoning of sleepers can be done by any one of the following processes.

Artificial seasoning in kiln This is a controlled method of seasoning the timber, normally used in the USA and other advanced countries, under conditions of temperature and relative humidity, which are in the range of natural air seasoning

Boulton or boiling under vacuum process This is a process in which unseasoned wood is treated with hot preservative to remove the moisture content. This is adopted in the Naharkatia depot

Air seasoning This is the method adopted extensively for the seasoning of wooden sleepers in India. The sleepers are stacked in the timber yard and a provision is made for enough space for the circulation of air in between the sleepers. The sleepers are stacked in any one of the following ways:

(a) One and nine method (Fig. 7.2)

(b) Close crib method

(c) Open crib method (Fig. 7.3

Normally, the one and nine method is adopted on Indian Railways for stacking the sleepers. About 6 months are required to air season the timber fully by this method.

Functions of Ballast: The ballast is a layer of broken stones, gravel, moorum, or any other granular material placed d packed below and around sleepers for distributing load from the sleepers to the formation. The ballast is a layer of broken stones, gravel, moorum, or any other granular material placed and packed below and around sleepers for distributing load from the sleepers to the formation. It provides drainage as well as longitudinal and lateral stability to the track.

Functions of Ballast: The ballast serves the following functions in a railway track.

l Provides a level and hard bed for the sleepers to rest on.

l Holds the sleepers in position during the passage of trains.

Transfers and distributes load from the sleepers to a large area of the formatio

l Provides elasticity and resilience to the track for proper riding comfort

l Provides the necessary resistance to the track for longitudinal and lateral stability

l Provides effective drainage to the track.

l Provides an effective means of maintaining the level and alignment of the track.

Types of Ballast

The different types of ballast used on Indian Railways are described in the following.

Sand ballast

Sand ballast is used primarily for cast iron (CI) pots. It is also used with wooden and steel trough sleepers in areas where traffic density is very low. Coarse sand is preferred in comparison to fine sand. It has good drainage properties, but has the drawback of blowing off because of being light. It also causes excessive wear of the rail top and the moving parts of the rolling stock.

Moorum ballast

The decomposition of laterite results in the formation of moorum. It is red, and sometimes yellow, in colour. The moorum ballast is normally used as the initial ballast in new constructions and also as sub-ballast. As it prevents water from percolating into the formation, it is also used as a blanketing material for black cotton soil.

Coal ash or cinder

This type of ballast is normally used in yards and sidings or as the initial ballast in new constructions since it is very cheap and easily available. It is harmful for steel sleepers and fittings because of its corrosive action.

Broken stone ballast

This type of ballast is used the most on Indian Railways. A good stone ballast is generally procured from hard stones such as granite, quartzite, and hard trap. The quality of stone should be such that neither is it porous nor does it flake off due to the vagaries of weather. Good quality hard stone is normally used for high-speed tracks. This type of ballast works out to be economical in the long run.

Other types of ballast

There are other types of ballast also such as the brickbat ballast, gravel ballast, kankar stone ballast, and even earth ballast. These types of ballast are used only in special circumstances.

Sizes of Ballast

Previously, 50-mm (2″) ballasts were specified for flat bottom sleepers such as concrete and wooden sleepers and 40-mm (1.5″) ballasts were specified for metal sleepers such as CST-9 and trough sleepers. Now, to ensure uniformity, 50-mm (2″) ballasts have been adopted universally for all type of sleepers.

As far as points and crossings are concerned, these are subjected to heavy blows of moving loads and are maintained to a higher degree of precision. A small sized, 25-mm (1″) ballast is, therefore, preferable because of its fineness for slight adjustments, better compaction, and increased frictional area of the ballast

Requirements of a Good Ballas

Ballast material should possess the following properties.

(a) It should be tough and wear resistant.
(b) It should be hard so that it does not get crushed under the moving loads.
(c) It should be generally cubical with sharp edges.
(d) It should be non-porous and should not absorb water.
(e) It should resist both attrition and abrasion.
(f) It should be durable and should not get pulverized or disintegrated under adverse weather conditions.
(g) It should allow for good drainage of water.
(h) It should be cheap and economical.

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Design of Ballast Section

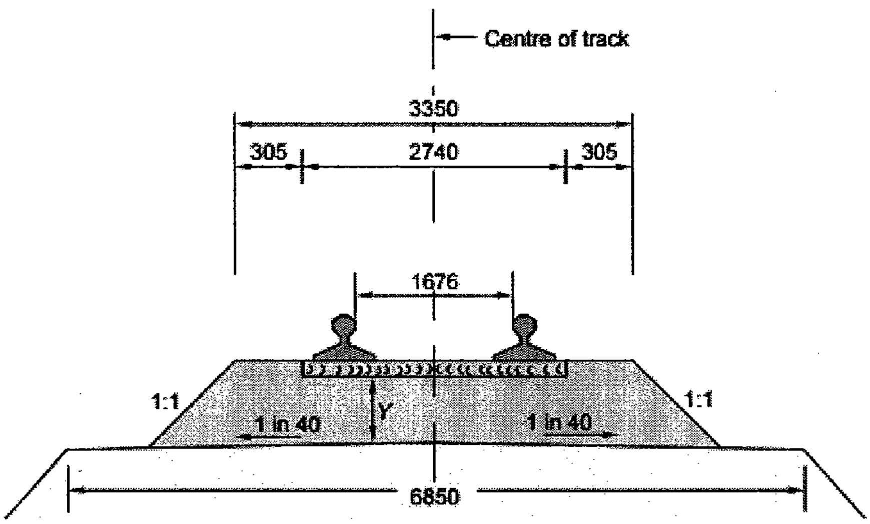

Fig. 8.2 Standard ballast profile for BG (Other than LWR/CWR)

The design of the ballast section includes the determination of the depth of the ballast cushion below the sleeper and its profile. These aspects are discussed below

Design of Ballast Section: The design of the ballast section includes the determination of the depth of the ballast cushion below the sleeper and its profile. These aspects are discussed below.

1 Minimum Depth of Ballast Cushion: The load on the sleeper is transferred through the medium of the ballast to the formation. The pressure distribution in the ballast section depends upon the size and shape of the ballast and the degree of consolidation. Though the lines of equal pressure are in the shape of a bulb, yet for simplicity, the dispersion of load can be assumed to be roughly 45 o to the vertical. In order to ensure that the load is transferred evenly on the formation, the depth of the ballast should be such that the dispersion lines do not overlap each other.

For the even distribution of load on the formation, the depth of the ballast is determined by the following formula (refer to Fig. 8.1):

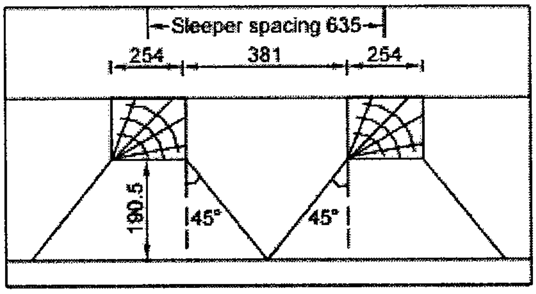

Fig. 8.1 Minimum depth of ballast cushion (dimensions in mm)

Fig. 8.1 Minimum depth of ballast cushion (dimensions in mm)

Sleeper spacing = width of the sleeper + 2 depth of ballast (8.1) If a BG track is laid with wooden sleepers with a sleeper density of $N + 6$, then the sleeper spacing would be 68.4 cm. If the width of the sleeper is 25.4 cm, then the depth of the ballast cushion would be

$$d = \frac{68.4 - 25.4}{2} = 21.5\text{cm}$$

A minimum cushion of 15-20 cm of ballast below the sleeper bed is normally prescribed on Indian Railways.

2 Ballast Profile for Fish-plated Track: The ballast profile for a fish-plated track is shown in Fig. 8.2. The requirements of ballast for different groups of railway lines as adopted by Indian Railways are given in Table 8.2.

* In the case of ordinary fish-plated tracks, to be increased on the outside of the curves to 400 mm in the case of sharper curves of a radius more than 600 m. In short welded panel tracks, it is to be increased to 400 mm on the outside of all curves flatter than 875 m and to 450 mm in the case of sharper curves with a radius more than 875 m. To be increased to 550 m on the outside of the turn on curves of turnouts in passenger yards. In the case of a short welded rail (SWR) track, the minimum depth of cushion should be 200 mm.

3 Ballast Profile for Long Welded Rail Tracks

The ballast profile for a long welded rail (LWR) track is shown in Fig. 8.3. The requirements of ballast for different types of sleepers on a BG railway line are given in Table 8.3.

The minimum clean stone ballast cushion below the bottom of sleeper (A) is 250 mm. For routes where speeds are to be more than 130 kmph, A is 300 mm- 200 mm along with 150 mm of sub-ballast. Suitable dwarf walls should be provided in the case of cuttings, if necessary, for retaining the ballast.

* On the outer side of the curves only. Cess may be widened where required depending on local conditions and the outer ends of the curves.200 mm over 150 mm sub-ballast.

Specifications for Track Ballast

The following specifications of ballast, which have recently been revised (June 2004), are followed on Indian Railways. These specifications are applicable for the stone ballast to be used for all types of sleepers on normal tracks, turnouts, tunnels, and deck slabs on all routes.

1 General Qualities

The ballast material should possess the general qualities described below.

Basic quality The ballast should be hard, durable, as far as possible angular along edges/corners, and free from weathered portions of parent rock, organic impurities, and inorganic residues.

Particle shape Ballasts should be cubical in shape as far as possible. Individual pieces should not be flaky and should have flat faces generally with not more than two rounded/sub-rounded faces.

Mode of manufacture Ballasts for all BG main lines and running lines, except on E routes, but including E special routes, should be machine crushed. For other BG lines and MG/NG routes planned or sanctioned for conversion, the ballast should preferably be machine crushed. Hand broken ballast can be used in exceptional cases with the prior approval of the chief track engineer or the CAO (chief administrative officer). Such approval should be obtained prior to the invitation of tenders. Hand broken ballasts can be used without any formal approval on MG and NG routes not planned or sanctioned for conversion.

2 Physical Properties

All ballast samples should possess the physical properties given in Table 8.4 when tested in accordance with IS:2386 (IV)-1963.

Table 8.4 Physical requirements of ballast

Table 8.4 Physical requirements of ballast

Characteristics	*BG, MG, and NG (planned/sanctioned for conversion)*	*NG and MG (other than those planned for conversion)*
Aggregate abrasion	30% maximum*	35% maximum
Aggregate impact	20% maximum*	30% maximum
Water absorption	1%	-

* In exceptional cases, relaxable on technical and/or economic grounds up to 35% and 25%, respectively, by the chief track engineer (CTE) in open lines and the chief administration officer (construction) (CAO/C) for construction projects. Relaxation in abrasion and impact values is given prior to the invitation of tender and should be incorporated in the tender document.

* In exceptional cases, relaxable on technical and/or economic grounds up to 35% and 25%, respectively, by the chief track engineer (CTE) in open lines and the chief administration officer (construction) (CAO/C) for construction projects. Relaxation in abrasion and impact values is given prior to the invitation of tender and should be incorporated in the tender document.

3 Size and Gradation

The ballast should satisfy the size and gradation requirements given in Table 8.5.

Table 8.5 Ballast gradation

Table 8.5 Ballast gradation

Size of sieve	*% retained*
65 mm	5% maximum
40 mm	40% to 60%
20 mm	Not less than 98% for machine crushed and not less than 95% for hand broken

4 Oversized Ballast

(a) *Retention on 65-mm square mesh sieve* A maximum of 5% ballast retained on a 65-mm sieve is allowed without deduction in payment. In case the ballast retained on a 65-mm sieve exceeds 5% but is less than 10%, payment at a 5% reduction of 5% in the contracted rate is made for the full stack. Stacks retaining more than 10% of ballast on a 65-mm sieve are rejected.

(b) *Retention on 40-mm square mesh sieve* In case the ballast retained on a 40-mm square mesh sieve (machine crushed only) exceeds the 60% limit prescribed above, payment at the following reduced rates is made for the full stack in addition to the reduction as worked out above.

(i) 5% reduction in contracted rates if the retention on a 40-mm square mesh sieve is between 60% (excluding) and 65% (including).

(ii) 10% reduction in contracted rates if retention on a 40-mm square mesh sieve is between 65% (excluding) and 70% (including).

(iii) In case the retention on a 40-mm square mesh sieve exceeds 70%, the stack is rejected.

(iv) In the case of hand broken ballast supply, 40-mm-sieve analysis may not be carried out. The executive may, however, ensure that the ballast is well graded between 65 mm and 20 mm.

5 Undersized Ballast

The ballast is treated as undersized and rejected if

(a) retention on a 40-mm sieve is less than 40% and

(b) retention on a 20-mm sieve is less than 98% (for machine crushed ballast) or 95% (for hand broken ballast).

6 Shrinkage Allowance

Payment is made for the gross measurements either in stacks or in wagons without any deduction for shrinkage/voids. However, when ballast is supplied in wagons, up to 8% shrinkage ipermitted at the destination by the consignee verifying the booked quantities.

7 Sampling and Testing

The following procedure is specified for the sampling and testing of the ballast.

(a) A minimum of three samples of ballast should be taken for sieve analysis for measurementdone on any particular date, even if the number of stacks to be measured is less than three.

(b) The tests for abrasion value, impact value, and water absorption should be done in approved laboratories or in the Railways' own laboratories (A list of these laboratories should be given in the tender document).

(c) In order to ensure the supply of a uniform quality of ballast, the specifications given in Table 8.6 should be followed with respect to sampling, testing, and acceptance of the ballast. The tests given in this table may be carried out more frequently if warranted at the discretion of the Railways.

(d) On supply of the first 100 m^3, tests for size gradation, abrasion value, impact value, and water absorption (if prescribed) should be carried out by the Railways. Further supply should be accepted only after the first batch satisfies these tests. The Railways reserves the right to terminate the contract as per the general conditions of contract (GCC) at this stage itself in case the ballast supply fails to meet any of these specifications.

Table 8.6 Frequency of tests for ballast supply

Table 8.6 Frequency of tests for ballast supply

Item	*Supply in stacks*		*Supply in wagons*
	For a stack of volumne less than 100 m^3	*For a stack of volume more than 100 m^3*	
Number of size and gradation tests	One for each stack	One for each stack	One for each wagon
Size of one sample* (m^3)	0.027	0.027 for every 100 m^3 or part thereof	0.027
Abrasion value, impact value, and water absorption test†	One test for every 2000 m^3 of ballast		

* This sample should be collected using a wooden box of internal dimensions 0.3 m × 0.3 m × 0.3 m from different parts of the stack/wagon.

† These tests should be done for the purpose of monitoring the quality during supply. In case the test results are not as per the prescribed specifications at any stage, further supplies should be suspended till suitable corrective action is taken and supply as per specifications is ensured.

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These tests should be done for the purpose of monitoring the quality during supply. In case the test results are not as per the prescribed specifications at any stage, further supplies should be suspended till suitable corrective action is taken and supply as per specifications is ensured.

Collection and Transportation of Ballasts

The collection and transportation of ballasts can be done by either of the following methods.

l Collecting the ballast at ballast depots and transporting it to the site in ballast trains.

l Collecting the ballast along the cess and putting the same on the track directly. The mode of collection is decided taking into account the proximity of the quarry, availability of good stone ballast, serving roads along side the railway line for the carriage of ballast, availability of ballast trains, turnround of ballast trains, and availability of traffic blocks for unloading.

1 Collection at Ballast Depots

The following procedure is adopted when ballasts are being collected at ballast depots.

(a) The space along side the railway line meant for stacking is divided into a convenient number of zones and demarcated.

(b) For each depot, a diagram indicating the site details of all the measured stacks is maintained.

(c) Each stack in each zone is serially numbered.

(d) Operations of collecting and training out materials should not be carried out at the same time in any zone.

(e) The ground on which the stacks are made should be selected and levelled.

(f) Measurements should be taken for complete stacks. The measured stack should be identified suitably by lime sprinkling or any other method.

(g) As soon as a stack is lifted, it should be recorded on the depot diagram, which should always be kept up-to-date. Challans should be prepared after loading the ballast into wagons.

2.Collection of Ballast Along the Cess

In case the ballast is collected along the side of the cess, the inspector in charge should maintain a separate register showing the measurement of stacks as well as its disposition (from km to km). The stacks should be serially numbered between successive posts. Entries should be made in a register whenever stacks are removed and ballast is put onto the track. The record should state the place where the removed ballast has been used as well as the date of removal of the stack. Materials passing through a 6-mm square mesh are classified as 'dust' (limited to 1%).

Methods of ballast Measurement

The quantity of the ballast can be measured either in a stack or in a wagon. Both methods are described below.

1 Stack Measurement

Stacking should be done on an almost plane and firm ground with good drainage. The height of the stack should not be less than 1 m except in hilly areas, where it may be 0.5 m. The top width of the stack should not be less than 1 m and should be kept parallel to the ground plane. The side slopes of the stack should not be flatter than 1.5:1 (horizontal:vertical). The volume of each stack should normally not be less than 30 m^3in plain areas and 15 m^3 in hilly areas.

2 Wagon Measurement

In the case of the ballast supply being directly loaded into wagons, a continuous white line should be painted inside the wagon to indicate the level up to which the ballast can be loaded. The volume in cubic metres corresponding to white line should also be painted outside the wagon on both sides. In addition to the painted line mentioned above, short pieces of flats (cut pieces of tie bars or otherwise) punched with the volume should be welded in the centre of all the four sides of the wagon.

Laboratory Tests for Physical Properties of Ballast

The following tests are recommended to judge the suitability of the ballast material for a railway track.

1 Aggregate Abrasion Value

To check for aggregate abrasion, a test sample of 10 kg of clean ballast conforming to the following grading is taken

Passing the 50-mm sieve and retained on the 40-mm square mesh sieve: 5000 g Passing the 40-mm and retained on the 25-mm square mesh sieve: 5000 g The sample, along with the abrasive charge, is placed in the Los Angeles machine,

which is rotated at a speed of 30-33 rpm for 1000 revolutions. The sample is sieved and material coarser than the 1.70-mm sieve is washed, dried, and weighed. The difference between the original weight (A) and the final weight of the sample (B) is expressed as a percentage of the original weight of the test sample. This value is reported as the abrasion value.

$$\text{Aggregate abrasion value} = \frac{A - B}{A} \times 100 \qquad (8.2)$$

2 Aggregate Impact Value

To check for aggregate impact, the test sample is prepared out of the track ballast in such a way that it has a grading that passes the 12.5-mm sieve and is retained on the 10-mm sieve. The ballast sample is oven dried and placed duly tamped in the different stages in a cylindrical metal container with 75 mm diameter. and 50 mm depth (weight A). The cup of the impact testing machine is fixed firmly in position on the base of the machine and entire test sample is placed in it and compacted by 25 strokes of the tamping rod. The test hammer weighing about 14 kg is raised 380 mm above the upper surface of the cup and dropped. The test sample is subjected to a total of 15 such blows. The sample is then removed and sieved using a 2.36-mm sieve and the weight of quantity retained is measured (weight B):

$$\text{Aggregate impact value} = \frac{A - B}{A} \times 100 \qquad (8.3)$$

3 Flakiness Index

The flakiness index of an aggregate is the percentage by weight of the particles with a least dimension (thickness) less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm.

Track ballast sample of sufficient quantity is taken to provide a minimum of 200 pieces, which is weighed (weight A). The sample consisting of aggregates is sieved as per the prescribed procedure in a series of sieves. The flaky material is separated and weighed (weight *B*). The flakiness index is then determined by the total weight of the material passing the various sieves, expressed as a percentage of the total weight of the sample gauged.

$$\text{Flakiness index} = \frac{B}{A} \times 100 \qquad (8.4)$$

4 Specific Gravity and Water Absorption Test

A sample consisting of at least 2000 g of aggregate is washed thoroughly to remove finer particles and dust. The whole material is then drained, placed in a wire basket, and immersed in distilled water at a temperature between 22 o C and 32 o C. The sample is shaken, jolted, and dried as per specific procedure. The sample is finally placed in an oven in a shallow tray at a temperature of 100 o C to 110 o C. It is then removed from the oven, cooled in the container, and weighed (weight *C*). The specific gravity and water absorption is calculated as follows:

$$\text{Specific gravity} = \frac{C}{B - A} \qquad (8.5)$$

$$\text{Water absorption (\% by weight)} = \frac{100\,(B - C)}{C} \qquad (8.6)$$

where A = weight in grams of saturated aggregate in water, B = weight in grams of saturated dry aggregate in air, and C = weight in grams of oven-dried aggregate in air.

Assessment of Ballast Requirements

The requirements of the ballast should be assessed separately for

(a) correcting the deficiencies existing in the track as well as those arising out of overhauling, through packing and deep screening,

(b) providing adequate cushion for mechanical tamping, and

(c) providing extra cushion while converting into LWR.

The ballast required for maintenance purposes is estimated by assessing the quantity approximately, if necessary by a survey, over every 1 km of rail length. Care should be taken to ensure that the cores under the sleepers are not disturbed.

In the case of deep screening, the ballast required for recoupment and providing a standard section should be assessed by deep screening the ballast on a trial basis. For this, full depth screening is done for a length of 2-3 sleepers at every 0.5 to 1 km interval. In this case, the screening is done under the sleepers as well. The quantity of ballast required for deep screening is roughly taken as 1.5% of the existing quantity of ballast based on field trials.

The quantities assessed above will be the net quantities of ballast required to recoup the deficiencies or to provide required profiles/sections. These net quantities of ballast may be enhanced suitably (say by 8%) to arrive at the gross quantities of ballast needed for the purpose of procurement in case the measurements are proposed to be taken in stacks or wagons at the originating station.

Guidelines for Provision of Sub-ballast

The sub-ballast is normally made of granular material and is provided between the formation and the ballast in order to distribute the load evenly over the formation. The following points should be kept in mind while selecting a material for sub-ballasts.

(a) The material should consist of coarse granular substance such as river gravel, stone chips, quarry grit, and predominantly coarse sand. Ash, cinder, and slag containing predominantly fine and medium sand should not be used.

(b) The material should be non-cohesive and graded. The uniformity coefficient should be more than 4 to ensure that the sub-ballast is well graded.

(c) The material should not contain more than 15% of fines that measure less than 75 microns.

(d) The thickness of the sub-ballast should not be less than 150 mm.

Subgrade and Formation

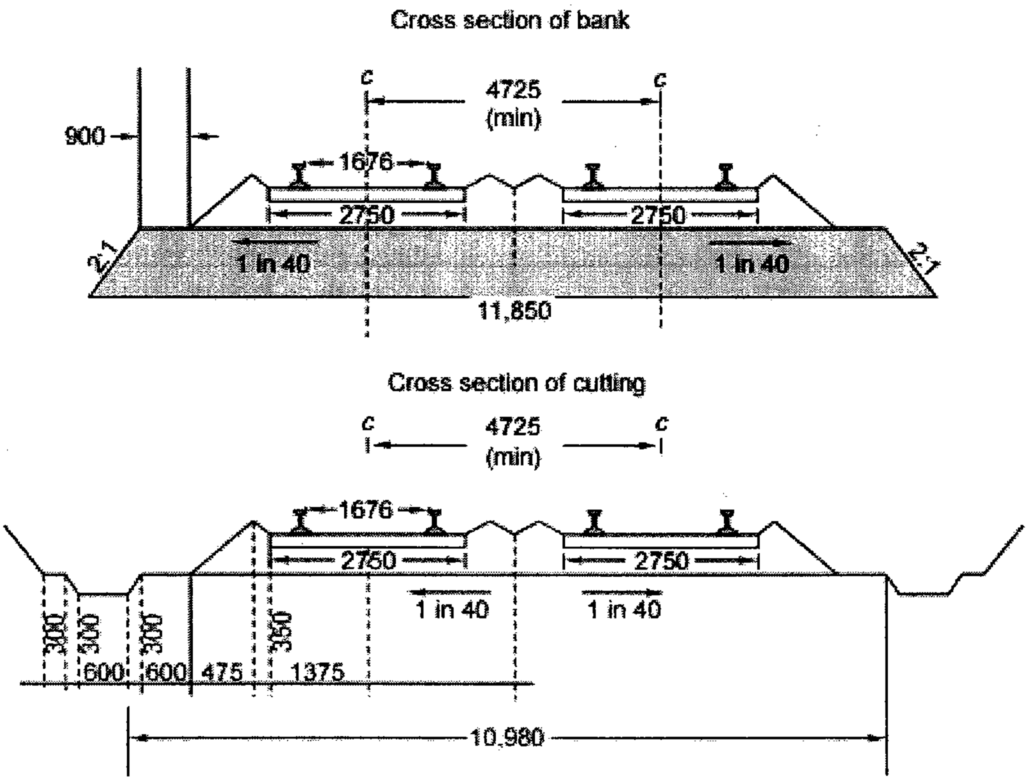


Fig. 9.1 Typical cross section of bank and cutting for BG double line (dimensions in mm)

Subgrade and Formation - Introduction

Subgrade is the naturally occuring soil which is prepared to receive the ballast. The prepared flat surface, which is ready to receive the ballast, sleepers, and rails, is called the formation. The formation is an important constituent of the track, as it supports the entire track structure. It has the following functions.

(a) To provide a smooth and uniform bed for laying the track.
(b) To bear the load transmitted to it from the moving load through the ballast.
(c) To facilitate drainage.
(d) To provide stability to the track.

The formation can be in the shape of an embankment or a cutting. When the formation is in the shape of a raised bank constructed above the natural ground, it is called an *embankment*. The formation at a level below the natural ground is called a *cutting*. Normally a cutting or excavation is made through a hilly or natural ground for providing the railway line at the required level below the ground level.

The formation (Fig. 9.1) is prepared either by providing additional earthwork over the existing ground to make an embankment or by excavating the existing ground surface to make a cutting. The formation can thus be in the shape of either an embankment or a cutting. The height of the formation depends upon the ground contours and the gradients adopted. The side slope of the embankment depends upon the shearing strength of the soil and its angle of repose. The width of the formation depends upon the number of tracks to be laid, the gauge, and such other factors. The recommended widths of formation as adopted on Indian Railways for BG, MG, and NG are given in Table 9.1.

The following points are relevant with respect to the dimensions given in Table 9.1.

(a) The widths have been calculated for a minimum width of 900 mm in banks and 600 mm in cuttings and a ballast profile slope of about 1:1.
(b) The width of a double-line section has been calculated with a track centre of 5.30 m on BG and 3.96 m on MG. These dimensions are based on a ballast cushion of 300 mm.
(c) The side drain should have a minimum of 0.30 m horizontal berm on the side (i.e., on other than the track side) in order to be fully effective.

Slopes of Formation

The side slopes of both the embankment and the cutting depend upon the shearing strength of the soil and its angle of repose. The stability of the slope is generally determined by the *slip circle method*. In actual practice, average soil such as sand or clay may require a slope of 2:1 (horizontal:vertical) for an embankment and 1:1 or 0.5:1 or even steeper particularly when rock is available for cutting.

To prevent erosion of the side slopes due to rain water, etc., the side slopes are turfed. A thin layer of cohesive soil is used for this purpose. Alternatively, the slopes are turfed with a suitable type of grass. Sometimes the bank also gets eroded due to standing water in the adjoining land. A toe and pitching are provided such cases.

Execution of Earthwork in Embankments and Cuttings

The stability of the formation depends, apart from other factors, upon the subgrade material and the methods of construction. Experience has shown that many of the problems in the maintenance of the track are due to incorrect methods of execution of earthwork. In order to have a certain uniformity in practices, guidelines have been laid down by Indian Railways for the execution of earthwork in embankments and cuttings in new constructions, doubling, and conversion projects. These guidelines, given briefly in the following sections, are required to be modified to suit local conditions and prevailing circumstances.

Mechanical compaction of earthwork

For mechanical compaction, earthwork should be done in layers not exceeding a thickness of 300 mm to 650 mm in the loose state using static and vibratory rollers, respectively. The layers should be compacted preferably at or near the optimum moisture content with suitable rollers so as to achieve the dry density 98% for laboratory density.

The top of the formation should be finished to a slope of 1 in 30 away from the centre. An extra wide bank of 50 cm should be rolled on either side and then dressed to size to avoid any loose earth at the shoulder.

Proper quality control should be exercised during mechanical compaction. Coarse-grained soil which contains fines up to 5% passing through a 75-micron sieve should be compacted to get the relative density of a minimum of 70%. However, all other types of soil, when compacted, should normally have at least 98% of the maximum dry density determined by using Proctor's compaction.

1 Soil Classification

Soil exploratory surveys are carried out in the beginning by taking soil samples from the site. The soil is then classified as 'good' or 'other-than-good' depending upon its grain size and consistency limits. Broadly speaking, coarse-grained soils come under the category of good soils. Fine-grained soils such as inorganic clay, silts, sandy soils, and clayey soils are grouped under the category of other-than-good soils. However, the Indian Standard method of soil classification, which is also based on grain size distribution and consistency limits of the soil, is more scientific and elaborate. The grain size is determined by mechanical analysis of the soil. The soil is screened through a set of sieves, and based on the sieve analysis, the soil is classified as gravel (coarser than 2.00 mm), coarse sand (2.00-0.60 mm), medium sand (0.60-0.20 mm), fine sand (0.20-0.60 mm), silt (0.06-0.002 mm), or clay (finer than 0.002 mm).

Black cotton soil

Black cotton soil is a type of shrinkable soil which changes its properties considerably with change in moisture content. With the addition of water, this type of soil swells, thereby losing its strength. Loss of moisture may result in cracks in the soil. During dry seasons, the ballast penetrates into these cracks causing the track to sink. The situation worsens during the rainy season, when water entering these cracks makes the soil soft, and with the hydrostatic pressure and impact of moving loads, deeper ballast pockets are formed. This undesirable property of swelling and shrinkage of black cotton soil presents a lot of problems in the maintenance of proper levels of subgrade.

Remedial Measures The suggested remedies for the problems discussed are as follows.

(a) Treating the top layer of the soil with quick lime so as to reduce the harmful effects of the soil.

(b) Providing a blanket of a graded inverted filter at the top of the embankment.

(c) Consolidating the soil at optimum moisture content.

(d) Providing a bituminous carpet or other similar intercepting material such as polythene sheets to intercept the surface water getting into the formation.

(e) Improving the drainage conditions of the formation at surface and sub-surface levels.

2 Specifications for Embankments in Good Soil

The following guidelines are followed by Indian Railways for embankment construction on good soil.

For embankments up to 6 m high

The earthwork should be carried out manually in layers not exceeding 30 cm in thickness. All clods of earth should be broken. Earthwork should be carried out in this manner for a height of up to 1 m below the formation. The earthwork is then to be exposed to rains for one season before taking up the remaining work. The remaining earthwork is carried out by mechanical compaction of the soil in layers not exceeding 30 cm at optimum moisture content in order to obtain at least 90% of the maximum dry density.

For embankments more than 6 m high

In the first working season, up to 6 m or less of earthwork should be done and exposed to the rains. In the second working season, earthwork should be progressed further up to a distance of 1 m lower than the formation level and exposed to rains. The remaining earthwork should be done in the third working season by mechanical compaction. The work can also be completed in the second working season if mechanical compaction is used.

On high-speed and heavy-density routes, a blanket of suitable material or a sub-ballast of 30 cm thickness may be provided. The formation should be given a cross slope of 1 in 40 or 1 in 30 from the centre towards the cess.

3 Specifications for Cuttings in a Good Soil

The following guidelines are followed by Indian Railways for cuttings in good soil.

(a) If the normal dry density of the top 30 cm of soil is less than 90% of the maximum dry density, the formation should be rolled to obtain the desired density.

(b) The road bed should be given a cross slope of 1 in 40 or 1 in 30 from the centre towards the drains on either side.

4 Embankments in Other-than-good Soils

The guidelines adopted by Indian Railways for embankment construction in soil that is not categorized as good are given below.

(a) The earthwork should be compacted to full height at optimum moisture content in layers not exceeding 30 cm in thickness in order to obtain 90% of the maximum dry density.

(b) A blanket of suitable material of height not less than 30 cm should be provided on the road bed and should be compacted.

(c) A cross slope of 1 in 30 should be provided from the centre towards the cess.

5 Cuttings in Other-than-good Soils

The guidelines listed here are followed by Indian Railways for digging cuttings in soil that is not categorized as good.

(a) The cutting should be provided with drainage.

(b) A 30-cm-thick blanket of suitable material should be provided in two layers at optimum moisture content and duly compacted.

(c) A cross slope of 1 in 30 should be provided.

Track drainage

Track drainage is defined as the interception, collection, and disposal of water from upon or under the track. It is accomplished by a surface and sub-surface drainage system. Proper drainage of the subgrade is very vital, as excess water reduces the bearing capacity of the soil as well as its resistance to shear. The full details about track drainage can be obtained from Chapter 19 where this subject is dealt with in depth.

Blanket and Blanketing Material

A blanket can be defined as an intervening layer of superior material that is provided in the body of the bank just underneath the ballast cushion. It is different from the sub-ballast, which is provided above the formation. The functions of the blanket are twofold:

(a) to minimize the puncturing of the stone ballast into the formation soil and

(b) to reduce the ingress of rain water in to the formation soil.

The blanket should generally cover the entire width of the formation from the shoulder, except in the case of sand or similar erodable material, where it should be confined within berms of a width of 60-75 cm. The depth of the blanket should normally be about 30 cm in ordinary clayey soil. However, if the formation soil is particularly weak, a thicker layer of up to 60 cm may be necessary, depending on the shear properties of the formation soil. The blanket material should have the following properties.

For sand, quarry grit, gravel, and other non-cohesive materials

(a) The blanket material should be coarse and granular.

(b) If the material contains plastic fines, the percentage of fines (particles measuring up to 75 microns) should not exceed 5. If the fines are non-plastic, then they can be allowed up to a maximum of 12%.

(c) The material should be properly graded and its particle size distribution curve should lie within the standard enveloping curves.

For Macadam

(a) The liquid limit should not exceed 35 and the plasticity index should be below 10.

(b) The uniformity coefficient should be above 4, preferably above 7. The coefficient of curvature, which is $D^2_{30}/D_{60}\ D_{10}$, should be between 1 and 3.

(c) When macadam is used as the blanketing material, it should be compacted in a suitable number of layers at or near the optimum moisture content so as to achieve not less than 90% of the maximum dry density as determined by Proctor's test using heavy compaction.

(d) If an erodable material is used as a blanket, it should be confined in a trench and sand drains should be provided across the track and the blanket. These cross sand drains with adequate slope should be 5-30 cm below the bottom of the blanket and spaced 2-4 m apart.

Rail-to-Rail Fastenings

Rail-to-rail fastenings involve the use of fish plates and bolts for joining rails in series. Detailed descriptions of these are given in the following sections.

1 Fish Plates

The name 'fish plate' derives from the fish-shaped section of this fitting (Fig. 10.1). The function of a fish plate is to hold two rails together in both the horizontal and vertical planes. Fish plates are manufactured using a special type of steel (Indian Railways specification T-1/57) with composition given below:

Carbon: 0.30-0.42% Manganese: not more than 0.6%
Silicon: not more than 0.15%

Sulphur and phosphorous: not more than 0.06%

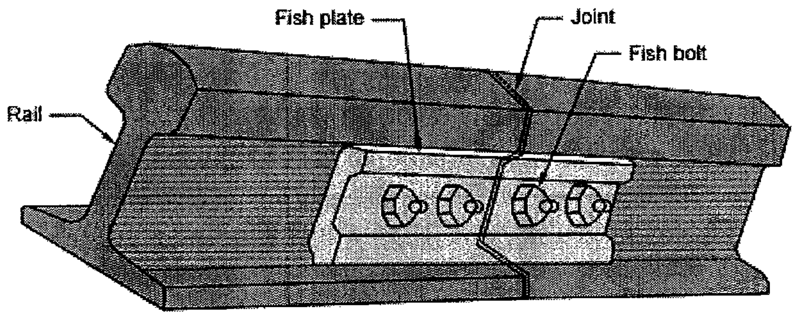


Fig. 10.1 Fish plate

The steel used for fish plates should have a minimum tensile strength of 5.58 to 6.51 t/cm^2 with a minimum elongation of 20%. Fish plates are designed to have roughly the same strength as the rail section, and as such the section area of two fish plates connecting the rail ends is kept about the same as that of the rail section. As fish plates do not go as deep as the rail, the strength of a pair of fish plates is less than that of the rail section, about 55%, when only vertical bending is taken into consideration. Fish plates are so designed that the fishing angles at the top and bottom surface coincide with those of the rail section so as to allow perfect contact with the rail as shown in Fig. 10.2. The details of standard fish plates used on Indian Railways for different rail sections are given in Table 10.3.

2 Combination Fish Plates

Combination or junction fish plates (Fig. 10.3) are used to connect rails of two differential sections. These are designed to cover the rail section at either end adequately up to the point in the centre where the rail section changes. Another design feature in these junction fish plates is the elimination of the expansion gap in order to give them more strength. In spite of the varying depths of the combination fish plates used in the fitting of 52 kg/90 R, 90 R/75 R, 75 R/60 R, etc. rail sections, the use of junction fish plates provides a common top table for the two rail sections they join. A uniform system of marking and exact nomenclature is adopted for each junction fish plate for proper identification. Fish plates are marked right in, right out, left in, and left out depending upon their position with respect to the direction from the lighter rail to the heavier rail (as shown in Fig. 10.4). In the case of any difficulty in obtaining a combination fish plate, the following alternate arrangement can be made.

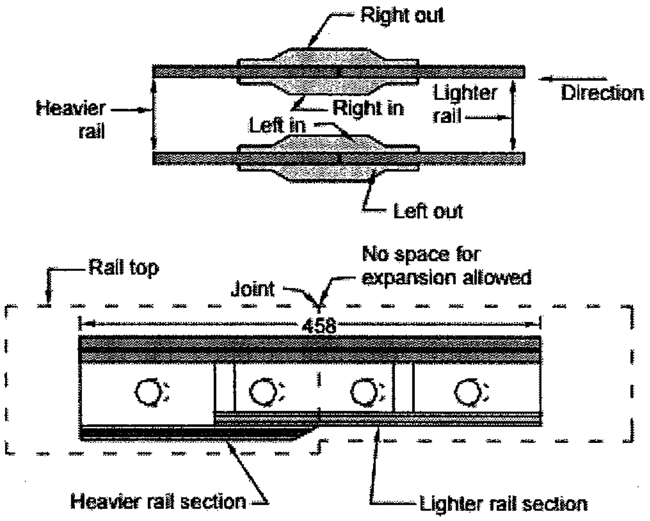


Fig. 10.3 Combination fish plate (dimensions in mm)

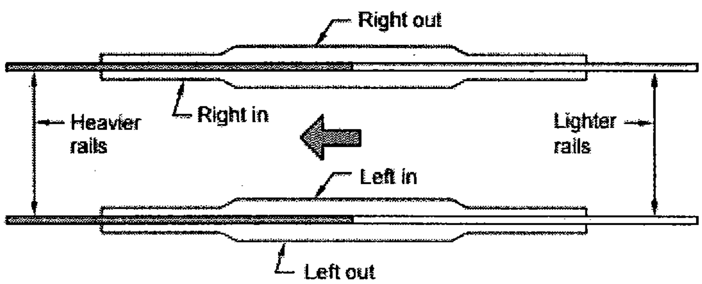


Fig. 10.4 Marking of combination fish plates

1. First the composite rail, normally of a length not less than 4 m, is prepared by welding together two rail pieces of different rail sections.
2. This composite rail piece is then inserted at the joint in lieu of the combination fish plate.

3. Normal fish plates are then used to join the composite rail piece to the rail lengths on either side, which have a rail section identical to that of the composite rail piece..

Fittings for Wooden Sleepers

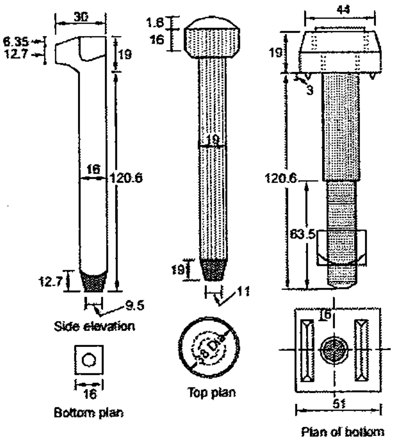


Fig. 10.5 Dog spike, round spike, and fang bolt

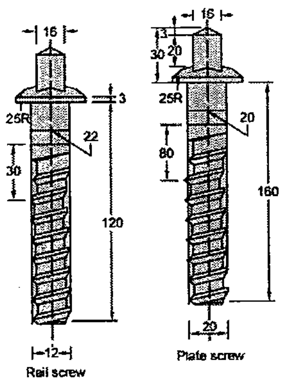


Fig. 10.6 Screw spikes

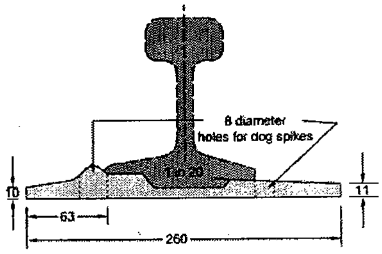


Fig. 10.7 Canted MS bearing plate for 90 R

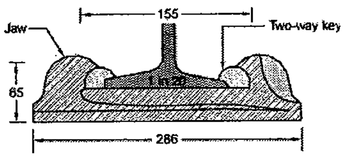


Fig. 10.9 CI anticreep bearing plate

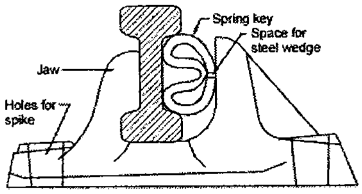


Fig. 10.10 CI bearing plate for BH rail

Rails are fixed to wooden sleepers with the help of simple types of fastenings such as spikes, screws, and bearing plates.

Fittings for Wooden Sleepers: Rails are fixed to wooden sleepers with the help of simple types of fastenings such as spikes, screws, and bearing plates.

1 Dog Spikes: This fastening is named dog spike (Fig. 10.5) because the head of this spike looks like the ear of a dog. Dog spikes are used for fixing rails to wooden sleepers. The number of dog spikes normally used is as follows:

Location	Number of dog spikes
1 On straight track	2 (1 on either side and duly staggered)
1 On curved track	3 (2 outside and 1 inside)
1 Joint sleepers, bridges	4 (2 outside and 2 inside)

The dog spike has a 16-mm square section and its length varies depending upon the location at which it is placed, as given in Table 10.4.

Table 10.4 Details of dog spikes

Table 10.4 Details of dog spikes

Location of dog spike	*Length of dog spike*	
	mm	*in.*
BG points and crossings	160	6.5
BG track with canted bearing plates; MG points and crossings	135	5.375
MG track with canted bearing plates; NG points and crossings	120	4.75
MG track without bearing plates; NG track with or without bearing plates	110	4.5
BG track without bearing plates	120	4.75

2 Round Spikes: Round spikes (Fig. 10.5) are used along with anticreep bearing plates for fixing rails to sleepers. These are also used for fixing assemblies of switches onto wooden sleepers. The round spike has a round section of a diameter of 18 mm, and its length depends upon the purpose it serves. Round spikes have become obsolete now

3 Fang Bolts : Fang bolts (Fig. 10.5) are employed under the switches for fastening slide chairs to the sleepers. These are used in locations where the gauge is to be preserved.

4 Screw Spikes : Indian Railways has developed screw spikes with diameters of 20 mm and 22 mm (Fig. 10.6) to be used on high-speed, main, and trunk routes in order to increase the lifespan of wooden sleepers. Screw spikes with a diameter of 20 mm are called 'plate screws' and are used in place of round spikes for fixing rails to sleepers with the help of anticreep bearing plates while screw spikes with a diameter of 22 mm are called 'rail screws' and are used to directly fasten the rails to the sleepers with or without the use of bearing plates. They are also used on bridges and platform lines. Plate and rail screws should be preferred to round and dog spikes in order to conserve the life of wooden sleepers.

5 Bearing Plates : Bearing plates are used for fixing wooden sleepers to rails. The different types of bearing plates in use on Indian Railways are described below.

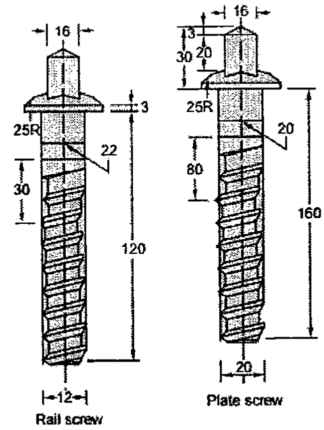


Fig. 10.6 Screw spikes

Mild steel canted bearing plates Mild steel canted bearing plates are used on all joints and curves to provide a better bearing area to the rails. They have a cant of 1 in 20 and a groove in the centre to prevent rocking. Mild steel (MS) canted bearing plates with only round holes are sanctioned for use on the Railways. The normal size of this kind of bearing plate is 260 mm � 220 mm � 18 mm for 52 kg and 90 R rails (Fig. 10.7).

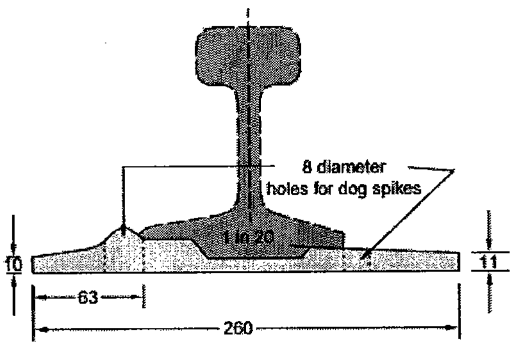


Fig. 10.7 Canted MS bearing plate for 90 R

Flat MS bearing plates Flat MS bearing plates are used at points and crossings in the lead portion of a turnout. No cant is provided in these bearing plates. The size of this bearing plate is 260 mm 220 mm 19 mm for 52 kg and 90 R rails (Fig. 10.8).

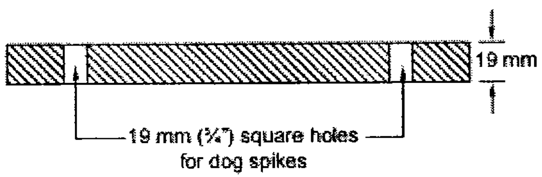


Fig. 10.8 Flat MS bearing plate

Cast iron anticreep bearing plates Cast iron (CI) anticreep bearing plates are provided with wooden sleepers at locations where the rails are likely to develop creep. These bearing plates have a cant of 1 in 20 and can be fixed using normal round spikes. The size of this bearing plate is 285 mm 205 mm for BG tracks (Fig. 10.9).

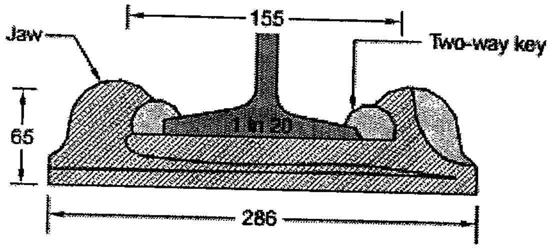


Fig. 10.9 CI anticreep bearing plate

Special CI bearing plates for BH rails Special cast iron bearing plates are used for fixing bull headed (BH) rails. The rail is held in position with the help of a spring key (Fig. 10.10).

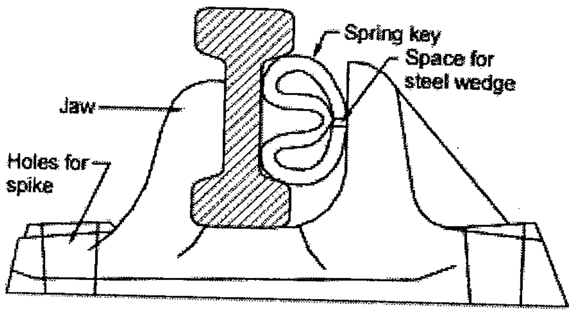


Fig. 10.10 CI bearing plate for BH rail

Fittings of Steel Trough Sleepers

The fittings required for metal sleepers are different form those used for wooden sleepers. Loose jaws, keys, and rubber pads are used to fix rails to steel sleepers.

Loose jaws

Loose jaws (Fig. 10.11) and keys are used for holding the rail and the steel trough sleeper together. The older type of trough sleepers were easily damaged, cracked, or deformed due to the provision of pressed-up lugs. There problems have been solved by introducing spring steel loose jaws, which have been standardized on Indian Railways. These jaws can be easily replaced whenever necessary. They are manufactured using spring steel and the weight of 100 loose jaws is approximately 28.8 kg.

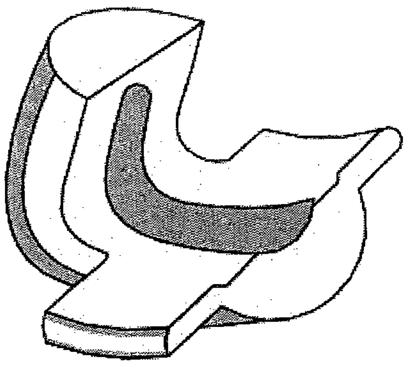


Fig. 10.11 Spring steel loose jaw

Two-way keys

Two-way keys (Fig. 10.12) are universally used for fixing trough sleepers, pot sleepers, and CST-9 sleepers. A two-way taper is provided at both ends of a two-way key and as such the key can be driven in either direction. These keys are manufactured using a special rolled section. The length of the keys for BG is about 190 mm with a taper of 1 in 32. A gauge variation of �3 mm can be adjusted by altering the extent to which these keys are driven in.

The various methods of driving keys for different types of sleepers are listed in Table 10.5.

Rubber-coated and epoxy-coated fish plates

Some time back, rubber-coated fish plates were used at insulated joints on Indian Railways on a trial basis. The results indicated that these fish plates get damaged early in service, thereby limiting their life. Therefore, epoxy-coated fish plates are now being tried.

Fittings of CI Sleepers

Rails are fixed to cast iron sleepers using cotters and tie bars. These fittings are described below.**Fittings of CI Sleepers** Rails are fixed to cast iron sleepers using cotters and tie bars. These fittings are described below.

Cotters Cotters (Fig. 10.14) are used for fixing tie bars to CI sleepers. Cotters are classified according to their methods of splitting. The four different types of cotters being used on Indian Railways are as follows.

(a) Centre split cotter

(b) Side split cotter

(c) Solid end split cotter

(d) Bent plate cotter

The overall dimensions, taper, etc. of these four cotters are by and large identical; they only differ in their methods of splitting. The length of a cotter is 152 mm and the approximate weight is 0.80 lb per piece

MS tie bars MS tie bars are used for holding the two plates of CST-9 sleepers together. The normal length of a tie bar is 2720 mm for BG and 1870 mm for MG. The section of a BG tie bar measures 50 mm 13 mm and that of an MG tie bar measures 45 mm 10 mm.

Elastic Fastenings The primary purpose of a fastening is to fix the rail to the sleeper. The rail may be fixed either directly or indirectly with the help of fastenings. In the process, the fastening gets subjected to strong vertical, lateral, and longitudinal forces. The forces, which are predominantly dynamic, increase rapidly with increasing loads and speeds. In addition, vibrations are generated by moving loads mainly on account of geometrical irregularities in the track and due to the forces set up by the imbalance in the rolling stock.

1 Requirements of an Elastic Fastening

The ideal elastic fastening should meet the following requirements.

(a) It should hold the gauge firmly in place.

(b) It should have an adequate toe load which should not reduce under service.

(c) It should provide sufficient elasticity to absorb the vibrations and shocks caused by moving loads.

(d) It should help in keeping the track well maintained.

(e) It should offer adequate resistance to lateral forces in order to maintain the stability of the track.

(f) It should provide adequate resistance to the longitudinal forces that are a result of the acceleration of moving loads and other miscellaneous factors. These longitudinal forces tend to cause the development of creep in the track.

(g) It should be of the 'fit and forget' type so that it requires least maintenance.

(h) It should not lose its properties even when it is used over and over.

(i) It should have as few parts as possible and these parts should be easy to manufacture, lay, and maintain.

(j) It should be irremoveable so that once fitted it cannot be taken out and as such it should not be vulnerable to sabotage or theft.

(k) It should be universally applicable so that it can be used with wooden, steel, or concrete sleepers.(l) It should be cheap and long lasting.

Types of Elastic Fastenings An elastic fastening is usually in the form of a clip. Various types of clips have been developed over the years; these are discussed here in detail.

Pandrol clip or elastic rail clip: The Pandrol PR 401 clip (also known as an elastic rail clip) (Fig. 10.15) is a standard type of elastic fastening used on Indian Railways, earlier manufactured by Messrs Guest, Keens & Williams. It is a 'fit and forget' type of fastening that requires very little attention towards its maintenance. The clip is made of a silico-manganese spring steel bar with a diameter of 20.6 mm and is heat treated. It exerts a toe load of 710 kg for a nominal deflection of 11.4 mm. The toe load is quite adequate to ensure that no relative movement is possible between the rail and the sleeper. Pandrol clips can be driven with the help of an ordinary 4-pound hammer and require no special tools. In order to ensure that the correct toe load is exerted, the Pandrol clip should be driven to such an extent that the outer leg of the clip is flush with the outer face of the CI insert. Figure 10.16 shows an isometric view of the clip fixed on the rail while Fig. 10.17 shows the clip fixed to a rail seat.

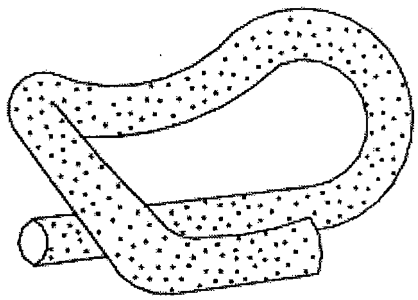


Fig. 10.15 Pandrol clip or elastic rail clip

The Pandrol or elastic clip can be fixed on wooden, steel, cast iron, and concrete sleepers with the help of a base plate and some other ancillary fittings. Pandrol clips are the most widely used clips with concrete sleepers on Indian Railways. Therefore, it becomes imperative that a detailed account of the same be given.

Concrete sleepers with Pandrol/elastic clips In the case of concrete sleepers, malleable cast iron inserts are punched directly into the sleepers during manufacture. The Pandrol clip is fixed in the holes of the CI insert. A 4.5-mm-thick grooved rubber pad is provided under the rail seat to make it doubly elastic. Insulated liners provide the necessary insulation (Fig. 10.18).

Drawbacks of Pandrol clip The Pandrol clip suffers from the following drawbacks

1. Their use makes the adjustment of the gauge impossible.

2. The Pandrol clip has a point contact and this causes indentation on the foot of the rail due to a heavy toe load and a small contact area.

3. It does not provide enough safeguard from theft or sabotage because it can easily be taken out using an ordinary hammer.

4. It gets caught inside the malleable cast iron (MCI) insert during service.

Toe load measuring device This device consists of a lever made of silico- manganese steel and is designed to grip the Pandrol rail slip toe. It is used in conjunction with a suitable block which is fitted on the rail head and acts as the fulcrum. To operate the device, a force is gradually applied to the handle and the reading of the dial gauge at which the Pandrol clip toe is just lifted above the rail seat is noted. The reading of the dial gauge indicates the toe load, which is pre-calibrated in the laboratory

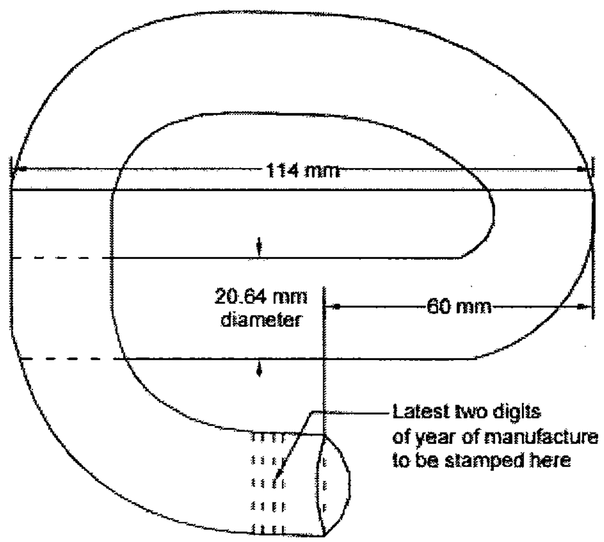


Fig. 10.22 Pandrol clip (ERC rail clip) MK III

The ERC MK-III clip has been modified from the standard elastic rail clip to the extent that the distance of the toe of the clip has increased with respect to the centre leg. The space curves of the clip have also been modified to achieve a higher toe load. The diameter of the standard ERC has been retained, i.e., 20.6 mm.

The new ERC MK-III has a toe load of 900-1100 kg with a toe deflection of 15.5 mm. The clip is still under trial.

Herbert Meir fastening

The Herbert Meir (HM) fastening (Fig. 10.23) basically consists of four coach screws which are tightened against the plastic dowels of the PRC sleepers and press the HM clip assembly to give the desired toe load. Each clip weighs about 510 g and can give a toe load of about 1 t. The gauge is maintained with the help of an angled guide plate. A thin insulated shim is placed between the angled plate and the concrete sleepers. A grooved rubber pad is placed below the seat to provide the necessary dampening effect and resistance to the lateral movement of rails.

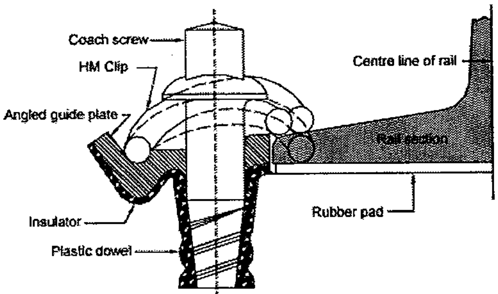


Fig. 10.23 HM fastening

The HM fastening can be used for 52-kg as well as 60-kg rails by using a suitable size of angled guide plates and insulating shims

Some Fittings and Fastenings

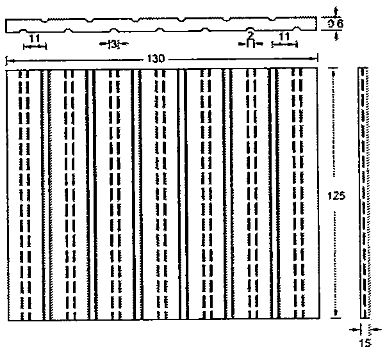


Fig. 10.24 Rubber pad

This section discusses malleable cast iron inserts, rubber pads, composite liners, and pilfer-proof elastic fastenings.

Other Fittings and Fastenings

This section discusses malleable cast iron inserts, rubber pads, composite liners, and pilfer-proof elastic fastenings.

1 MCI Inserts: Malleable cast iron inserts are directly fixed onto concrete sleepers during manufacture. MCI inserts are manufactured according to the Indian Railway Standard (IRS) specification T-32-76. These inserts are of two types.

(a) Stem-type MCI insert for use in normal pre-tension concrete sleepers. This insert is provided in concrete sleepers being manufactured in all the concrete sleeper factories in India except the one located at Allahabad. The weight of the stem-type insert is about 1.6 kg per piece.

(b) Gate-type MCI insert for use in the post-tension concrete sleepers being manufactured at Allahabad. The approximate weight of the gate-type MCI insert is 1.7 kg per piece.

2 Rubber Pads

A rubber pad (Fig. 10.24) is an integral part of an elastic fastening. It is provided between the rails and the sleepers and has the following functions.

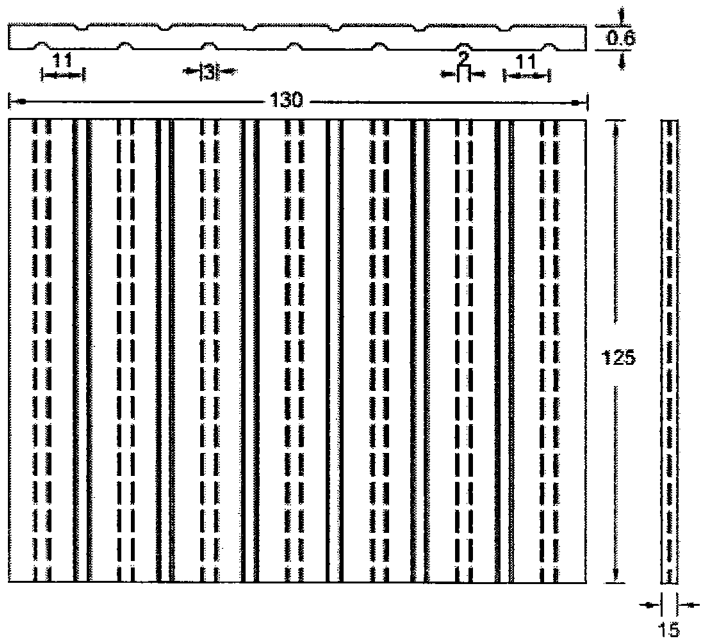


Fig. 10.24 Rubber pad

(a) It absorbs shocks.

(b) It dampens and absorbs vibrations.

(c) It resists the lateral movements of the rails.

(d) It prevents the abrasion of the bottom surface of the rail, which would otherwise come in direct contact with the sleepers.

(e) It provides electrical insulation between the rails in an electrified area. Indian Railways uses grooved rubber pads of 4.5 mm thickness made of specialquality rubber. The grooves aid in the uniform distribution of the load on sleepers and help to limit the lateral expansion of the rubber under the pressure of dynamic loads. The RDSO has recently designed 6-mm-thick grooved rubber pads with horns (Drg. No. RDSO/T-37) for use on 60-kg rails (Fig. 10.25). It was noticed that normal 4.5-mm-thick rubber pads (IRST-37-1982) got crushed wihtin 6-7 years and, therefore, thicker, grooved rubber pads with a service life of 15-20 years were designed particularly for use on 60-kg UIC rails. These rubber pads are still under trial.

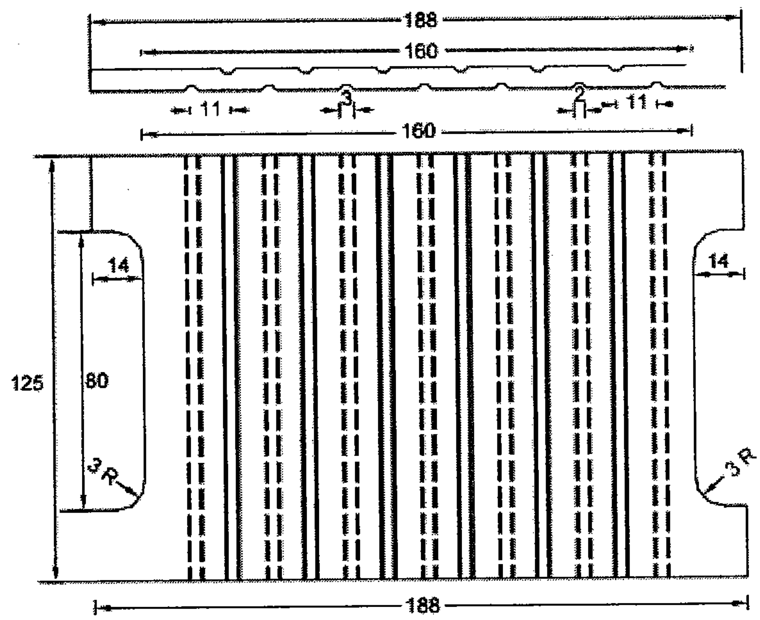


Fig. 10.25 6-mm-thick grooved rubber pad

3 Composite Liners The Indian Railways mostly uses nylon insulating liners. These liners, however, get crushed under the toe load exerted by Pandrol clips. To eliminate such premature failure, the following two types of composite liners have been evolved by RDSO.

Composite liner with malleable cast iron and nylon components (Drg. No. RDSO/T653/1)

(b) Composite liners with MS and nylon components (Drg. No. RDSO/T-1895) These liners have been developed on the basis of the designs of the liners adoptedon British Railways, which have been reported to provide trouble-free service. Composite liners have been used on Indian Railways for the last few years and are serving the railways well.

Glass-filled nylon liners

The RDSO has developed glass-filled nylon liners (Fig. 10.26) (GFN-66) of 4 mm thickness particularly for track-circuited areas and sections subject to server corrosion. These glass-filled nylon liners are considered to be technically superior to other liners because they are single piece, have a longer life, and are free from corrosion. These liners are used extensively on Indian Railways particularly with the ERC clip assembly on 60-kg and 52-kg rails and PRC sleepers.

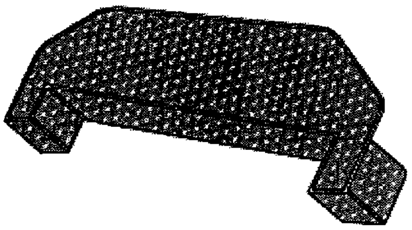


Fig. 10.26 Glass-filled nylon liner

It has been noticed that the GFN-66 liners tend to break, particularly in yards where these liners have been fitted in the ERC clip assembly on concrete sleepers. This happens due to the rusting of the rail surface and uneven seating. To avoid breakage of GFN-66 liners, it is necessary that proper precautions be taken during initial laying to ensure that the rail surface is free from rust, etc. and that the liners are fitted evenly on the 1 in 6 sloping surface of the rail flange. A new design of GFN-66 liners with a thickness of 6 mm (Drg. No. DSO/T-2505 Alt II) has recently been developed and is expected to be sturdier and provide a better service life.

4 Pilfer-proof Elastic Fastenings for Concrete Sleepers

The present design of elastic fastenings (Pandrol clips) is such that they can be easily removed by a single stroke of a hammer. A new type of elastic rail clip, which is pilfer-proof, has been recently developed by RDSO. A pilfer-proof elastic fastening may be defined as an elastic fastening system which is easy to fit in the assembly but is difficult to remove without damaging the system .The design of a pilfer-proof elastic rail fastening consists of clip of almost the same design as that of the normal elastic fastening as well as a new fitting known as the *pilfer-proof circlip*. The circlip is a standard mechanical component manufactured according to IS specifications and is generally used for restraining the axial movements of the components mounted on shafts.

Testing of Fastenings

Both elastic and rigid fastenings are tested in the laboratory for their suitability in the field. The vibrogir and pulsator are used to test these fastenings.

The vibrogir is used in laboratories for checking the effectiveness of various fastenings. With the help of this equipment it is possible to produce high-frequency vibrations in the laboratory, very similar to those produced on a real track. By applying a frequency of 50 Hz, the rail and sleeper are made to vibrate at a rate of 700-800 Hz with an acceleration of 70 g and an amplitude of the order of 0.1- 0.3 mm. One hour of working of a vibrogir corresponds to almost 4.05 GMT of traffic and 300 hours of its working creates the same effect on a fastening as 20 years of service under normal track conditions.

UNIT II GEOMETRIC DESIGN OF RAILWAY TRACK

Selection of a Good Alignment

Normally, a direct straight route connecting two points is the shortest and most economical route for a railway line, but there are practical problems and other compulsions which necessitate deviation from this route. The various factors involved is the selection of a good alignment for a railway line are given below.

Obligatory or Controlling Points

These are the points through which the railway line must pass due to political, strategic, and commercial reasons as well as due to technical considerations. The following are obligatory or controlling points.

Important cities and towns These are mostly intermediate important towns, cities, or places which of commercial, strategic, or political importance.

Major bridge sites and river crossings The construction of major bridges for large rivers is very expensive and suitable bridge sites become obligatory points for a good alignment.

Existing passes and saddles in hilly terrain Existing passes and saddles should be identified for crossing a hilly terrain in order to avoid deep cuttings and high banks.

Sites for tunnels The option of a tunnel in place of a deep cut in a hilly terrain is better from the economical viewpoint. The exact site of such a tunnel becomes an obligatory point.

Topography of the Country

The alignment of a new railway line depends upon the topography of the country it traverses. The following few situations may arise.

Plane alignment When the topography is plane and flat, the alignment presents no problems and can pass through obligatory points and yet have very easy gradients.

Valley alignment The alignment of a railway line in valley is simple and does not pose any problem. If two control points lie in the same valley, a straight line is provided between these points with a uniform gradient.

Cross-country alignment The alignment of a railway line in such terrain crosses the watersheds of two or more streams of varied sizes. As the levels vary in cross-country, the gradients are steep and varying and there are sags and summits. The controlling or obligatory points for cross-country alignment may be the lowest saddles or tunnels. It may be desirable to align the line for some length along the watersheds so that some of the drainage crossings may be avoided.

Mountain alignment The levels in mountains vary considerably, and if normal alignment is adopted, the grades would become too steep, much more than the ruling gradient (allowable gradient). In order to remain within the ruling gradient, the length of the railway line is increased artificially by the 'development process'. The following are the standard methods for the development technique:

Zigzag line method In this method, the railway line traverses in a zigzag alignment (Fig. 3.1) and follows a convenient side slope which is at nearly right angles to the general direction of the alignment. The line then turns about 180 o in a horseshoe pattern to gain height.

Switch-back method In the case of steep side slopes, a considerable gain in elevation is accomplished the switch-back method (Fig. 3.2). This method involves a reversal of direction achieved by a switch, for which the train has to necessarily stop. The switch point is normally located in a station yard. In Fig. 3.2, A and B are two switches and A_1 and B_1 are two buffer stops. A train coming from D will stop at B_1 and move in back gear to line BA. It will stop at A_1 again and then follow the line AC.AC.

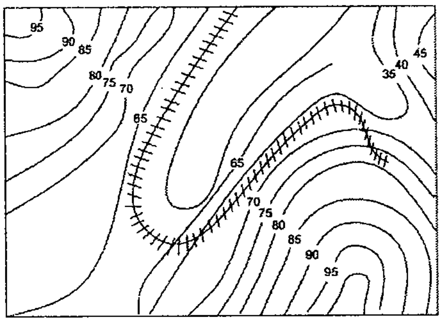


Fig. 3.1 Zigzag line alignment

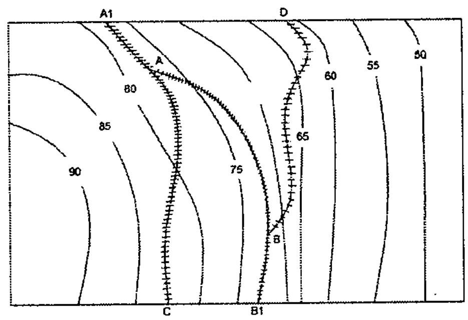


Fig. 3.2 Switch-back alignment

Spiral or complete loop method This method is used in a narrow valley where a small bridge or viaduct has been constructed at a considerable height to span the valley (Fig. 3.3). In this case, normally a complete loop of the railway line is constructed, so that the line crosses the same point a second time at a height through a flyover or a tunnel.

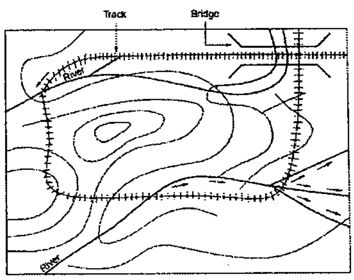


Fig. 3.3 Complete loop alignment

Geometrical Standards

Geometrical standards should be so adopted as to economize as much as possible as well as provide safety and comfort to passengers. This can be done by adopting gradients and curves within permissible limits. Transition as well as vertical curves should be used to provide better comfort and safety.

Geological Formation

The alignment should be so selected that it normally runs on good and stable soil formation as far as possible. Weak soil and marshy land present a number of problems including those of maintenance. Though rocky soil, provides a stable formation, it is a costly proposal.

Effect of Flood and Climate

The alignment should normally pass through areas which are not likely to be flooded. The climatic conditions should also be taken into consideration for alignment. In hot climate and sandy areas, the alignment should pass by those sides of sand dunes that face away from the direction of the wind. Similarly, in cold regions, the alignment should pass by those sides of hills that face away from the direction of the wind. A *sunny* side is more desirable.

Position of Roads and Road Crossings

A railway line should cross a road at right angles so as to have a perpendicular level crossing and avoid accidents.

Proximity of Labour and Material

The availability and proximity of local labour and good and cheap building material should also be considered when deciding the alignment.

Location of Railway Stations and Yards

Railway stations and yards should be located on level stretches of land, preferably on the outskirts of a town or village so as to have enough area for the free flow of traffic.

Religious and Historical Monuments

The alignment should avoid religious and historical monuments, as it is normally not possible to dismantle these buildings.

Cost Considerations

The alignment should be such that the cost of construction of the railway line is as low as possible. Not only the initial cost of construction but also the maintenance cost should be as low as possible. For this purpose, the alignment should be as straight as possible, with least earthwork, and should pass through terrain with good soil.

Traffic Considerations

The alignment should be so selected that it attracts maximum traffic. In this context, traffic centres should be well planned; so that the railway line is well patronized and the gross revenue arising out of traffic receipts is as high as possible.

Economic Considerations

Keeping in mind the various considerations, it should be ensured that the alignment is overall economical. For this purpose, various alternate alignments are considered and the most economical one, which is cost effective and gives the maximum returns is chosen.

The maximum annual return ($\gamma =$) is calculated by the formula

$$\gamma = \frac{R - E}{I}$$

where R is the gross revenue earned by the railway line and E denotes the annual running expenses.

It may be noted here that R depends upon the route that proves to be advantageous when taking traffic into consideration and, therefore, should be given due weightage. The other way to maximize the annual return is to have sound and economical construction work so as to reduce the annual running expenses. A suitable balance has to be achieved between construction cost and operating expenses.

Political Considerations

The alignment should take into account political considerations. It should not enter foreign soil and should preferably be away from common border areas.

Need for Construction of a New Railway Line

The need for construction of a new railway line arises because of one or more of the following considerations.

(a) *Strategic reasons* It is sometimes necessary to extend the existing railway line to a new point of strategic importance so that the defence forces can move quickly to the same areas in case of any emergency such as the threat of war.

(b) *Political reasons* A new line sometimes becomes necessary to serve the political needs of the country, for example, the railway line from Pathankot to Jammu.

(c) *Development of backward areas* Railway lines are sometimes constructed to develop backward areas. Experience has shown that once railway communication is available, backward areas develop very fast. The Assam rail link can be classified in this category.

(d) *To connect new trade centres* Sometimes new trade centres are connected with railway lines for the quick transportation of goods between two trade centres or from the point of production to the point of consumption.

(e) *To shorten the existing rail link* The existing routes between two important points may be longer than required. New railway lines are constructed on a shorter alignment in such cases. A short route is not only economical, but also helps in the faster movement of goods and passengers. The Konkan Railway is a typical example.

Doubling of existing single railway lines is also done in a few cases to cope up with the additional requirement of traffic. Recently, a large number of projects have also been under taken for converting the existing metre gauge lines into broad gauge lines in order to have a uniform gauge for the smooth flow of traffic.

Preliminary Investigations for a New Railway Line

Whenever the construction of a new railway line is under consideration, preliminary investigations are done by the railway administration to determine how the proposed line will fit in with the general scheme of future railway development. The preliminary investigations are normally based on a careful study of the following:

(a) Existing topo sheets and other maps of the area

(b) Published figures of trade and population of the area to be served

(c) Statistical data of existing railway lines in similar terrain in other areas

As a result of these investigations, it becomes possible to decide whether or not the new railway line is required and surveys should then be undertaken to get more details of the new line being contemplated.

Types of Surveys

Once a decision has been taken during preliminary investigations about the general feasibility and desirability of a railway line, surveys are undertaken before the construction of the new line. The following types of surveys are normally conducted:

(a) Traffic survey
(b) Reconnaissance survey
(c) Preliminary survey
(d) Final location survey

The details of these surveys are discussed in the following sections

1 Traffic Survey

Traffic survey includes a detailed study of the traffic conditions in the area with a view to determine the

(a) most promising route for the railway in the area,
(b) possible traffic the railway line will carry, and
(c) standard of railway line to be followed.

Traffic surveys are normally undertaken in conjunction with reconnaissance or preliminary engineering surveys so that the technical feasibility and relative costs of alternative proposals can be formulated. The traffic survey team should work in close cooperation with the engineering survey team. The survey team should visit all trade centres in the area and consult local bodies, state governments, and prominent citizens regarding trade and industry and propose the most suitable alignment for the new line.

Traffic survey consists of an economic study of the area keeping in mind the following considerations, information on which should be collected in detail:

(a) Human resources
(b) Agricultural and mineral resources
(c) Pattern of trade and commerce
(d) Industries located and projected
(e) Prospects of tourist traffic
(f) Existing transport facilities
(g) Locations of important government and private offices
(h) Planning for economic development of the area

The traffic survey team should make an assessment of the traffic likely to be carried by to the new line. While carrying out the survey, details of traffic likely to be offered by various government organizations, public bodies, or private enterprises should be gathered.

At the end of the survey, a report should be formulated by the officer-in-charge of the survey. The formation of the report is governed largely by the nature of the terms of reference and the investigations made. The traffic survey report should normally contain the following information:

(a) History of the proposal and terms of reference
(b) General description
(c) Potentials and prospects

(d) Industrial and economic development and traffic projections
(e) Population projection and volume of passenger traffic
(f) Existing rates and rates to be charged
(g) Location of route or routes examined, alternate routes, and possible extensions
(h) Station sites and their importance
(i) Train services, section capacity, and various alternative ways of increasing capacity
(j) Coaching earnings
(k) Goods earnings
(l) Working expenses and net receipts
(m) Engineering features
(n) Telecommunication facilities
(o) Financial appraisal
(p) Conclusions and recommendations

2 Reconnaissance Survey

This survey consists of a rapid and rough investigation of the area with a view to determine the technical feasibility of the proposal as well as the rough cost of one or more alternatives to the new line. The reconnaissance survey (RECCE) is normally based on contoured survey maps and other data already available without carrying out detailed investigations in the field. With the help of the maps, different alternative alignments of the new line are studied.
The general topography of the country is studied by the survey team and then field data are collected.

2.1 Survey Instruments

The reconnaissance survey is mostly conducted using survey instruments that rapidly measure approximate distances and heights. The survey instruments used are the following:
Prismatic compass To get magnetic bearings of the proposed alignment.
Aneroid barometer To ensure relative heights of various points.
Abney level or hand level or clinometer To measure the gradients or angles of slopes.
Binocular To view the physical features.
Pedometer To get an idea of the total length traversed while walking.

2.2 Modern Surveying Instruments and Techniques

Modern surveying instruments make extensive use of infrared beams, laser beams, as well as computers. Using these instruments, it is possible to carry out fairly accurate surveying efficiently at all times, eliminating human error.

Electromagnetic Distance Measurement (EDM) Instruments

EDM instruments rapidly and automatically measure both horizontal and vertical distances. The readings can be displayed on built-in computer screens. Examples of such instruments are the geodimeter and the tellurimeter, which have been used in the past for electronic distance measurement of up to 80 km during day or night. Modern EDM instruments are much more advance and versatile.

Use of Computers

The results of the field survey are recorded in the form of angles and distances in the normal field book or electronic notebook. Using computers, it is possible to do all calculations as well as plot accurately. Thus, output from the EDM can be fed into the computer, which in turn can plot plans and sections.

Use of Laser in Surveying

Laser is an acronym for light amplification by stimulated emission of radiation. Its property of low diversion is used for alignment purposes. The invisible line of sight in ordinary survey instruments is replaced by the bright red beam of the Laser. This beam is intercepted by the target composed of light-sensitive cells connected to the display panel. Its most important aspect is that the beam is in a perfect straight line. Distances up to 70 km can be measured using laser. For short distances infrared beams are used.

2.3 Field Data

The following field data are collected during the reconnaissance survey.

(a) General topography of the country

Approximate heights of the different points falling on the alignment

(c) Positions of rivers, streams, and some hydrological details of the same

(d) Positions of roads and highways

(e) Nature of soil at different places

(f) Rough location of various station sites

(g) Controlling points on the alignment, through which the railway line must pass

(h) Facilities for construction

2.4Project Report for Reconnaissance Survey

Based on the above data, a report should be prepared by the engineer in charge of the project bringing out clearly from the financial point of view whether or not the prospects of the line surveyed are such as to make it worthwhile to undertake further investigations to construct the line. The project report should be accompanied by an abstract estimate of the cost of the line.

The report and estimate should be accompanied by a map of the area on a scale of 20 km to 1 cm and an index map of 2.5 km to 1 cm.

3 Preliminary Survey

The preliminary survey consists of a detailed instrumental examination of the route to be selected as a result of the reconnaissance survey in order to estimate the cost of the proposed railway line. Based on the preliminary and traffic survey reports, the railway administration decides whether or not the proposed railway line is to be constructed.

3.1 Instruments for Preliminary Survey

The instruments to be used for a preliminary survey will depend on the topography of the country and its flora. The survey instruments normally used are the following.

(a) Theodolite for traversing and pegging the centre line

(b) Tacheometer for plotting the main features

(c) Dumpy level for taking the longitudinal and cross levels
(d) Plane table for getting details of various features
(e) Prismatic compass for measuring the magnetic bearings of a particular alignment .

3.2 Field Survey

The route selected is surveyed in greater detail in the preliminary survey. The survey normally covers a width of 200 m on either side of the proposed alignment. The following survey work is carried out.

(a) An open traverse is run along the centre line of the proposed alignment with the help of a theodolite, tacheometer, or a compass.
(b) Longitudinal and cross levelling on the proposed route for a width of 200 m on either side in order to make an accurate contour map.
(c) Plane tabling of the entire area to obtain various geographical details.
(d) Special survey of station sites, level crossings, and bridges using the plane table.

3.3 Data

The following information should normally be collected during a preliminary survey.

(a) Geological information such as type of soil strata and the nature of rocks.
(b) Source of availability of construction materials such as sand, aggregate, bricks, cement, and timber.
(c) Facilities for construction such as the availability of labour and drinking water.
(d) Full details of the land and buildings to be acquired.
(e) Details of existing bridges and culverts along with information about proximity of tanks, bunds, etc., which may affect the design of bridges.
(f) Details of road crossings along with the angles of crossing and the traffic expected on the level crossings.
(g) High flood level and low water level of all the rivers and streams falling on the alignment.
(h) Full details of station sites along with the facilities required.

3.4 Preparation of Project Repor

A report based on the preliminary survey is prepared after obtaining an estimate of the cost. The project report should contain the following details.

(a) Introduction
(b) Characteristics of the project area
(c) Standard of construction
(d) Route selection
(e) Project engineering including cost estimate and construction schedule
(f) Conclusions and recommendations

3.5 Cost Estimate

The report should be accompanied by cost estimate. The estimate based on the preliminary report should be sufficiently accurate to enable a competent authority to take a decision regarding the construction of the new line. The estimate should contain the following details.

(a) An abstract cost estimate of the line surveyed accompanied by an abstract estimate of junction arrangements.
(b) Detailed estimates of land, tunnels, major bridges, minor bridges, one kilometre of permanent way, rolling stock, and general charges.

The report and estimate should be accompanied by the following drawings.

(a) Map of the area (scale 20 km = 1 cm)
(b) Index plan and section (scale 0.5 km to 1 cm horizontal and 10 m to 1 cm vertical)
(d) Detailed plans and sections Plans of station yard
(e) Plans of junction arrangements

4.Preliminary Engineering-cum-traffic Survey

In practice, and quite often, both the traffic survey and the preliminary engineering survey are carried out simultaneously in order to expedite the project. In such cases techno-economic survey reports based on preliminary-cum-traffic surveys are compiled. Such techno-economic survey reports contain the following details.

(a) Introduction
(b) Traffic projections
(c) Analysis of alternatives
(d) Characteristics of project area
(e) Standards of construction (for new lines, multiple tracking schemes, gauge conversions)
(f) Route selection and project description
(g) Project engineering (for new lines, multiple tracking schemes, and gauge conversions)
(h) Cost, phasing, and investment schedules
(i) Financial appraisal
(j) Recommendations

5.Final Location Surve

Once a decision has been taken for a particular railway line to be constructed, a final location survey is done. The instruments used are generally the same as in the case of the preliminary survey. Final location survey is done to prepare working details and make accurate cost estimates in certain cases. The principal differences between the preliminary survey and the final survey are as follows.

(a) In the final location survey, the alignment is fully staked with the help of a theodolite, whereas it is not obligatory to do so in the case of preliminary survey.
(b) In the final location survey, a more detailed project report is prepared and submitted
(c) All working drawings are prepared in the final location survey.

The following tasks are carried out in the final location survey.

(a) The centre line is fully marked by pegs at 20 m. At each 100 m, a large peg should be used.
(b) Masonry pillars are built at tangent points of curves and along the centre line at intervals of 500 m.
(c) Longitudinal and cross levelling is done to ascertain the final gradient of the alignment. All gradients are compensated for curves.

(d) The sites for station yards are fully demarcated.

In the final location survey, the following set of drawings is prepared.

(b) General map of the country traversed by the project at a scale of about 20 km to 1 cm Index map, scale about 2.5 km to 1 cm

(c) Index plan and sections

(d) Detailed plans and sections

(e) Plans and cross section

(f) Plans of station yards

(g) Detailed drawings of structures

(h) Plans of junction arrangements

Necessity for Geometric Design of Track

The need for proper geometric design of a track arises because of the following considerations

Introduction

The geometric design of a railway track includes all those parameters which determine or affect the geometry of the track. These parameters are as follows.

1. Gradients in the track, including grade compensation, rising gradient, and falling gradient.
2. Curvature of the track, including horizontal and vertical curves, transition curves, sharpness of the curve in terms of radius or degree of the curve, cant or superelevation on curves, etc.
3. Alignment of the track, including straight as well as curved alignment.

It is very important for tracks to have proper geometric design in order to ensure the safe and smooth running of trains at maximum permissible speeds, carrying the heaviest axle loads. The speed and axle load of the train are very important and sometimes are also included as parameters to be considered while arriving at the geometric design of the track.

Necessity for Geometric Design

The need for proper geometric design of a track arises because of the following considerations

(a) To ensure the smooth and safe running of trains

(b) To achieve maximum speeds

(c) To carry heavy axle loads

(d) To avoid accidents and derailments due to a defective permanent way

(e) To ensure that the track requires least maintenance.

(f) For good aesthetics

Gradients of Track

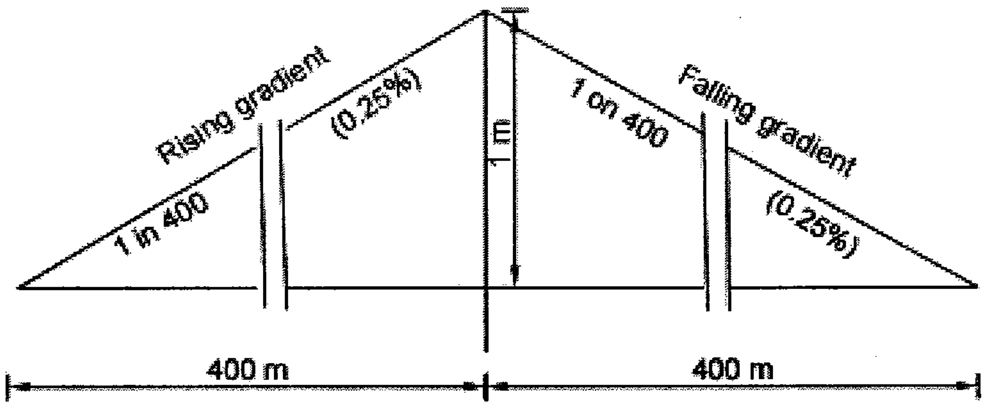


Fig. 12.1 Rising and falling gradient

Gradients are provided to negotiate the rise or fall in the level of the railway track.

Details of Geometric Design of Track

The geometric design of the track deals with the various aspects described in the following.

Alignment of railway track The subject of railway track alignment has been covered in Previous Pages.

Curves Details regarding curves and their various aspects have been discussed in Previous Pages.

Gradients Details regarding gradients are discussed in the following section.

Gradients of Track

Gradients are provided to negotiate the rise or fall in the level of the railway track. A rising gradient is one in which the track rises in the direction of the movement of traffic and a down or falling gradient is one in which the track loses elevation in the direction of the movement of traffic.

A gradient is normally represented by the distance travelled for a rise or fall of one unit. Sometimes the gradient is indicated as per cent rise or fall. For example, if there is a rise of 1 m in 400 m, the gradient is 1 in 400 or 0.25%, as shown in Fig. 12.1.

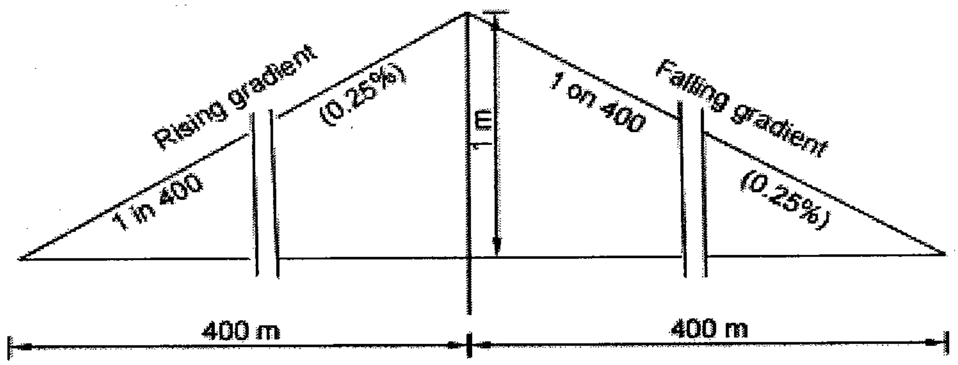


Fig. 12.1 Rising and falling gradient

Gradients are provided to meet the following objectives.

(a) To reach various stations at different elevations

(b) To follow the natural contours of the ground to the extent possible

(c) To reduce the cost of earthwork.

The following types of gradients are used on the railways.

(a) Ruling gradient

(b) Pusher or helper gradient

(c) Momentum gradient

(d) Gradients in station yards

1 Ruling Gradient

The ruling gradient is the steepest gradient that exists in a section. It determines the maximum load that can be hauled by a locomotive on that section. While deciding the ruling gradient of a section, it is not only the severity of the gradient but also its length as well as its position with respect to the gradients on both sides that have to be taken into consideration. The power of the locomotive to be put into service on the track also plays an important role in taking this decision, as the locomotive should have adequate power to haul the entire load over the ruling gradient at the maximum permissible speed.

The extra force P required by a locomotive to pull a train of weight W on a gradient with an angle of inclination θ is

$$P = W \sin \theta$$

$$= W \tan \theta \text{ (approximately, as } \theta \text{ is very small)} = W * \text{ gradient}$$

Indian Railways does not specify any fixed ruling gradient owing to enormous variations in the topography of the country, the traffic plying on various routes, and the speed and type of locomotive in use on various sections. Generally, the following ruling gradients are adopted on Indian Railways when there is only one locomotive pulling the train.

In plain terrain: 1 in 150 to 1 in 250

In hilly terrain: 1 in 100 to 1 in 150

Once a ruling gradient has been specified for a section, all other gradients provided in that section should be flatter than the ruling gradient after making due compensation for curvature.

2 Pusher or Helper Gradient

In hilly areas, the rate of rise of the terrain becomes very important when trying to reduce the length of the railway line and, therefore, sometimes gradients steeper than the ruling gradient are provided to reduce the overall cost. In such situations, one locomotive is not adequate to pull the entire load, and an extra locomotive is required.

When the gradient of the ensuing section is so steep as to necessitate the use of an extra engine for pushing the train, it is known as a pusher or helper gradient. Examples of pusher gradients are the Budni-Barkhera section of Central Railways and the Darjeeling Himalayan Railway section.

3 Momentum Gradient

The momentum gradient is steeper than the ruling gradient and can be overcome by a train because of the momentum it gathers while running on the section. In valleys, a falling gradient is sometimes followed by a rising gradient. In such a situation, a train coming down a falling gradient acquires good speed and momentum, which gives additional kinetic energy to the train and allows it to negotiate gradients steeper than the ruling gradient. In sections with momentum gradients there are no obstacles provided in the form of signals, etc., which may bring the train to a critical juncture.

4 Gradients in Station Yards

The gradients in station yards are quite flat due to the following reasons.

(a) To prevent standing vehicles from rolling and moving away from the yard due to the combined effect of gravity and strong winds.

(b) To reduce the additional resistive forces required to start a locomotive to the extent possible.

It may be mentioned here that generally, yards are not levelled completely and certain flat gradients are provided in order to ensure good drainage. The maximum gradient prescribed in station yards on Indian Railways is 1 in 400, while the recommended gradient is 1 in 1000.

Grade Compensation on Curves

Curves provide extra resistance to the movement of trains. As a result, gradients are compensated to the following extent on curves

(a) On BG tracks, 0.04% per degree of the curve or 70/R, whichever is minimum

(b) On MG tracks, 0.03% per degree of curve or 52.5/R, whichever is minimum

(c) On NG tracks, 0.02% per degree of curve or 35/R, whichever is minimum where R is the radius of the curve in metres. The gradient of a curved portion of the section should be flatter than the ruling gradient because of the extra resistance offered by the curve.

Example Find the steepest gradient on a 2 o curve for a BG line with a ruling gradient of 1 in 200.

Solution

(i) Ruling gradient = 1 in 200 = 0.5%

(ii) Compensation for a 2 o curve = 0.04 % 2 = 0.08%

(iii) Compensated gradient = 0.5 - 0.08 = 0.42% = 1 in 238 The steepest gradient on the curved track is 1 in 238.

Curves and Super elevation - **Introduction**

Curves are introduced on a railway track to bypass obstacles, to provide longer and easily traversed gradients, and to pass a railway line through obligatory or desirable locations. Horizontal curves are provided when a change in the direction of the track is required and vertical curves are provided at points where two gradients meet or where a gradient meets level ground. To provide a comfortable ride on a horizontal curve, the level of the outer rail is raised above the level of the inner rail. This is known as superelevation.

Circular Curves

This section describes the defining parameters, elements, and methods of setting out circular curves.

Radius or degree of a curve

A curve is defined either by its radius or by its degree. The degree of a curve (D) is the angle subtended at its centre by a 30.5-m or 100-ft chord.

Angle subtended at the centre by a circle with this circumference = 360 o

Angle subtended at the centre by a 30.5-m chord, or degree of curve

$$= \frac{360^\circ}{2\pi R} \times 30.5$$

$$= 1750/R \text{ (approx., } R \text{ is in metres)}$$

In cases where the radius is very large, the arc of a circle is almost equal to the chord connecting the two ends of the arc. The degree of the curve is thus given by the following formulae

D = 1750/R (when R is in metres)

D = 5730/R (when R is in feet)

A 2 o curve, therefore, has a radius of 1750/2 = 875 m.

Relationship between radius and versine of a curve

The versine is the perpendicular distance of the midpoint of a chord from the arc of a circle. The relationship between the radius and versine of a curve can be established as shown in Fig. 13.1. Let R be the radius of the curve, C be the length of the chord, and V be the versine of a chord of length C.

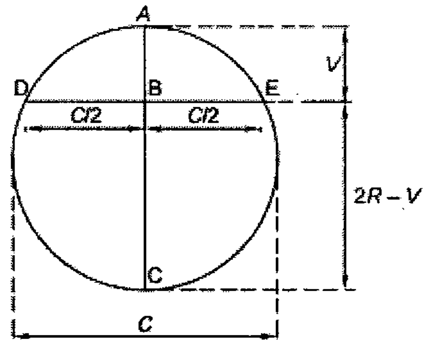


Fig. 13.1 Relation between radius and versine of a curve

AC and DE being two chords meeting perpendicularly at a common point B, simple geometry can prove that

AB × BC = DB × BE

or

$$V(2R - V) = (C/2) \times (C/2)$$

or

$$2RV - V^2 = C^2/4$$

V being very small, V^2 can be neglected. Therefore,

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

or

$$V = \frac{C^2}{8R} \quad (13.1)$$

In Eqn (13.1), V, C, and R are in the same unit, say, metres or centimetres. This general equation can be used to determined versines if the chord and the radius of a curve are known.

Case I: Values in metric units Formula (13.1) can also be written as

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

where R is the radius of the curve, C is the chord length in metres, and V is the versine in centimetres, or

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

$$\frac{12.5C^2}{R} \text{ cm or } \frac{125C^2}{R} \text{ mm} \quad (13.2)$$

Case II: Values in fps units When R_1 is the radius in feet, C_1 is the chord length in feet, and V_1 is the versine in inches, Formula (13.1) can be written as

$$\frac{V_1}{12} = \frac{C_1^2}{8R_1}$$

or

$$V_1 = \frac{1.5C_1^2}{R_1} \qquad (13.3)$$

Using formulae (13.2) and (13.3), the radius of the curve can be calculated once the versine and chord length are known.

Determination of degree of a curve in field

For determining the degree of the curve in the field, a chord length of either 11.8 m or 62 ft is adopted. The relationship between the degree and versine of a curve is very simple for these chord lengths as indicated below.

Versine on a 11.8-m chord

Versine on a 11.8-m chord

$$V = \frac{12.5C^2}{R} \text{cm} \quad \text{[from formula (13.2)]}$$

$$D = \frac{1750}{R} \quad \text{(as specified before)}$$

From the two equations given above, the degree of the curve for a 11.8-m chord can be determined as follows. Substituting the value of $R = 12.5C^2/V$,

$$D = \frac{1750V}{12.5C^2} = \frac{1750V}{12.5 \times (11.8)^2}$$

$$= V \text{ approx. (cm)}$$

Versine on a 62-ft chord

$$V_1 = \frac{1.5C^2}{R_1} \text{in} \quad \text{[from formula (13.3)]}$$

$$D = \frac{5730}{R_1} \quad \text{(as specified before)}$$

The degree of the curve for a 62-ft chord can be determined as follows. Substituting the value of

$$R_1 = \frac{5730V_1}{1.5C_1^2} = \frac{5730V_1}{1.5 \times (62)^2}$$

$$= V_1 \text{ approx. (in.)}$$

This important relationship is helpful in determining the degree of the curve at any point by measuring the versine either in centimetres on a 11.8-m chord or in inches on a 62-ft chord. The curve can be of as many degrees as there are centimetres or inches of the versine for the chord lengths given above.

Maximum Degree of a Curve The maximum permissible degree of a curve on a track depends on various factors such as gauge, wheel base of the vehicle, maximum permissible superelevation, and other such allied factors. The maximum degree or the minimum radius of the curve permitted on Indian Railways for various gauges is given in Table 13.1.

Table 13.1 Maximum permissible degree of curves

Table 13.1 Maximum permissible degree of curves

Gauge	*On plain track*		*On turnouts*	
	Max. degree	*Min. radius (m)*	*Max. degree*	*Min. radius (m)*
BG	10	175	8	218
MG	16	109	15	116
NG	40	44	17	103

Elements of a circular curve

In Fig. 13.2, AO and BO are two tangents of a circular curve which meet or intersect at a point O, called thepoint of intersection or apex. T_1 and T_2 are the points where the curve touches the tangents, called tangent points (TP). OT_1 and OT_2 are the tangent lengths of the curve and are equal in the case of a simple curve. T_1T_2 is the chord and EF is the versine of the same. The angle AOB formed between the tangents AO and OB is called the angle of intersection (1) and the angle BOO_1 is the angle of deflection . The following are some of the important relations between these elements:

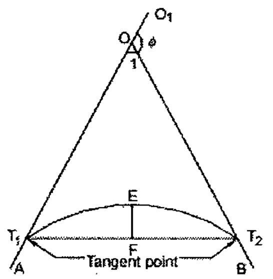


Fig. 13.2 Elements of a circular curve

$$\angle 1 + \angle \phi = 180^\circ$$

$$\text{Tangent length} = OT_1 = OT_2 = R\tan\frac{\phi}{2}$$

$$T_1T_2 = \text{length of the long chord} = 2R\sin\frac{\phi}{2}$$

$$\text{Length of the curve} = \frac{2\pi R}{360}\times\phi = \frac{\pi R\phi}{180}$$

1.Setting Out a Circular Curve

A circular curve is generally set out by any one of the following methods.

Tangential offset method

The tangential offset method is employed for setting out a short curve of a length of about 100 m (300 ft). It is generally used for laying turnout curves.

In Fig. 13.3, let PQ be the straight alignment and T be the tangent point for a curve of a known radius. Let AA , BB , CC , etc. be perpendicular offsets from the tangent. It can be proved that Value of offset O_1 = C12= 2R
where C_1 is the length of the chord along the tangent. Similarly,

$$O_2 = \frac{C_2^2}{2R}$$

$$O_3 = \frac{C_3^2}{2R}$$

$$O_n = \frac{C_n^2}{2R}$$

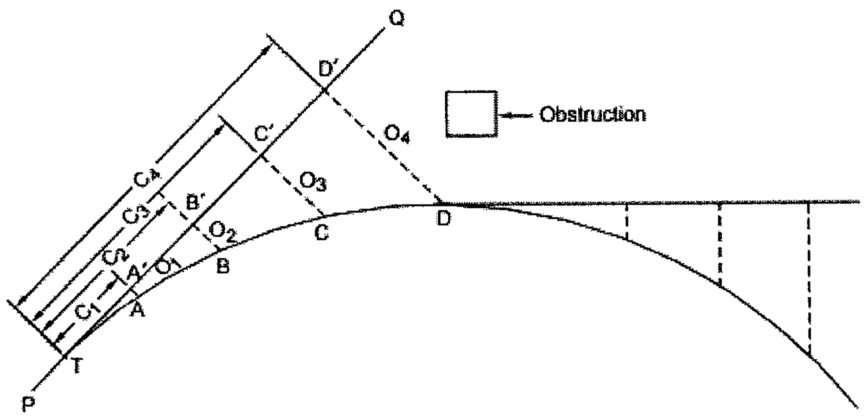


Fig. 13.3 Tangential offset method

The various steps involved in the laying out of a curve using this method are as follows.

(a) Extend the straight alignment PT to TQ with the help of a ranging rod. TQ is now the tangential direction.

(b) Measure lengths C_1, C_2, C_3, etc. along the tangential direction and calculate the offsets O_1, O_2, O_3, etc. for these lengths as per the formulae given above. For simplicity, the values of C_1, C_2, C_3, etc. may be taken in multiples of three or so.

(c) Measure the perpendicular offsets O_1, O_2, O_3, etc. from the points A, B, C, In practice, sometimes it becomes difficult to extend the tangent length beyond a certain point due to the presence of some obstruction or because the offsets become too large to measure accurately as the length of the curve increases. In such cases, the curve is laid up to any convenient point and another tangent is drawn out at this point. For laying the curve further, offsets are measured at fixed distances from the newly drawn tangent.

Long chord offset method

The long chord offset method is employed for laying curves of short lengths. In such cases, it is necessary that both tangent points be located in such a way that the distance between them can be measured, and the offsets taken from the long chord.
In Fig. 13.4, let T_1T_2 be the long chord of a curve of radius R.

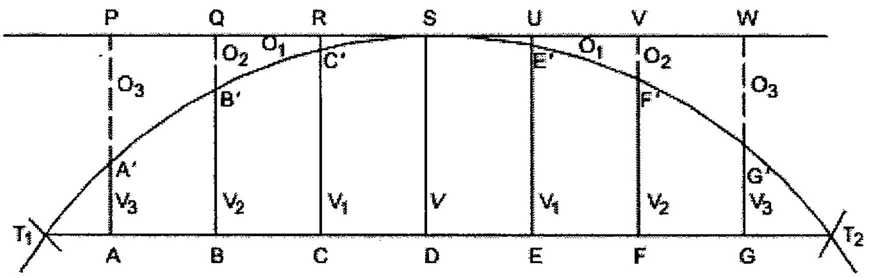


Fig. 13.4 Long chord offset method

Let the length of the long chord be C and let it be divided into eight equal parts T_1 A, AB, BC, CD, etc., where each part has a length $x = C/8$. Let PW be a line parallel to the long chord and let O_1, O_2, and O_3 be the offsets taken from points R, Q, and P.

Versine V from the long chord C is calculated by the formula

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

$$= DS = \frac{(T_1T_2)^2}{8R} \qquad (13.4)$$

Offset O_1 from the line PW is calculated by the formula

$$O_1 = \frac{x^2}{2R} = \frac{(RS^2)}{2R} = \frac{C^2}{128R}$$

or

$$RC' = \frac{C^2}{128R} \qquad (13.5)$$

Using formulae (13.4) and (13.5), the values of the perpendicular offsets V_1, V_2, V_3, etc. can be calculated as follows:

$$V_1 = \frac{C^2}{8R} - \frac{C^2}{128R} = \frac{15}{16} \times \frac{C^2}{8R} = \frac{15}{16}V$$

$$V_2 = \frac{C^2}{8R} - \frac{(2C)^2}{128R} = \frac{12}{16} \times \frac{C^2}{8R} = \frac{12}{16}V$$

$$V_3 = \frac{C^2}{8R} - \frac{(3C)^2}{128R} = \frac{7}{16} \times \frac{C^2}{8R} = \frac{7}{16}V$$

During fieldwork, first the long chord is marked on the ground and its length measured. Then points A, B, C, etc. are marked by dividing this long chord into eight equal parts. The values of the perpendicular offsets V_1, V_2, V_3, etc. are then calculated and the points A , B , C, etc. identified on the curve.

Quartering of versine method

The quartering of versine method (Fig. 13.5) is also used for laying curves of short lengths, of about 100 m (300 ft). In this method, first the location of the two tangent points (T_1 and T_2) is determined and then the distance between them is measured. The versine (V) is then calculated using the formula

$$V = \frac{125C^2}{R}(mm)$$

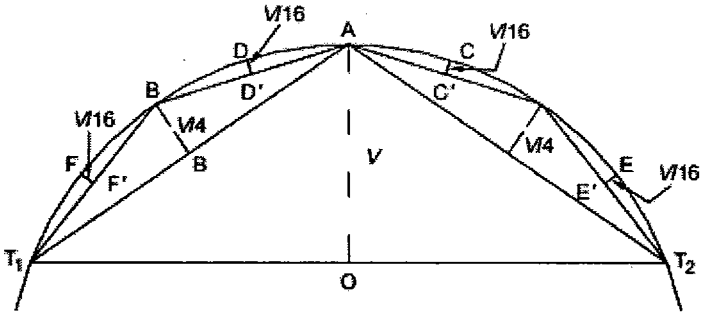


Fig. 13.5 Quartering of versine method

V is measured in the perpendicular direction at the central point O of the long chord. The tangent points $T_1$and T_2 are joined and the distance AT_1 measured. As AT_1 is almost half the length of chord T_1T_2 and as versines are proportional to the square of the chord, the versine of chord AT_1 is V/4.

For laying the curve in the field, the versine V/4 is measured at the central point B on chord AT_1 and the position of point B is thus fixed. Similarly, a point is also fixed on the second half of the curve. AB is further taken as a sub-chord and the versine on this sub-chord is measured as V/16. In this way the points D and F are also fixed. The curve can thus be laid by marking half-chords and quartering the versines on these half-chords.

Chord deflection method

The chord deflection method of laying curves is one of the most popular methods with Indian Railways. The method is particularly suited to confined locations, as most of the work is done in the immediate proximity of the curves. In Fig. 13.6, let T_1 be the tangent point and A, B, C, D, etc. be successive points on the curve. Let X_1, X_2, X_3 and X_4 be the length of chords T_1A, AB, BC, and CD. In practice, all the chords are of equal length. Let the value of these chords be c. The last chord may be of a different length. Let its value be c_1. It can be proved that

1. The position of the tangent point T_1 is located by measuring a distance equal to the tangent length R tan□/2 from the apex point O. In this case, □ is the deflection angle.
2. A length equal to the first chord (c) is measured along the tangent line T_1O and point Ais marked.
3. The zero end of the tape is placed at the tangent point T_1. It is then swung and the arc A_1A marked. Then the first offset on the arc is measured. The value of the offset is $c^2/2R$. The position of point A is thus fixed.
4. The chord T_1A is extended to point B and AB is marked as the second chord length equal to c.

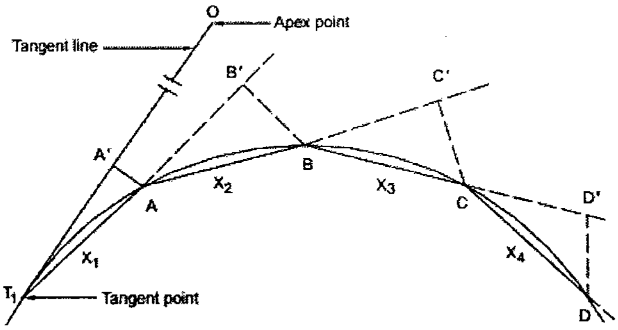


Fig. 13.6 Chord deflection method

First offset $A'A = \frac{x_1^2}{2R} = \frac{c^2}{2R}$

Second offset $B'B = \frac{x_1 x_2}{2R} + \frac{x_2^2}{2R} = \frac{c^2}{R}$

Third offset $C'C = \frac{x_2 x_3}{2R} + \frac{x_3^2}{2R} = \frac{c^2}{R}$

Last offset $N'N = \frac{x_{n-1} x_n}{2R} + \frac{x_n^2}{2R} = \frac{cc_1}{2R} + \frac{c_1^2}{2R} = \frac{c_1(c + c_1)}{2R}$

The procedure for laying the curve is as follows.

5. The position of point B is then fixed on the curve since the value of the second offset is known and is equal to c^2/R.

6. Similarly, the positions of other points C, D, etc. are also located.

7. The last point on the curve is located by taking the value of the offset as $c_1 (c \square c_1)/R$, where c_1 is the length of the last chord.

The various points on the curve should be set with great precision because if any point is fixed inaccurately, its error is carried forward to all subsequent points.

Theodolite method

The theodolite method for setting out curves is also a very popular method with Indian Railways, particularly when accuracy is required. This method is also known as Rankine's method of tangential angles. In this method, the curve is set out using tangential angles with the help of a theodolite and a chain or a tape.

In Fig. 13.7, let A, B, C, D, etc. be successive points on the curve with lengths $T_1A = x_1$, $AB = x_2$, $BC = x_3$, $CD = x_4$, etc. Let $\square_1$, $\square_2$, $\square_3$, $\square_4$ be the tangential angles OT_1A, AT_1B, BT_1C, and CT_1D made by the successive chords amongst themselves.

Let $\square_1$, $\square_2$, $\square_3$, and $\square_4$ be the deflection angles of the chord from the deflection line.

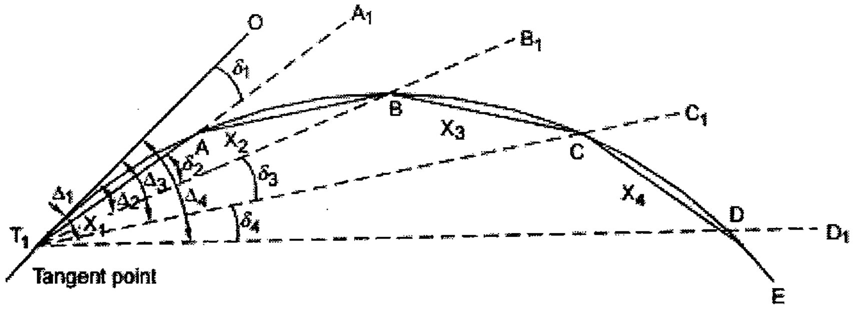


Fig. 13.7 Theodolite method

Angle subtended at centre by a 100-ft chord = D o Tangential angle for a 100-ft chord = D/2

Tangential angle for an x-ft chord, □ = (D/2) (1/100) x degree

= (5730/2R) (1/100) 60 x minutes

= 1719(x/R)

The procedure followed for setting the curve is as follows.

(a) The theodolite is set on the tangent point T_1 in the direction of T_2O.

(b) The theodolite is rotated by an angle , which is already calculated, and the line T_1A_1 is set.

(c) The distance x_1 is measured on the line T_1A_1 in order to locate the point A.

(d) Now the theodolite is rotated by a deflection angle $□_2$ to set it in the direction of T_1B_1 and point B is located by measuring AB as the chord length x_2.

(e) Similarly, the other points C, D, E, etc. are located on the curve by rotating the theodolite to the required deflection angles till the last point on the curve is reached.

(f) If higher precision is required, the curve can also be set by using two theodolites.

Railway Engineering: Superelevation

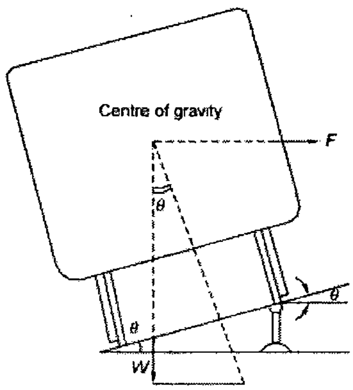


Fig. 13.8 Equilibrium superelevation

Superelevation or cant Superelevation or cant (Ca) is the difference in height between the outer and the inner rail on a curve. It is provided by gradually lifting the outer rail above the level of the inner rail.

Superelevation or cant Superelevation or cant (C_a) is the difference in height between the outer and the inner rail on a curve. It is provided by gradually lifting the outer rail above the level of the inner rail. The inner rail is taken as the reference rail and is normally maintained at its original level. The inner rail is also known as the gradient rail. The main functions of superelevation are the following.

(a) To ensure a better distribution of load on both rails
(b) To reduce the wear and tear of the rails and rolling stock
(c) To neutralize the effect of lateral forces
(d) To provide comfort to passengers

Equilibrium speed When the speed of a vehicle negotiating a curved track is such that the resultant force of the weight of the vehicle and of radial acceleration is perpendicular to the plane of the rails, the vehicle is not subjected to any unbalanced radial acceleration and is said to be in equilibrium. This particular speed is called the equilibrium speed. The equilibrium speed, as such, is the speed at which the effect of the centrifugal force is completely balanced by the cant provided.

Maximum permissible speed This is the highest speed permitted to a train on a curve taking into consideration the radius of curvature, actual cant, cant deficiency, cant excess, and the length of transition. On cruves where the maximum permissible speed is less than the maximum sectional speed of the section of the line, permanent speed restriction becomes necessary.

Cant deficiency Cant deficiency (C_d) occurs when a train travels around a curve at a speed higher than the equilibrium speed. It is the difference between the theoretical cant required for such high speeds and the actual cant provided.

Cant excess Cant excess (C_e) occurs when a train travels around a curve at a speed lower than the equilibrium speed. It is the difference between the actual cant provided and the theoretical cant required for such a low speed.

Cant gradient and cant deficiency gradient These indicate the increase or decrease in the cant or the deficiency of cant in a given length of transition. A gradient of 1 in 1000 means that a cant or a deficiency of cant of 1 mm is attained or lost in every 1000 mm of transition length.

Rate of change of cant or cant deficiency This is the rate at which cant deficiency increases while passing over the transition curve, e.g., a rate of 35 mm per second means that a vehicle will experience a change in cant or a cant deficiency of 35 mm in each second of travel over the transition when travelling at the maximum permissible speed.

1 Centrifugal Force on a Curved Track

A vehicle has a tendency to travel in a straight direction, which is tangential to the curve, even when it moves on a circular curve. As a result, the vehicle is subjected to a constant radial acceleration:

Radial acceleration = g = V^2/R

where V is the velocity (metres per second) and R is the radius of curve (metres). This radial acceleration produces a centrifugal force which acts in a radial direction away from the centre. The value of the centrifugal force is given by the formula

Force = mass * acceleration F = m (V^2/R)
= (W/g) *(V^2/R)

where F is the centrifugal force (tonnes), W is the weight of the vehicle (tonnes), V is the speed (metre/sec),g is the acceleration due to gravity (metre/sec^2), and R is the radius of the curve (metres).

To counteract the effect of the centrifugal force, the outer rail of the curve is elevated with respect to the inner rail by an amount equal to the superelevation. A state of equilibrium is reached when both the wheels exert equal pressure on the rails and the superelevation is enough to bring the resultant of the centrifugal force and the force exerted by the weight of the vehicle at right angles to the plane of the top surface of the rails. In this state of equilibrium, the difference in the heights of the outer and inner rails of the curve known as equilibrium superelevation.

2 Equilibrium Superelevation

In Fig. 13.8, if □ is the angle that the inclined plane makes with the horizontal line, then

$$\tan\theta = \frac{\text{superelevation}}{\text{gauge}} = \frac{e}{G}$$

Also,

$$\tan\theta = \frac{\text{centrifugal force}}{\text{weight}} = \frac{F}{W}$$

From these equations

$$\frac{e}{G} = \frac{F}{W}$$

or

$$e = F \times \frac{G}{W}$$

$$e = \frac{W}{g} \times \frac{V^2}{R} \times \frac{G}{W} = \frac{GV^2}{gR}$$

where e is the equilibrium superelevation, G is the gauge, V is the velocity, g is the acceleration due to gravity, and R is the radius of the curve. In the metric system equilibrium superelevation is given by the formula

$$e = \frac{GV^2}{127R} \qquad (13.6)$$

where e is the superelevation in millimetres, V is the speed in km/h, R is the radius of the curve in metres, and G is the dynamic gauge in millimetres, which is equal to the sum of the gauge and the width of the rail head in millimetres. This is equal to 1750 mm for BG tracks and 1058 mm for MG tracks.

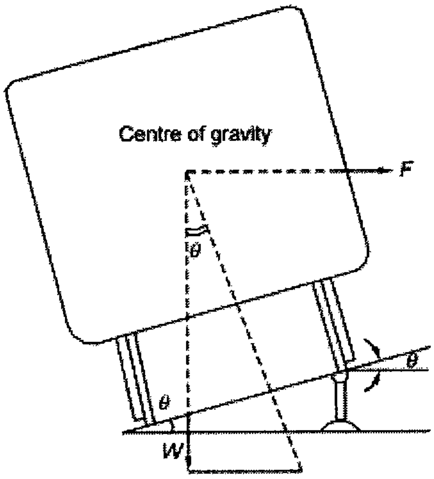


Fig. 13.8 Equilibrium superelevation

3 Thumb Rules for Calculating Superelevation in the Field

A field engineer can adopt the following thumb rules for determining the superelevation of any curve.

(a) Superelevation for BG in cm

$$= \left(\frac{\text{speed in km/h}}{10}\right)^2 \times \frac{\text{degre of curve}}{13}$$

(b) For MG tracks the value of superelevation is taken as three-fifths of the value calculated using the preceding formula. The equilibrium speed is used in this formula.

For example, if the maximum sanctioned speed (MSS) of the section is 100 km/h, the equilibrium speed may be taken as 75% of the MSS, i.e., 75 km/h. The superelevation for a 1 o curve as calculated by the thumb rule is as follows:

$$SE = \left(\frac{75}{10}\right)^2 \times \frac{1}{13} = 4.32\text{cm} = 43.2 \text{ mm}$$

Note that presuming that the MSS is 100 km/h, the thumb rule is that for every 1 o of curve, the cant is approximately 43 mm for BG tracks and 25 mm for MG tracks.

4 Equilibrium Speed for Providing Superelevation

The amount of superelevation that is to be provided on a curve depends not only on the maximum speed of the fastest train, but also on the average speed of the goods traffic moving on that section. A compromise, therefore, has to be achieved by providing superelevation in a way that fast trains run smoothly without causing any discomfort to the passengers and slow trains run safely without fear of derailment due to excessive superelevation.

Earlier stipulations

Earlier the equilibrium speed prescribed on a level track under average conditions was as follows.

(a) Where the maximum sanctioned speed of the section on both BG and MG tracks was over 50 km/h (30 mile/h), three-fourths of the maximum sanctioned speed of the section was taken as the equilibrium speed, subject to a choice between minimum speed of 50 km/h (30 mile/h) and the safe speed of the curve, whichever was less.

(b) Where the maximum sanctioned speed of the section on both BG and MG tracks was 50 km/h (30 mile/h) or less, the maximum sanctioned speed of the section or the safe speed of the curve, whichever was less, was taken as the equilibrium speed.

Revised standards

The standards for deriving the equilibrium speed stated in the preceding section have been revised by Indian Railways recently. As per the revised standards, the chief engineer (CE) should decide the equilibrium speed that would be required for the determination of the cant to be provided on a curve after careful deliberation and taking into consideration the following factors.

(a) The maximum permissible speed which can actually be achieved both by fast trains and by goods trains

(b) Permanent and temporary speed restrictions

(c) Number of stoppages

Gradients

Composition of both slow and fast trains

After deciding the equilibrium speed as described, the amount of superelevation to be provided is calculated using the following formula:

$$e = \frac{GV^2}{127R} = \frac{13.76V^2}{R} \text{ (for BG)}$$

$$= \frac{8.33V^2}{R} \text{ (for MG)}$$

where e is the superelevation in mm, V is the speed in km/h, G is the dynamic gauge (1750 mm for BG and 1058 mm for MG tracks), and R is the radius of the curve in metres.

5 Maximum Value of Superelevation

The maximum value of superelevation has been laid down based on experiments carried out in Europe on a standard gauge for the overturning velocity, taking into consideration the track maintenance standards. The maximum value of the superelevation generally adopted around many railways around the world is 1/10th to 1/12th of the gauge. The values of maximum superelevation prescribed on Indian Railways are given in Table 13.2.

Table 13.2 Maximum value of superelvation

Table 13.2 Maximum value of superelvation

Gauge	*Group*	*Limiting value of cant (mm)*	
		Under normal conditions	*With special permission of CE*
BG	A	165	185
BG	B and C	165	-
BG	D and E	140	-
MG	-	90	100
NG	-	65	75

According to Table 13.2, a cant of 185 mm may be provided for the purpose of setting up permanent structures, etc. besides curves that have been laid on new construction sites and doublings on group A routes, which have the potential for allowing an increase in speed in the future. The transition length should also be provided on the basis of this cant of 185 mm for the purpose of planning and laying curves.

6 Cant Deficiency and Cant Excess

Cant deficiency is the difference between the equilibrium cant that is necessary for the maximum permissible speed on a curve and the actual cant provided. Cant deficiency is limited due to two considerations:

higher cant deficiency causes greater discomfort to passengers and

higher cant deficiency leads to greater unbalanced centrifugal forces, which in turn lead to the requirement of stonger tracks and fastenings to withstand the resultant greater lateral forces.

The maximum values of cant deficiency prescribed for Indian Railways are given in Table 13.3.

Table 13.3 Allowable cant deficiency

Table 13.3 Allowable cant deficiency

Gauge	*Group*	*Normal cant deficiency (mm)*	*Remarks*
BG	A and B	75	For BG group
BG	C, D, and E	75	A and B routes; 100 mm cant deficiency permitted only for nominated stock and routes with the approval of the CE
MG	-	50	
NG	-	40	

The limiting values of cant excess have also been prescribed. Cant excess should not be more than 75 mm on broad gauge and 65 mm on metre gauge for all types of rolling stock. Cant excess should be worked out taking into consideration the booked speed of the trains running on a particular section. In the case of a section that carries predominantly goods traffic, cant excess should be kept low to minimize wear on the inner rail. Table 13.4 lists the limiting values of the various parameters that concern a curve.

Table 13.4 Limiting values of various parameters concerning curves

Table 13.4 Limiting values of various parameters concerning curves

Parameter	*Limiting values*	
	BG	*MG*
Maximum degree	10°	16° for MG and 40° for NG
Maximum cant	Groups A, B, and C—65 mm Groups D and E—140 mm	90 mm (100 mm with special permission of chief engineer)
Maximum cant deficiency	In normal cases—75 mm (in special cases, 100 mm for group A and B routes with a nominated rolling stock and with permission of the chief engineer)	50 mm
Cant excess	75 mm	65 mm
Maximum cant gradient	1 in 720 (in exceptional cases, 1 in 360 with permission of CE)	1 in 720
Rate of change of cant or cant deficiency	Desirable—35 mm/sec Maximum—55 mm/sec	Desirable—35 mm/sec Maximum—35 mm/sec
Minimum cant deficiency in turnout	75 mm	50 mm

7 Negative Superelevation

When the main line lies on a curve and has a turnout of contrary flexure leading to a branch line, the superelevation necessary for the average speed of trains running over the main line curve cannot be provided. In Fig. 13.9, AB, which is the outer rail of the main line curve, must be higher than CD. For the branch line, however, CF should be higher than AE or point C should be higher than point A. These two contradictory conditions cannot be met within one layout. In such cases, the branch line curve has a negative superelevation and, therefore, speeds on both tracks must be restricted, particularly on the branch line.

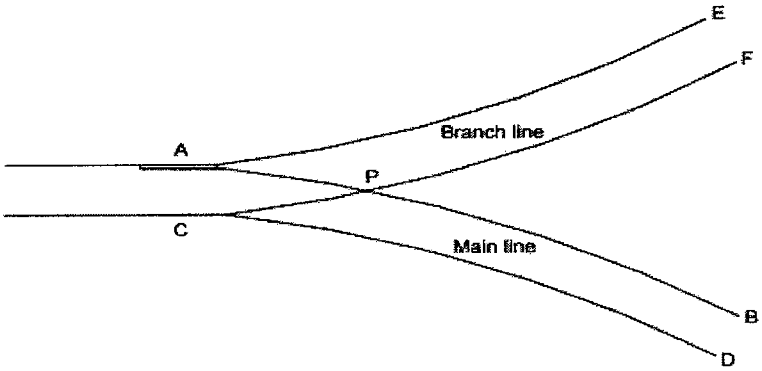


Fig. 13.9 Negative superelevation

The provision of negative superelevation for the branch line and the reduction in speed over the main line can be calculated as follows.

(i)The equilibrium superelevation for the branch line curve is first calculated using the formula

$$e = \frac{GV^2}{127R}$$

(ii) The equilibrium superelevation e is reduced by the permissible cant deficiency C_d and the resultant superelevation to be provided is

$$x = e - C_d$$

where, x is the superelevation, e is the equilibrium superelevation, and C_d is 75 mm for BG and 50 mm for MG. The value of C_d is generally higher than that of e, and, therefore, x is normally negative. The branch line thus has a negative superelevation of x.

(iii) The maximum permissible speed on the main line, which has a superelevation of x, is then calculated by adding the allowable cant deficiency ($x + C_d$). The safe speed is also calculated and smaller of the two values is taken as the maximum permissible speed on the main line curve.

Safe Speed on Curves

For all practical purposes safe speed means a speed which protects a carriage from the danger of overturning and derailment and provides a certain margin of safety. Earlier it was calculated empirically by applying Martin's formula:

For BG and MG

Transitioned curves

$$V = 4.4\sqrt{R - 70} \qquad (13.7)$$

where V is the speed in km/h and R is the radius in metres.

Non-transitioned curves Safe speed = four-fifths of the speed calculated using Eqn (13.7).

For NG

Transitioned curves

$$V = 3.65\sqrt{R - 6} \qquad (13.8)$$

(subject to a maximum of 50 km/h).

Non-transitioned curves

$$V = 2.92\sqrt{R - 6} \qquad (13.9)$$

(subject to a maximum of 40 km/h).

Indian Railways no longer follows this concept of safe speed on curves or the stipulations given here.

1.New Formula for Determining Maximum Permissible Speed on Transitioned Curves

Earlier, Martin's formula was used to work out the maximum permissible speed or safe speed on curves. This empirical formula has been changed by applying a formula based on theoretical considerations as per the recommendations of the committee of directors, chief engineers, and the ACRS. The maximum speed for transitioned curves is now determined as per the revised formulae given below.

On Broad Gauge

$$V = \sqrt{\frac{(C_a + C_d) \times R}{13.76}} = 0.27\sqrt{(C_a + C_d) \times R} \qquad (13.10)$$

where V is the maximum speed in km/h, C_a is the actual cant in mm, C_d is the permitted cant deficiency in mm, and R is the radius in m. This equation is derived from Eqn (13.6) for equilibrium superelevation and is based on the assumption that G = 1750 mm, which is the centre-to-centre distance between the rail heads of a BG track with 52-kg rails.

On Metre Gauge

$$V = 0.347\sqrt{(C_a + C_d)R} \qquad (13.11)$$

This is based on the assumption that the centre-to-centre (c/c) distance between the rail heads of an MG track is 1058 mm.

Narrow Gauge (762 min.)

$$V = 3.65\sqrt{R-6} \text{ (subject to a maximum of 50 km/h)} \qquad (13.12)$$

2.New Criteria for Determining Maximum Speed on Curves Without Transition

As per the procedure being followed at present, the determination of the maximum permissible speed on curves without transitions involves the concept of virtual transitions. The linear velocity of a train moving with uniform velocity on a straight track begins to change into angular velocity as soon as the first bogie reaches the tangent point. This change continues till the rear bogie reaches the tangent point, at which moment the train acquires full angular velocity. The change in the motion of the train from a straight line to a curve takes place over the shortest distance between the bogie centres and is considered a virtual transition. Normally, this distance is 14.6 m on BG, 13.7 m on MG, and 10.3 m on NG, commencing on a straight line at half the distance before the tangent point and terminating on the curve at half the distance beyond the tangent point. The deficiency of cant is considered as being gained over the length of the virtual transition and the cant has to be gained in a similar manner. The cant gradient must not be steeper than 1 in 360 on BG and 1 in 720 on MG and NG under any circumstance.

The safe speed should be worked out on the basis of the the cant that can be practically provided based on these criteria, and increased by the permissible amount of cant deficiency. In the case of non-transitioned curves, where no cant is provided, the safe speed for the curve can be worked out by calculating the permissible cant deficiency after taking into consideration the rate at which the cant deficincy is gained or lost over the virtual transition.

3 Maximum Permissible Speed on a Curve

The maximum permissible speed on a curve is the minimum value of the speed that is calculated after determining the four different speed limits mentioned here. The first three speed limits are taken into account for the calculation of maximum permissible speed, particularly if the length of the transition curve can be increased. For high-speed routes, however, the fourth speed limit is also very important, as cases may arise when the length of the transition curve cannot be altered easily.

(i) Maximum sanctioned speed of the section This is the maximum permissible speed authorized by the commissioner of railway safety. This is determined after an analysis of the condition of the track, the standard of interlocking, the type of locomotive and rolling stock used, and other such factors.

(ii) Maximum speed of the section taking into consideration cant deficiency

This is the speed calculated using the formula given in Table 13.5. First, the equilibrium speed is decided after taking various factors into consideration and the equilibrium superelevation (C_a) calculated. The cant deficiency (C_d) is then added to the equilibrium superelevation and the maximum speed is calculated as per this increased superelevalion ($C_a + C_d$).

Table 13.5 Calculation of permissible speed on curves

Table 13.5 Calculation of permissible speed on curves

Type of curve	*Procedure for calculating max. permissible speed or safe speed*
Fully transitioned curve	(i) For BG $V = 0.27\sqrt{R(C_a + C_d)}$ (ii) For MG $V = 0.347\sqrt{R(C_a + C_d)}$ (iii) For NG $V = 3.65\sqrt{R - 6}$ (subject to a maximum of 50 km/h)
Non-transitioned curve with cant on virtual transition	(i) Cant to be gained over virtual transition is 14.6 m on BG, 13.7 m on MG, and 10.3 m on NG, and the cant gradient is to be calculated accordingly (ii) The cant gradient is not to exceed 1 in 360 (2.8 mm/m) on BG and 1 in 720 (1.4 mm/m) on MG and NG.
Non-transitioned curves with no cant	(i) Calculate permissible cant deficiency that is to be gained or lost over the virtual transition (ii) The desirable value of rate of change of cant deficiency is 35 mm/sec for BG and 55 mm/sec for MG
Curves with inadequate transition	(i) Calculate the actual cant or cant deficiency which can be provided taking into consideration its limiting value (ii) The cant or cant deficiency has to be run over the transition length. The rate of change of cant or cant deficiency should not exceed its limiting value. For BG, the desirable value is 35 mm/sec and the maximum permissible value is 55 mm/sec.

(iii) Maximum speed taking into consideration speed of goods train and cant excess Cant (C_a) is calculated based on the speed of slow moving traffic, i.e., goods train. This speed is decided for each section after taking various factors into account, but generally its value is 65 km/h for BG and 50 km/h for MG.

The maximum value of cant excess (C_e) is added to this cant and it should be ensured that the cant for the maximum speed does not exceed the value of the sum of the actual cant + and the cant excess ($C_a + C_e$).

(iv) Speed corresponding to the length of the transition curves This is the least value of speed calculated after taking into consideration the various lenths of transition curves given by the formulae listed in Table 13.6.

The following points may be noted when calculating the maximum permissible speed on a curve.

(a) Criterion (iv) is to be used only in cases where the length of the transition curve cannot be increased due to site restrictions. The rate of change of cant or cant deficiency has been permitted at a rate of 55 mm/sec purely as an interim measure for the existing curves on BG tracks.

(b) For high-speed BG routes, when the speed is restricted as a result of the rate of change of cant deficiency exceeding 55 mm/sec, it is necessary to limit the cant deficiency to a value lower than 100 mm in such a way that optimum results are obtained. In this situation, the maximum permissible speed is determined for a cant deficiency less than 100 mm, but gives a higher value of the maximum permissible speed. This concept is further explained with the help of the following solved problems.

Table 13.6 Various lengths of transition curves to be considered when calculating speed

Table 13.6 Various lengths of transition curves to be considered when calculating speed

Criteria for length of transition curve	*Desirable length of transition curve**	*Minimum length of transition curve*
When the rate of change of cant is taken as 35 mm/sec for normal cases and 55 mm/sec for exceptional cases	$C_a = V_m/125$ $(0.008\ C_a V_m)$	$C_a = V_m/198$
When the rate of change of cant deficiency is taken as 35 mm/sec for normal cases and 55 mm/sec for exceptional cases	$C_d = V_m/125$ $(0.008\ C_d V_m)$	$C_d = V_m/198$
Taking the cant gradient into account	Cant gradient not to exceed 1 in 720	Cant gradient not to exceed 1 in 360 for BG and 1 in 720 for MG and NG

Table 13.6 Various lengths of transition curves to be considered when calculating speed

Criteria for length of transition curve	*Desirable length of transition curve**	*Minimum length of transition curve*
When the rate of change of cant is taken as 35 mm/sec for normal cases and 55 mm/sec for exceptional cases	$C_a = V_m/125$ $(0.008\ C_a V_m)$	$C_a = V_m/198$
When the rate of change of cant deficiency is taken as 35 mm/sec for normal cases and 55 mm/sec for exceptional cases	$C_d = V_m/125$ $(0.008\ C_d V_m)$	$C_d = V_m/198$
Taking the cant gradient into account	Cant gradient not to exceed 1 in 720	Cant gradient not to exceed 1 in 360 for BG and 1 in 720 for MG and NG

* Notation used in the table: C_a is the value of actual cant in mm, V_m is the maximurm permissible speed in km/h, and C_d is the cant deficiency in mm.

Example 13.1 Calculate the superelevation and the maximum permissible speed for a 2 o BG transitioned curve on a high-speed route with a maximum sanctioned speed of 110 km/h. The speed for calculating the equilibrium superelevation as decided by the chief engineer is 80 km/h and the booked speed of goods trains is 50 km/h.

Solution

Solution

(i) $R = \frac{1750}{D} = \frac{1750}{2} = 875\text{m}$

(ii) Superelevation for equilibrium speed = $\frac{GV^2}{127R}$

where $G = 1750$ mm (c/c distance of 52-kg rail) $V = 80$ km/h and $R = 875$ m.

$$\text{SE} = \frac{1750 \times 80^2}{127 \times 875} = 100.8 \text{ mm}$$

(iii) Superelevation for maximum sanctioned speed (110 km/h):

$$\frac{GV^2}{127R} = \frac{1750 \times 110^2}{127 \times 875} = 190.6 \text{ mm}$$

Cant deficiency = 190.6 – 100.8 = 89.8 mm

(which is less than 100 mm and hence permissible).

(iv) Superelevation for goods trains with a booked speed of (50 km/h)

$$\frac{GV^2}{127R} = \frac{1750 \times 50^2}{127 \times 875} = 39.4 \text{ mm}$$

Cant excess = 100.8 – 39.4 = 61.4 mm (which is less than 75 mm and hence permissible).

(v) Maximum speed potential or safe speed of the curve as per theoretical considerations, being a high-speed route:

$$V = \sqrt{\frac{(C_a + C_d) \times R}{13.76}} = 0.27\sqrt{(C_a + C_d) \times R}$$

where $C_a = 100.8$ mm, $C_d = 89.8$ mm, and $R = 875$ m.

$$V = \sqrt{\frac{(100.8 + 89.8) \times 875}{13.76}} = 110.1 \text{ km/h}$$

/i) The maximum permissible speed on the curve is the least of the following:

- maximum sanctioned speed, i.e., 110 km/h.
- maximum or safe speed over the curve based on theoretical considerations, i.e., 110.1 km/h.
- Also, there is no constraint on speed due to the transition length of the curve.

Therefore, the maximum permissible speed over the curve is 110 km/h and the superelevation to be provided is 100.8 mm or approx. 100 mm.

Simplified method of calculating permissible cant and speed

Often a simplified method is used for calculating the permissible cant and the maximum permissible speed in the field. This simplified method is applicable to most cases except those involving very flat curves.

Step 1 Calculate the cant for the maximum sanctioned speed of the section, say, 110 km/h, using the standard formula $C = GV^2/127R$. This is C_{110}.

Step 2 Calculate the cant using the same standard formula as for the slowest traffic, i.e., for a goods train which may be running at, say, 50 km/h. This is C_{50}. To this add cant excess. This becomes $C_{50} + C_e$.
Step 3 Calculate the cant for equilibrium speed (if decided) using the same standard formula. Let it be 80 km/h. This value is C_{80}.
Step 4 Adopt the lowest of the three values obtained from the preceding steps and that becomes the permissible cant (C_a). The three values are C_{110}, $C_{50} + C_e$, and C_{80}. **Step 5** Taking this cant value (C_a), add the cant deficiency and find the maximum permissible speed using the Eqn (13.10).

Solution to example 13.1

Step 1

$$C_{110} = \frac{GV^2}{127R} = \frac{1750 \times 110 \times 110}{127 \times 875} = 190.6\,\text{mm} \qquad \text{(i)}$$

Step 2

$$C_{50} = \frac{GV^2}{127R} = \frac{1750 \times 50 \times 50}{127 \times 875} = 39.4\,\text{mm}$$

On adding cant excess,

$$C_a + C_e = 39.4 + 75 = 114.4\text{ mm} \qquad \text{(ii)}$$

Step 3

$$C_{80} = \frac{GV^2}{127R} = \frac{1750 \times 80 \times 80}{127 \times 875} = 100.8\,\text{mm} \qquad \text{(iii)}$$

Step 4 The lowest of the three values calculated in the preceding steps is 100.8 mm. Therefore, 100 mm is adopted as the actual cant.

Step 5 Cant to be provided 100 mm, cant deficiency = 75 mm

$$V = 0.27\sqrt{(C_a + C_d) \times R} = 0.27\sqrt{(100 + 75) \times 875}$$
$$= 110.1 = 110\text{ km/h approx.}$$

Therefore, the maximum cant to be provided 100 mm and the maximum permissible speed is 110 km/h.

Example 13.2 Calculate the superelevation, maximum permissible speed, and transition length for a 3 o curve on a high-speed BG section with a maximum sanctioned speed of 110 km/h. Assume the equilibrium speed to be 80 km/h and the booked speed of the goods train to be 50 km/h.

Solution

(i) Radius of curve = $\frac{1750}{D} = \frac{1750}{3} = 583.3$ m

(ii) Equilibrium superelevation for 80 km/h = $\frac{GV^2}{127R} = \frac{1750 \times 80^2}{127 \times 583.3} = 151.2$ mm

(iii) Equilibrium superelevation for maximum sanctioned speed (110 km/h)

$$= \frac{1750 \times 110^2}{127 \times 583.3} = 285.5 \text{ mm}$$

(iv) Cant deficiency = 285.8 mm – 151.2 mm = 134.6 mm
This value of cant deficiency is more than 100 mm (the permitted value of C_d), therefore, take C_d as 100 mm. Now,
Actual cant = 285.8 – 100 = 185.8 mm

However, actual cant is to be limited to 165 mm, and, therefore, this value will be adopted.

v) Equilibrium superelevation for a goods train with a speed of 50 km/h

$$= \frac{1750 \times 50^2}{127 \times 583.3} = 59 \text{ mm}$$

i) Cant excess = actual cant – 59 mm
= 165 – 59 = 106 mm
which is in excess of 75 mm—the permitted value. With 75 mm taken as cant excess, the actual cant to be provided now is 75 + 59 mm = 134 mm. Therefore, a cant of 135 mm should be provided (rounding off to the higher multiple of 5).

i) Safe speed or speed potential (for high-speed route)

$$= \frac{\sqrt{(C_a + C_d) \times R}}{13.76} = \frac{\sqrt{(135 + 100) \times 583.3}}{13.76}$$

= 99.6 km/h (or approx. 100 km/h).

ii) Maximum permissile speed on the curve is the least of the following:

- maximum permissible speed of the section, i.e., 110 km/h
- safe speed on the curve, i.e., 100 km/h

The maximum permissible speed on the curve is, therefore, 100 km/h.

x) The length of transition is the maximum value from among the following:

- When taking the rate of change of cant into consideration (35 mm/sec),
  $L = 0.008\ (C_a \times V_m) = 0.008 \times 135 \times 100$ m = 108 m
- When taking the rate of change of cant deficiency into consideration (35 mm/sec),
  $L = 0.008\ (C_d \times V_m)$
  $= 0.008 \times 100 \times 100$ m
  = 80 m
- When taking the cant gradient into consideration (1 in 720),
  $L = 0.72 \times e = 0.72 \times 135$ m = 97.2 m

Therefore, the superelevation to be provided is 135 mm, the maximum permissible speed over the curve is 100 km/h, and the length of transition curve is 108 m.

Example 13.3 Calculate the maximum permissible speed on a curve of a high speed BG group A route having the following particulars: degree of the curve = 1 o , superelevation = 80 mm, length of transition curve = 120 m, maximum speed likely to be sanctioned for the section =160 km/h.

Solution

(i) Radius of curve = 1750/*D* = 1750/1 = 1750 m

(ii) Safe speed over the curve as per theoretical considerations, this being a high-speed route,

$$V = 0.27\sqrt{(C_a + C_d) \times R}$$

where C_d = 100 mm (assumed), C_a = 80 mm, R = 1750 m

$$V = 0.27\sqrt{(80 + 100) \times 1750} = 151.3 \text{ km/h}$$

(iii) Speed based on transition length:

(a) Rate of gain of cant (not to exced 55 mm/sec)

$$V_m = \frac{198L}{E} = \frac{198 \times 120}{80} = 297.0 \text{ km/h}$$

(b) Rate of gain of cant deficiency (not to exceed 55 mm/sec)

$$V_m = \frac{198L}{C_d} = \frac{198 \times 120}{100} = 237.6 \text{ km/h}$$

(c) Cant gradient

$$= 1 \text{ in } \frac{120 \times 1000 \text{ mm}}{80 \text{ mm}} = 1 \text{ in } 1500$$

(which is not steeper than 1 in 720).

iv) Maximum permissible speed is the least of the following:

- maximum sanctioned speed of the section, i.e., 160 km/h
- safe speed based on theorectical considerations, i.e., 151.3 km/h
- speed based on the transition length, i.e., 237.6 km/h

Therefore, the maximum permissible speed over the curve is 151.3 km/h or about 150 km/h. As the controlling factor in this case is the safe speed based on theoretical considerations (and not the rate of change of C_d), hence no further analysis is necessary.

Example 13.4 Calculate the maximum permissible speed on a 1 o curve on a Rajdhani route with a maximum sanctioned speed of 130 km/h. The superelevation provided is 50 mm and the transition length is 60 m. The transition length of the curve cannot be increased due to the proximity of the yard.

Solution

(i) Radius of the curve = 1750/D = 1750/1 = 1750 m

(ii) Safe speed on the curve as per theoretical considerations,

$$V = 0.27\sqrt{(C_a + C_d) \times R}$$

where

C_a = 50 mm, C_d = 100 mm, R = 1750 m

$$V = 0.27\sqrt{(50 + 100) \times 1750} = 138.3 \text{ km/h}$$

(iii) Speed based on transition length:

(a) Rate of change of cant (not to exceed 55 mm/sec)

$$V_m = \frac{198L}{C_d} = \frac{198 \times 60}{50} = 237.6 \text{ km/h}$$

(b) Rate of change of cant deficiency (not to exceed 55 mm/sec)

$$V_m = \frac{198L}{C_d} = \frac{198 \times 60}{100} = 118.8 \text{ km/h}$$

(c) Cant gradient $= \dfrac{60 \times 1000 \text{ mm}}{50 \text{ mm}} = 1$ in 1200

(which is not steeper than 1 in 720).

(iv) Maximum sanctioned speed on the curve is the least of the following:

- Maximum speed sanctioned for the section, i.e., 130 km/h
- Safe speed based on theoretical considerations, i.e., 138.3 km/h
- Speed based on transition length, i.e., 118.3 km/h.

In this case, the speed has to be restricted to 118.8 km/h, because of the constraint of transition length. A cant deficiency of 100 mm has been assumed, which is its maximum possible value. On the field, the cant deficiency may be somewhat lower, giving a lower rate of change of C_d for the given transition length and a higher permissible speed. The optimum value of this maximum permissible speed can be found from the following equation:

Equilibrium superelevation = actual cant + cant deficiency for maximum permissible speed for a given transition length

or

$$\frac{GV^2}{127R} = \text{actual cant} + \frac{198L}{V}$$

where G = 1750 mm, R = 1750 m, L = 60 m, and V is the maximum permissible speed. Therefore,

$$\frac{1750V^2}{127 \times 1750} = 50 + \frac{198 \times 60}{V}$$

Solving this equation, V = 133 km/h. This value however, cannot be more than the MSS of the section, i.e., 130 km/h. Therefore, the maximum permissible speed over the curve is 130 km/h.

$$\text{With } V = 130 \text{km/h}, C_d = \frac{198 \times L}{V} = \frac{198 \times 60}{130}$$

$$= 91.4 \text{ mm}$$

which is less than 100 mm. Therefore, the maximum permissible speed over the circular curve is 130 km/h and that over the transition curve is 118 km/h.

Example 13.5 A BG branch line track takes off as a contrary flexure through a 1 in 12 turnout from a main line track of a 3 o curvature. Due to the turnout, the maximum permissible speed on the branch line is 30 km/h. Calculate the negative superelevation to be provided on the branch line track and the maximum permissible speed on the main line track (when it takes off from a straight track).

Solution

(i) For a branch line track, the degree of the curve is $4 - 3 = 1°$
Radius = $1750/D = 1750/1 = 1750$ m

$$e = \frac{GV^2}{127R} = \frac{1676 \times 30^2}{1270 \times 1750} = 6.8 \text{ mm}$$

After rounding it off to a higher multiple of 5, it is taken as 10 mm.

(ii) The value of negative superelevation for a branch line track,
$x = e - C_d = 10 \text{ mm} - 75 \text{ mm} = 65 \text{ mm}$ (negative)

(iii) The superelevation to be provided on the main line track is 65 mm, which is the same as the superelevation of the branch line track, but in the opposite direction.

(iv) The maximum permissible speed is calculated by taking the actual superelevation of the main line track (65 mm) and adding it to the cant deficiency (75 mm), and then using this value of superelevation, i.e., 140 mm (65 + 75) in the formula for equilibrium speed. The main line track has a 3° curve, i.e., 1750/3 = 583.3 m radius.
Therefore, the maximum permissible speed on the main line track,

$$e = \frac{GV^2}{127R} = \frac{1676 \times V^2}{127 \times 583.3} = 140 \text{mm}$$

or

$$V = \sqrt{\frac{127 \times 583.3 \times 140}{1676}} = 78.7 \text{km/h}$$

Alternatively, the maximum permissible speed can also be calculated as follows

$$V = 0.27\sqrt{(C_a + C_d) \times R}$$
$$= 0.27\sqrt{(65 + 75) \times 583.3}$$
$$= 77.16 \text{ km/h}$$

Therefore, the maximum permissible speed on the main line track is 77.16 km/h. After rounding it off to a lower multiple of 5, it becomes 75 km/h.

Transition Curve

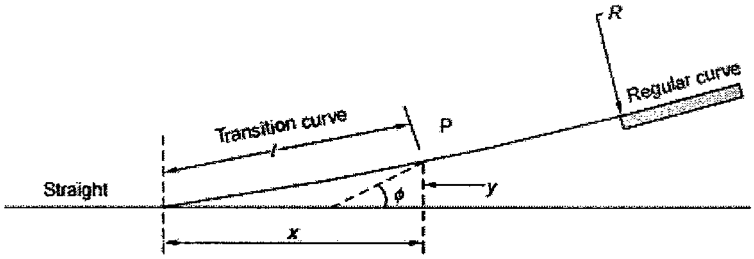


Fig. 13.10 Transition curve

As soon as a train commences motion on a circular curve from a straight line track, it is subjected to a sudden centrifugal force, which not only causes discomfort to the passengers but also distorts the track alignment and affects the stability of the rolling stock.

Transition Curve

As soon as a train commences motion on a circular curve from a straight line track, it is subjected to a sudden centrifugal force, which not only causes discomfort to the passengers but also distorts the track alignment and affects the stability of the rolling stock. In order to smoothen the shift from the straight line to the curve, transition curves are provided on either side of the circular curve so that the centrifugal force is built up gradually as the superelevation slowly runs out at a uniform rate (Fig. 13.10). A transition curve is, therefore, the cure for an uncomfortable ride, in which the degree of the curvature and the gain of superelevation are uniform throughout its length, starting from zero at the tangent point to the specified value at the circular curve. The following are the objectives of a transition curve.

(a) To decrease the radius of the curvature gradually in a planned way from infinity at the straight line to the specified value of the radius of a circular curve in order to help the vehicle negotiate the curve smoothly.
(b) To provide a gradual increase of the superelevation starting from zero at the straight line to the desired superelevation at the circular curve.
(c) To ensure a gradual increase or decrease of centrifugal forces so as to enable the vehicles to negotiate a curve smoothly.

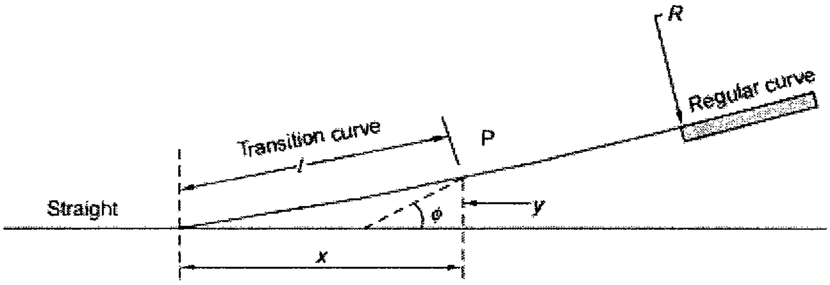


Fig. 13.10 Transition curve

1 Requirements of an Ideal Transition Curve

The transition curve should satisfy the following conditions.

(a) It should be tangential to the straight line of the track, i.e., it should start from the straight part of the track with a zero curvature.

(b) It should join the circular curve tangentially, i.e., it should finally have the same curvature as that of the circular curve.

(c) Its curvature should increase at the same rate as the superelevation.

(d) The length of the transition curve should be adequate to attain the final superelevation, which increases gradually at a specified rate.

2 Types of Transition Curves

The types of transition curves that can be theoretically provided are described here. The shapes of these curves are illustrated in Fig. 13.11.

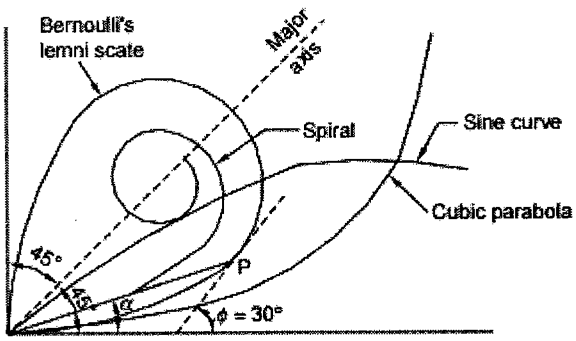


Fig. 13.11 Different types of transition curves

Euler's spiral This is an ideal transition curve, but is not preferred due to mathematical complications. The equation for Euler's sprial is

$$\phi = \frac{l^2}{2RL} \qquad (13.13)$$

Cubical spiral This is also a good transition curve, but quite difficult to set on the field.

$$y = \frac{l^3}{6RL} \qquad (13.14)$$

Bernoulli's lemniscate In this curve, the radius decreases as the length increases and this causes the radial acceleration to keep on falling. The fall is, however, not uniform beyond a 30 o deflection angle. This curve is not used on railways.

Cubic parabola Indian Railways mostly uses the cubic parabola for transition curves. The equation of the cubic parabola is

$$y=\frac{x^3}{6Rl} \qquad (13.15)$$

In this curve, both the curvature and the cant increase at a linear rate. The cant of the transition curve from the straight to the curved track is so arranged that the inner rail continues to be at the same level while the outer rail is raised in the linear form throughtout the length of the curve. A straight line ramp is provided for such transition curves.

The notations used in Eqns (13.13) to (13.15) are as follows: f is the angle between the straight line track and the tangent to the transition curve, l is the distance of any point on the transition curve from the take-off point, L is the length of the transition curve, x is the horizontal coordinate on the transition curve, y is the vertical coordinate on the transition curve, and R is the radius of the circular curve.

S-shaped transition curve In an S-shaped transition curve, the curvature and superelevation assume the shape of two quadratic parabolas. Instead of a straight line ramp, an S-type parabola ramp is provided with this transition curve. The special feature of this curve is that the shift required ('shift' is explained in the following section) in this case is only half of the normal shift provided for a straight line ramp. The value of shift is

$$S=\frac{L^2}{48R} \qquad (13.16)$$

Further, the gradient is at the centre and is twice steeper than in the case of a straight line ramp. This curve is desirable in special conditions-when the shift is restricted due to site conditions.

The Railway Board has decided that on Indian Railways, transition curves will normally be laid in the shape of a cubic parabola.

3 Shift

For the main circular curve to fit in the transition curve, which is laid in the shape of a cubic parabola, it is required be moved inward by a measure known as the 'shift' (Fig. 13.12). The value of shift can be calculated using the formula

$$S=\frac{L^2}{24R} \qquad (13.17)$$

where S is the shift in m, L is the length of the transition curve in m, and R is the radius in m.

The offset (in centimetres) from the straight line to any point on the transition curve is calculated using the equation.

$y = 16.7\ x^2/LR$

where y is the offest from the staight line in cm, x is the distance from the commencement of the curve in m,L is the length of transition in m, and R is the radius of curve in m.

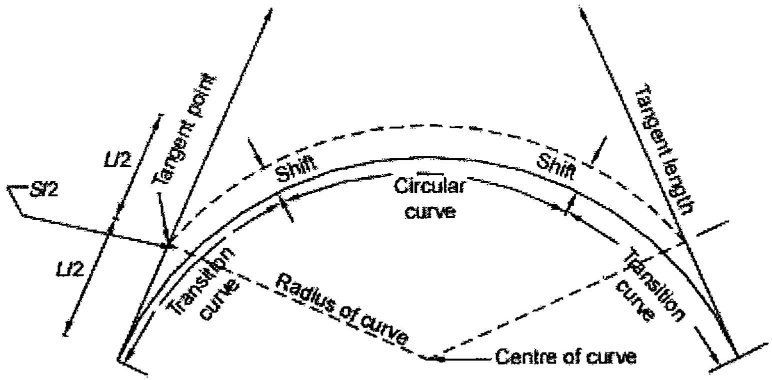


Fig.13.12 Shift

4 Length of Transition Curve

The length of the transition curve prescribed on Indian Railways is the maximum of the following three values:

$$L = 0.008C_a \times V_m = \frac{C_a \times C_d}{125} \qquad (13.19)$$

$$L = 0.008C_d \times V_m = \frac{C_d \times V_m}{125} \qquad (13.20)$$

$$L = 0.72C_a \qquad (13.21)$$

where L is the length of the curve in m, C_a is the actual cant or superelevation in mm, and C_d is the cant deficiency in mm.

Formulae (13.19) and (13.20) are based on a rate of change of a cant or cant deficiency of 35 mm/sec. Formula (13.21) is based on a maximum cant gradient of 1 in a 720 or 1.4 mm/m.

Other provisions made to meet the requirements of special situations are as follows.

(a) When deciding the length of transition curves, particularly on high-speed routes, future speeds expected to be implemented on those tracks, such as 160 km/h for group A routes and 130 km/h for group B routes, may be taken into account.

(b) In exceptional cases, when there is no space available for providing full length transition curves, particularly on high-speed routes as per the preceding calculations, the length of the transition curve may be reduced to two-thirds of the desirable length as worked out by Eqns (13.19) and (13.20). This is based on the assumption that the rate of change of cant or cant deficiency will not exceed 55 mm/sec and the maximum cant gradient will not be steeper than 1 in 360 or 2.8 mm/m. This relaxation is permitted only for BG sections. For MG and NG sections, however, the cant gradient should not be steeper than 1 in 720 or 1.4 mm/h. For MG sections, the change of cant or cant deficiency should not exceed 35 mm/sec.

(c) At locations where the length of the transition curve is restricted and as such may be inadequate to permit the maximum speed calculated for the circular curve, the design should be such that both the cant and the cant deficiency are lowered, which will reduce the maximum speed on the transition curve to permit the highest speed on the curve as a whole.

Example 13.6 A curve of 600 m radius on a BG section has a limited transition of 40 m length. Calculate the maximum permissible speed and superelevation for the same. The maximum sectional speed (MSS) is 100 km/h.

Solution In a normal situation, a curve of a 600 m radius will have quite a long transition curve for an MSS of 100 km/h. However, as the transition curve has been restricted to 40 m, the cant should be so selected that the speed on the main circular curve is equal to the speed on the transition curve as a whole.

(i) For the circular curve, the maximum speed is calculated from Eqn (13.10):

$$V = 0.27\sqrt{R(C_a + C_d)}$$

The most favourable value of speed is obtained when $C_a = C_d$.

(ii) For the transition curve, the maximum change of cant is taken as 55 mm/sec and the maximum speed is then calculated:

$$L = \frac{C_a \times V_m}{198} \text{ or } V = \frac{198L}{C_a}$$

Therefore,

$$0.27\sqrt{R(C_a + C_d)} = \frac{198L}{C_a}$$

or

$$0.27\sqrt{R(600 + 2\,C_a)} = \frac{198 \times 40}{C_a}$$

On solving this equation, C_a = 89.50 mm ≅ 90 mm.

(iii) On limiting the value of C_d to 75 mm,

$$\text{Maximum speed} = 0.27\sqrt{R(C_a + C_d)}$$
$$= 0.27\sqrt{600(90 + 75)}$$
$$= 84.95 \text{ or approx. } 85 \text{ km/h}$$

(iv) Cant gradient $= \dfrac{90 \text{ mm}}{40 \times 1000}$

= 1 in 444

which is within the permissible limits of 1:360.

Therefore, the maximum permissible speed is 85 km/h and the superelevation to be provided is 90 mm.

5 Laying a Transition Curve

A transition curve is laid in the following steps (Fig. 13.13).

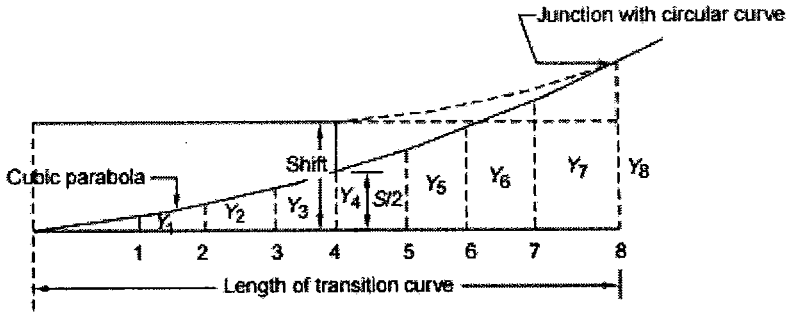


Fig. 13.13 Laying a transition curve

1. The length of the transition curve is calculated by the formulae given in Eqns (13.19) to (13.21).

2. This transition length is divided into an even number of equal parts, usually eight.

3. The equations for a cubic parabola and the shift [Eqns (13.15) and (13.17)], reproduced here, are used for calculations.

$$y = \frac{x^3}{6RL} = 0.167\,\frac{x^3}{RL} \qquad \text{(i)}$$

$$S = \frac{L^2}{24R} = 0.042\,\frac{L^2}{R} \qquad \text{(ii)}$$

(all measurements are in the same units).

4. The shift is calculated using Formula (ii).

5. The ordinates are then calculated at points 1, 2, 3, etc. using Formula (i).
6. The point at which the transition curve starts is then determined approximately by shifting the existing tangent point backwards by distance equal to half the length of the transition curve.

7. The offsets y_1, y_2, y_3, etc. are measured perpendicular to the tangent to get the profile of the transition curve.

$$y_1 = \frac{(L/8)^3}{6RL} = \frac{S}{128}$$

$$y_2 = \frac{(L/4)^3}{6RL} = \frac{S}{16}$$

$$y_3 = \frac{(3L/8)^3}{6RL} = 0.211S$$

$$y_4 = \frac{(L/2)^3}{6RL} = 0.500S$$

$$y_5 = \frac{(5L/8)^3}{6RL} = 0.976S$$

$$y_6 = \frac{(6L/8)^3}{6RL} = 1.688S$$

$$y_7 = \frac{(7L/8)^3}{6RL} = 2.680S$$

$$y_8 = \frac{L^3}{6RL} = 4S$$

Compound and Reverse Curve

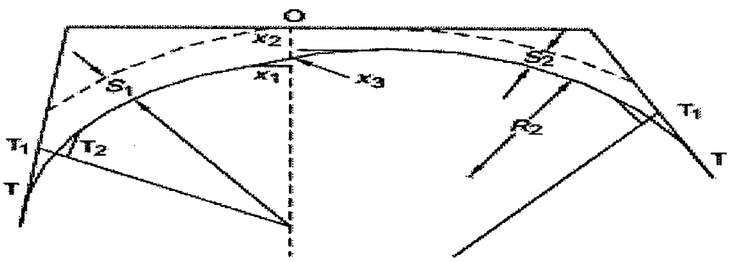


Fig. 13.14 Compound curve

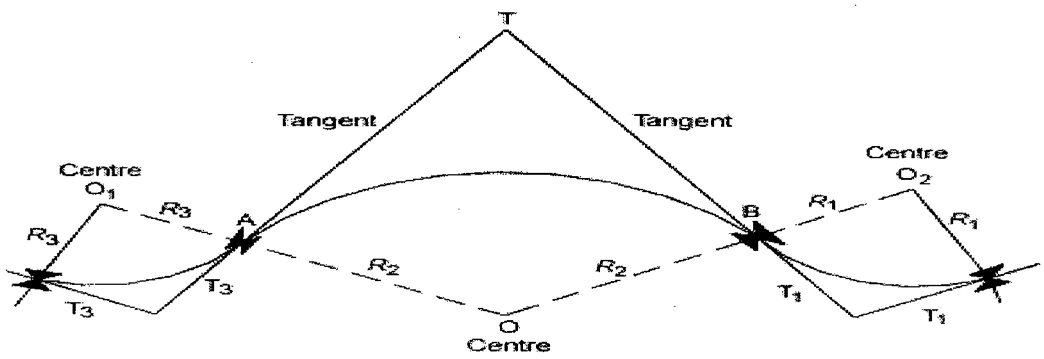


Fig. 13.15 Reverse curve

A compound curve is formed by the combination of two circular curves of different radii curving in the same direction. A reverse curve is formed by the combination of two circular curves with opposite curvatures. A common transition curve may be provided between the two circular curves of a reverse curve.

Compound Curve

A compound curve (Fig. 13.14) is formed by the combination of two circular curves of different radii curving in the same direction. A common transition curve may be provided between the two circular curves of a compound curve. Assuming that such a connecting curve is to be traversed at a uniform speed, the length of the transition curve connecting the two circular curves can be obtained from the formula

$$L = 0.008\,(C_{a1} - C_{a2}) \times V$$

or

$$L = 0.008\,(C_{d1} - C_{d2}) \times V_m, \text{ whichever is greater}$$

where C_{a1} and C_{d1} are the cant and cant deficiency for curve 1 and C_{a2} and C_{d2} are the cant and cant deficiency for curve 2 in millimetres. L is the length of the transition curve, in m,and V_m is the maximum permissible speed in km/h.

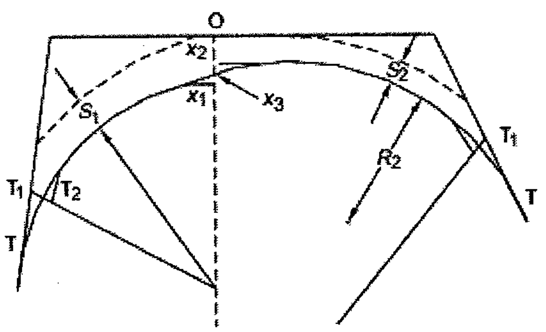


Fig. 13.14 Compound curve

Reverse Curve

A reverse curve (Fig. 13.15) is formed by the combination of two circular curves with opposite curvatures. A common transition curve may be provided between the two circular curves of a reverse curve. The total length of the transition curve, from the common circular curve to the individual circular curve, may be obtained in the same manner as explained for a compound curve in Section 13.15.

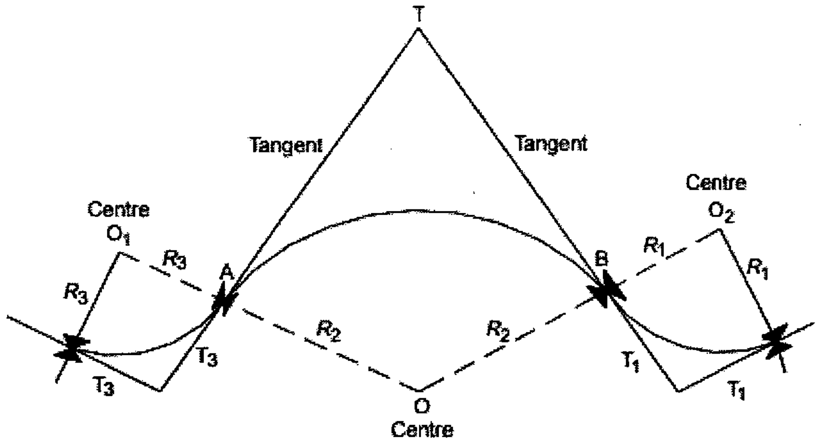


Fig. 13.15 Reverse curve

It has been stipulated that for high-speed group A and B routes, a minimum straight length of 50 m should be kept between the two curves constituting a reverse curve. In the case of a high-speed MG route, the distance to be kept should be 30 m. Straight lines between the circular curves measuring less than 50 m on BG sections of group A and B routes and less than 30 m on high-speed MG routes should be eliminated by suitably extending the transition lengths. When doing so, it should be ensured that the rate of change of cant and versine along the two transition lengths being extended is kept the same. When such straight lines between reverse curves cannot be eliminated and their lengths cannot be increased to over 50 m in the case of BG routes and 30 m in the case of MG routes, speeds in excess of 130 km/h on BG routes and 100 km/h on MG routes should not be permitted.

xtra Clearance on Curves

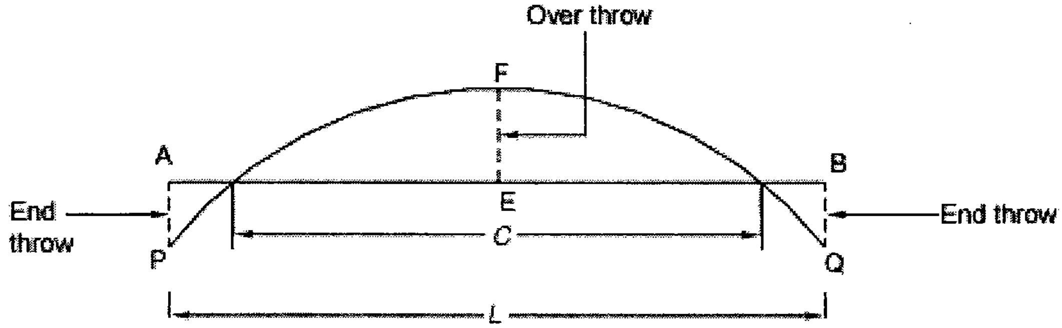


Fig. 13.16 Effect of curvature on long vehicle

Extra clearances are provided on horizontal curves keeping the following considerations in mind.

Extra Clearance on Curves

Extra clearances are provided on horizontal curves keeping the following considerations in mind.

Effect of curvature

When a vehicle negotiates a horizontal curve, its frame does not follow the path of the curve, since, being a rigid structure, it is unable to bend. The vehicle, therefore, projects towards the inside of the curve at its central point and toward the outside of the curve near its ends. The distance by which the longitudinal axis of the body of vehicle moves out from the central line of the track is the extra clearance required (Fig. 13.16).

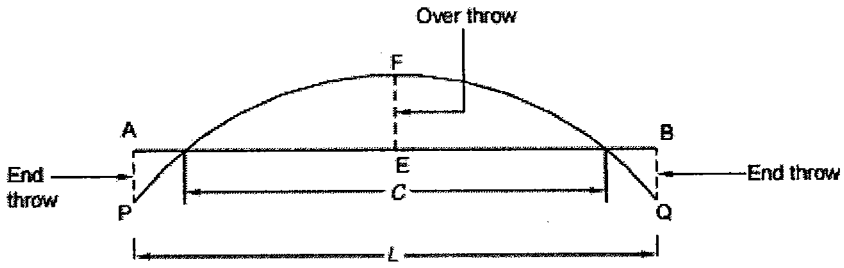


Fig. 13.16 Effect of curvature on long vehicle

(i) The extra clearance required at the centre of the vehicle, which projects towards the inside of the curve, is called overthrow and is given by the equation

$EF = c^2/8R$

(ii) The extra clearance required at the ends of the vehicle, which project towards the outside of the curve, is called end-throw and is given by the equation

AP or BQ = $L^2 - C^2 / 8R$

where L is the length of the vehicle, C is the centre-to-centre distance between the bogies and R is the radius of the curve.

Effect of leaning due to superelevation

On account of the superelevation provided on a curve, the vehicle leans towards the inside of the curve, thereby requiring extra clearance as shown in Fig. 13.17. The extra clearance required for leaning is as follows:

Lean = he/G

where h is the height of the vehicle, e is the superelevation, and G is the gauge.

In case the superelevation is not known, it is suggested that its value be assumed to be 70 mm up to a 1 o curve and 115 mm for curves above 1 o . No extra clearance, however, is required for leaning on the outside of the curve.

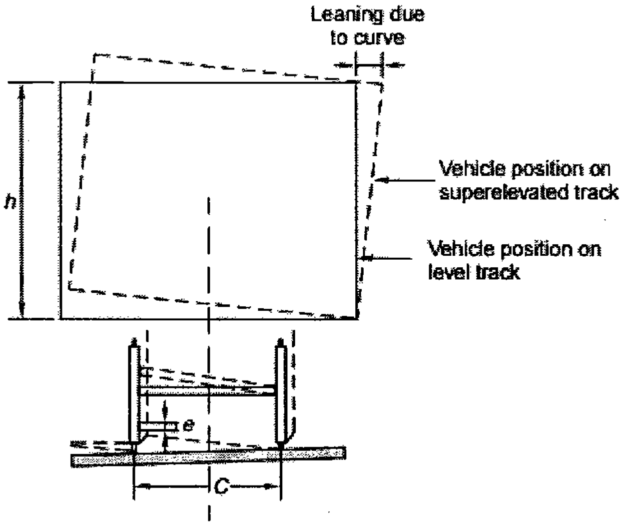


Fig. 13.17 Effect of lean due to superelevation

Effect of sway of vehicles

On account of unbalanced centrifugal forces caused due to cant deficiency or cant excess, the vehicles tend of experience an additional sway. The extra clearance required on the inside of the curve due to the sway is taken as one-fourth of the clearance necessary due to leaning.

On summarizing, the total extra clearance (in mm) required on curves is as follows:

(i) Extra clearance inside the curve = overthrow + lean + sway

$$Ec_1 = \frac{C^2}{8R} + \frac{eh}{G} + \frac{1}{4} \times \frac{eh}{G} \qquad (13.24)$$

(ii) Extra clearance outside the curve = end-throw

$$Ec_2 = \frac{L^2 - C^2}{8R} \qquad (13.25)$$

where C is the centre-to-centre distance between bogies, which is 14,785 mm for BG routes and 13,715 mm for MG routes, R is the radius of the curve in mm, L is the length of a bogie, which is 21,340 mm for BG routes and 19,510 mm for MG routes, e is the superelevation in mm, h is the height of the vehicle, which is 3350 mm for BG tracks and 3200 mm for MG tracks, and G is the gauge, which is 1676 mm for BG tracks and 1000 mm for MG tracks.

The empirical formulae normally adopted in the field for determining the extra clearance due to the curvature effect are as follows:

	BG	MG
Overthrow (mm)	27,330/R	23,516/R
End-throw (mm)	29,600/R	24,063/R

These empirical formulae are based on standard BG and MG bogie lengths and the value of R is in metres.

1 Extra Clearance Required in Various Situations

This section discusses the extra clearances required in different situations with regard to the track and the platform.

Between adjacent and curved tracks

In this case, the lean will not be taken into consideration, as both the tracks will have almost the same superelevation. The extra clearance required in this case will be the sum of the clearances required on the inside and the outside of the curve as follows:

$Ec = (Ec_1 - \text{lean}) + Ec_2$

= Overthrow + sway + end-throw

$$\frac{C^2}{8R} + \frac{1}{4} \times \frac{eh}{G} + \frac{L^2 - C^2}{8R} \qquad (13.26)$$

where e is the superelevation in mm, h is the height of the vehicle (3.35 m for BG and 3.2 m for MG), and Gis the gauge.

For adjacent tracks with structures in between

When there is a structure between two adjacent tracks, each track is treated independently and extra clearances are provided by considering each track with respect to the structure.

For platforms

In the case of platforms, it has been observed that the provision of extra clearance on curves as discussed may lead to excessive gap between the footboard and the platform. It is, therefore, stipulated that next to platforms this extra clearance be reduced by 51 mm (2 in.) on the inside of the curve and 25 mm (1 in.) on the outside of the curve.

Example 13.7 Two high-level platforms are to be provided on the inside as well as the outside of a 2 o curve on a BG track with a superelevation of 100 mm. What should the required extra clearances for these platforms, both on the inside and the outside of the curve, be? (Length of bogie = 21,340 mm, c/c bogie distance = 14,785 mm, height of platform = 840 mm.)

Solution Radius of the curve = 1750/D = 1750/2 o = 875 m.

(i) Extra clearance required on the inside of the curve, Ec_1 = overthrow + lean + sway - 51 mm.

Solution Radius of the curve = 1750/*D* = 1750/2° = 875 m.

(i) Extra clearance required on the inside of the curve,

Ec_1 = overthrow + lean + sway − 51 mm.

$$\frac{C^2}{8R} + \frac{eh}{G} + \frac{1}{4} \times \frac{eh}{G} - 51\text{mm}$$

In this example, C = 14,875 mm, R = 875,000 mm, e = 100 mm, G = 1676 mm, and h = 840 mm. Therefore,

$$Ec_1 = \frac{14{,}785^2}{8 \times 875{,}000} + \frac{100 \times 840}{1676} + \frac{1}{4} \times \frac{100 \times 840}{1676} - 51\text{mm}$$

= 42.88 mm = 45 mm approx.

(ii) Extra clearance required on the outside of the curve,

$$Ec_2 = \text{End-throw} - 25 \text{ mm} = \frac{L^2 - C^2}{8R} - 25$$

where $L = 21{,}340$ mm, $C = 14{,}875$ mm, and $R = 875{,}000$ mm. Therefore,

$$Ec_2 = \frac{21{,}340^2 - 14785^2}{8 \times 875{,}000} - 25$$

$$= 33.83 - 25 \text{ mm} = 8.83 \text{ mm or approx. } 10 \text{ mm}$$

Therefore, an extra clearance of 45 mm should be provided for the outside platform on the inner side of the curve and of 10 mm for the inside platform on the outer side of the curve.

Widening of Gauge on Curves

A vehicle normally assumes the central position on a straight track and the flanges of the wheels stay clear of the rails. The situation, however, changes on a curved track. As soon as the vehicle moves onto a curve, the flange of the outside wheel of the leading axle continues to travel in a straight line till it rubs against the rail. Due to the coning of wheels, the outside wheel travels a longer distance compared to the inner wheel. This, however, becomes impossible for the vehicle as a whole since the rigidity of the wheel base causes the trailing axle to occupy a different position. In an effort to make up for the difference in the distance travelled by the outer wheel and the inner wheel, the inside wheels slip backward and the outer wheels skid forward. A close study of the running of vehicles on curves indicates that the wear of flanges eases the passage of the vehicle round curves, as it has the effect of increasing the gauge. The widening of the gauge on a curve has, in fact, the same effect and tends to decrease the wear and tear on both the wheel and the track.

The stipulations laid down with regard to the gauge on straight tracks and curves on Indian Railways are given in Table 13.7.

The widening of the gauge on curves can be calculated using the formula

$$\text{Extra width on curves } (w) = \frac{13(B+L)^2}{R} \qquad (13.27)$$

where B is the wheel base of the vehicle in metres, R is the radius of the curve in metres, $L = 0.02\,(h^2 + Dh)^{1/2}$ is the lap of the flange in metres, h is the depth of flange below top of the rail, and D is the diameter of the wheel of the vehicle.

Table 13.7 Gauge standard for curves

Type of track	*Gauge tolerances for BG*	*Gauge tolerances for MG and NG*
Straight track including curves of 350 m for BG, 290 m for MG, and 400 m and more for NG	–5 mm to + 3 mm	MG: – 2 mm to + 3 mm NG: – 3 mm to + 3 mm
For curves of radius less than 350 m for BG, 290 m for MG, and 400 m to 100 m for NG	Up to + 10 mm	Up to +10 mm
For curves with radius less Than 100 m for NG	–	up to + 15 mm

• The gauge on a track with wooden sleepers need not be disturbed if it is likely to cause spike killing of sleepers.

Example 13.8 The wheel base of a vehicle moving on a BG track is 6 m. The diameter of the wheels is 1524 mm and the flanges project 32 mm below the top of the rail. Determine the extra width of the gauge required if the radius of the curve is 168 m. Also indicate the extra width of gauge actually provided as per Indian Railways standards.

Solution

(i) Lap of flange $L = 0.02\sqrt{h^2 + Dh}$

where h = 3.2 cm is the depth of the flange below the top of the rail and D = 152.4 cm is the diameter of the wheel. Therefore,

$$L = 0.02\sqrt{h^2 + Dh}$$

$$= 0.02\sqrt{3.2^2 + (152.4 \times 3.2)} = 0.446\,\text{m}$$

(ii) Extra width of gauge (w) = $\dfrac{13(B + L)^2}{R}$

$$= \frac{13(6 + 0.446)^2}{168} = 3.21\,\text{cm} = 32.1\,\text{mm}$$

(iii) As per Indian Railways standards, an extra width of 5 mm is provided for curves with a radius less than 400 m in actual practice.

Vertical Curves The angle formed at the point of contact of the gradients is smoothened by providing a curve called the vertical curve in the vertical plane.

Vertical Curves

An angle is formed at the point where two different gradients meet, forming a summit or a sag as explained in Fig. 13.18. The angle formed at the point of contact of the gradients is smoothened by providing a curve called the vertical curve in the vertical plane. In the absence of a vertical curve, vehicles are likely to have a rough run on the track. Besides this, a change in the gradient may also cause bunching of vehicles in the sags and a variation in the tension of couplings in the summits, resulting in train parting and an uncomfortable ride. To avoid these ill effects, the change in gradient is smoothened by providing a vertical curve. A rising gradient is normally considered positive and a failing gradient is considered negative.

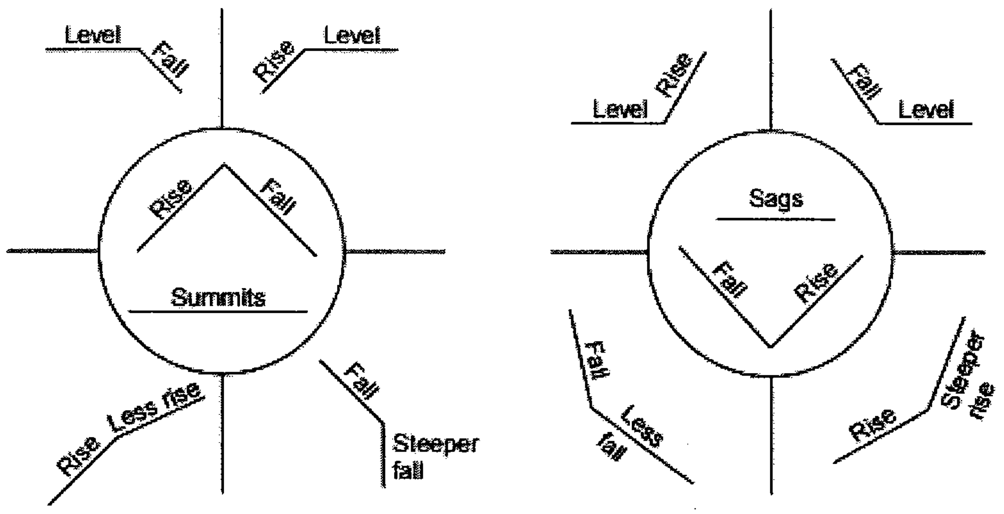


Fig. 13.18 Summits and sags in vertical curves

A vertical curve is normally designed as a circular curve. The circular profile en-sures a uniform rate of change of gradient, which controls the rotational acceleration.

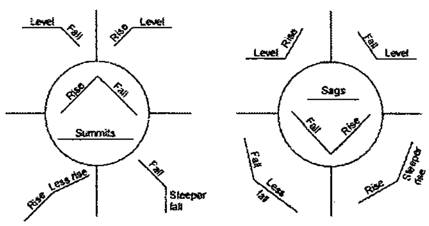


Fig. 13.18 Summits and sags in vertical curves

1 Calculating the Length of a Vertical Curve (Old Method)

The length of a vertical curve depends upon the algebraic difference between the gradients and the type of curve formed (summit or sag). The rate of change of gradient in the case of summits should not exceed 0. 1% between successive 30.5-m (100-ft) chords, whereas the corresponding figure for sags is 0.05% per 30.5-m (100-ft) chord. The required length of a vertical curve for achieving the maximum permissible speed is given by the formula

$L = (a/r)\ 30.5$ m (13.28) where L is the length of the vertical curve in m, a is the per cent algebraic difference between successive gradients, and r is the rate of change of the gradient, which is 0.1% for summit curves and 0.05% for sag curves.

2 Existing Provisions on Indian Railways

As per the existing provisions, vertical curves are provided only at the junction of gradients, when the alegebraic difference between the gradients is equal to or more than 0.4 per cent. The minimum radii for vertical curves are given in Table 13.8.

Table 13.8 Minimum radii for vertical curves

Table 13.8 Minimum radii for vertical curves

Broad gauge (BG)		*Metre gauge (MG)*	
Group	*Min. radius (m)*	*Group*	*Min. radius (m)*
A	4000	All routes	2500
B	3000		
C, D, and E	2500		

3 Setting a Vertical Curve

A vertical curve can be set by various methods, such as the tangent correction method and the chord deflection method. The tangent correction method, which is considered simpler than the other methods and is more convenient for the field staff, is described here (Fig. 13.19). It involves the following steps.

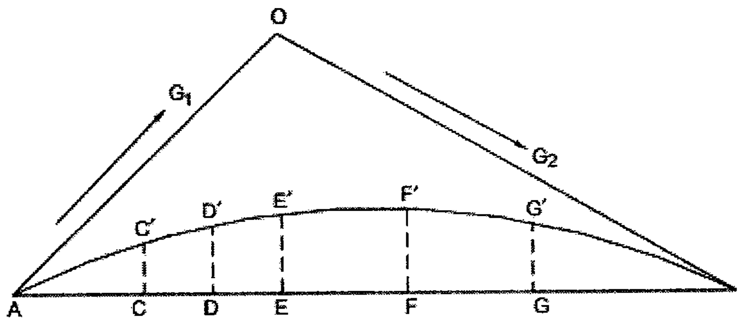


Fig 13.19 Setting out a vertical curve

d reduced levels (RL) of the tangent points and apex are then worked out.

2. Tangent corrections are then computed with the help of the following equation:

$y = cx^2$ (13.29)

and $C = g_1 - g_2 / 4.n$

where y is the vertical ordinate, x is the horizontal distance from the springing point, g1 is gradient number 1 (positive for rising gradients), g2 is gradient number 2 (negative for falling gradients), and n is the number of chords up to half the length of the curve.

1. The elevations of the stations on the curve are determined by algebrai adding the tangent corrections on tangent OA.

Example 13.9 Calculate the length of the vertical curve between two gradients meeting in a summit, one rising at a rate of 1 in 100 and the other falling at a rate of 1 in 200.

Solution

Gradient of the rising track (1 in 100) = 1% (+)
Gradient of the falling track (1 in 200) = 0.5% (–)
Change of gradient (a) = 1 – (–0.5) = 1 + 0.5% = + 1.5%
Rate of change of gradient (r) for summit curve = 0.1%

$$\text{Length of vertical curve} = \frac{1.5}{0.1}\frac{a}{r} \times 30.5\text{ m} = \frac{1.5}{0.1} \times 30.5$$
$$= 457.5\text{ m}$$

4 New Method of Calculating Length of Vertical Curve

According to the new method, the length of a vertical curve is calculated as follows: L = RQ (13.30) whereL is the length of the vertical curve, R is the radius of the vertical curve as
per the existing provisions given in Table 13.8, and Q is the difference in the percentage of gradients (expressed in radians).

It is seen that the length of the vertical curve calculated as per the new practice is relatively small compared to the length calculated using the old method. The length of the vertical curve according to the new practice is considered very reasonable for the purpose of laying the curve in the field, as can be seen from the next solved example.

Note that when the change in gradient (a) is positive it forms a summit and when it is negative it forms a sag.

Example 13.10 A rising gradient of 1 in 100 meets a falling gradient of 1 in 200 on a group A route. The intersection point has a chainage of 1000 m and its RL is 100 m. Calculate the length of the vertical curve, and the RL and the chainage of the various points in order to set a vertical curve at this location

Solution

First gradient = 1 in 100 (rising) = + 1% Second gradient = 1 in 200 (falling) = -0.5% Difference in gradient = (+ 1) - (-0.5) = 1.5% Length of vertical curve = L= RQ

= 4000 (1.5/100) = 60 m Chainage of point A (refer Fig. 13.19) = 1000 - 30 = 970 m Chainage of point B = 1000 + 30 = 1030 m

RL of point A = 100 - (30/100) = 99.70 m RL of point B = 100 - (30/200) = 99.85 m

Increase in RL for 60 m = 99.85 - 99.70 = 0.15 m

$$\text{First offset on vertical curve} = \frac{x(L-x)}{2R}$$

where $L = 60$ m, $R = 4000$ m, and $x = 10$ m.

The calculations for the RL of different points on the curve are shown in Table 13.9.

Table 13.9 Setting a vertical curve

Chainage	*Point*	*RL of point*	*Offset = [x(L − x)]/2R*	*Points on vertical curve*	*RL of points on curve*
970	A	99.700	0.0000	A	99.7000
980	C	99.7000 + 0.025 = 99.725	$\frac{10 \times 50}{2 \times 4000} = 0.0625$	C	99.725 + 0.0625 = 99.7875
990	D	99.725 + 0.025 = 99.750	$\frac{20 \times 40}{2 \times 4000} = 0.1000$	D	99.750 + 0.1000 = 99.850
1000	E	99.750 + 0.025 = 99.775	$\frac{30 \times 30}{2 \times 4000} = 0.1125$	E	99.775 + 0.1125 = 99.8875
1010	F	99.775 + 0.025 = 99.800	$\frac{40 \times 20}{2 \times 4000} = 0.1000$	G	99.800 + 0.100 = 99.900
1020	G	99.800 + 0.025 = 99.825	$\frac{50 \times 10}{2 \times 4000} = 0.0625$	G	99.825 + 0.0625 = 99.8875
1030	B	99.825 + 0.025 = 99.850	0.0000	B	99.850

Cutting Rails on Curves

Rails on curves are usually laid with square joints. The inner rail gradually gains the lead over the outer rail on a curved track.

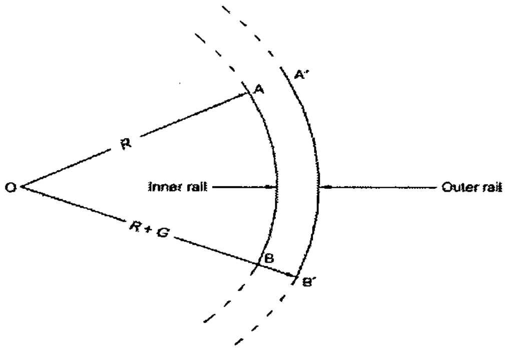


Fig. 13.21 Cutting rails on curves

Cutting Rails on Curves

Rails on curves are usually laid with square joints. The inner rail gradually gains the lead over the outer rail on a curved track. The excess length D, which the inner rail gains over the outer rail for a length L of the circular curve is calculated as follows (Fig. 13.21).

(i) Difference in circumference of outer rail and inner rail (i.e., gain):

2p R - 2p R (R - G) = 2p G

$$\text{Gain for length } L = \frac{2\pi G}{2\pi R} \times L = \frac{GL}{R}$$

$$= \frac{DL}{1000} \text{ for BG and } \frac{DL}{1654} \text{ for MG}$$

Gain for length 2p R = 2p G

where L is the length of outer rail of the circular curve, R is the radius of outer rail of the circular curve, D is the degree of curvature of outer rail, and G is the dynamic gauge (i.e., gauge + width of rail head), which is 1750 mm for BG and 1058 mm for MG.

Normally, when the inner rail of the curve leads over the outer rail by an amount equal to half the pitch of the fish bolt holes, the inner rail is cut by an amount equal to one full pitch and another hole is drilled for fastening the joint with a fish plate. The number of rails to be cut for a particular curve is worked out depending upon the degree and length of the curve and the pitch of the bolt holes.

Check Rails on Curves Check rails are provided parallel to the inner rail on sharp curves to reduce the lateral wear on the outer rail.

Check Rails on Curves

Check rails (Fig. 13.22) are provided parallel to the inner rail on sharp curves to reduce the lateral wear on the outer rail. They also prevent the outer wheel flange from mounting the outer rail and thus decrease the chances of derailment of vehicles. Check rails wear out quite fast but since, normally, these are worn out rails, further wear is not considered objectionable

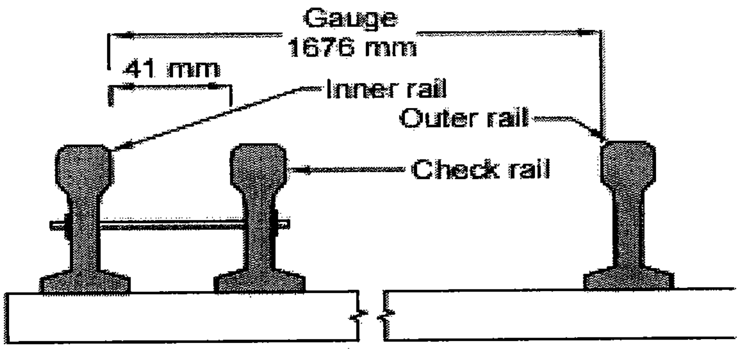


Fig. 13.22 Check rails on curves

According to the stipulations presently laid down by Indian Railways, check rails are provided on the gauge face side of the inner rails on curves sharper than 8 o on BG, 10 o on MG, and 14 o on NG routes. The minimum clearance prescribed for check rails is 44 mm for BG and MG routes and 41 mm for NG routes.

UNIT III TRUNOUTS AND CONTROLLERS

Railway Engineering: Points and Crossings - Important Terms

Points and crossings are provided to help transfer railway vehicles from one track to another. The tracks may be parallel to, diverging from, or converging with each other.

Points and Crossings

IntroductionPoints and crossings are provided to help transfer railway vehicles from one track to another. The tracks may be parallel to, diverging from, or converging with each other. Points and crossings are necessary because the wheels of railway vehicles are provided with inside flanges and, therefore, they require this special arrangement in order to navigate their way on the rails. The points or switches aid in diverting the vehicles and the crossings provide gaps in the rails so as to help the flanged wheels to roll over them. A complete set of points and crossings, along with lead rails, is called a *turnout.*

Important Terms

The following terms are often used in the design of points and crossings.

Turnout It is an arrangement of points and crossings with lead rails by means of which the rolling stock may be diverted from one track to another. Figure 14.1(a) shows the various constituents of a turnout. The details of these constituents are given in Table 14.1.

Direction of a turnout A turnout is designated as a right-hand or a left-hand turnout depending on whether it diverts the traffic to the right or to the left. In Fig. 14.1(a), the turnout is a right-hand turnout because it diverts as the traffic towards the right side. Figure 14.1(b) shows a left-hand turnout. The direction of a point (or turnout) is known as the*facing direction* if a vehicle approaching the turnout or a point has to first face the thin end of the switch. The direction is*trailing direction* if the vehicle has to negotiate a switch in the trailing direction i.e., the vehicle first negotiates the crossing and then finally traverses on the switch from its thick end to its thin end. Therefore, when standing at the toe of a switch, if one looks in the direction of the crossing, it is called the*facing direction* and the opposite direction is called the *trailing direction*.

Tongue rail It is a tapered movable rail, made of high-carbon or -manganese steel to withstand wear. At its thicker end, it is attached to a running rail. A tongue rail is also called a *switch rail.*

Stock rail It is the running rail against which a tongue rail operates.

Table 14.1 Parts of a turnout

Name of the main assembly	*Various constituents of the assembly*
Set of switches (Figs 14.1 and 14.2)	A pair of stock rails, a pair of tongue rails, a pair of heel blocks, several slide chairs, two or more stretcher bars, and a gauge tie plate
Crossing	A nose consisting of a point rail and splice rails, two wind rails, and two check rails
Lead rails (Fig. 14.1)	Four sets of lead rails

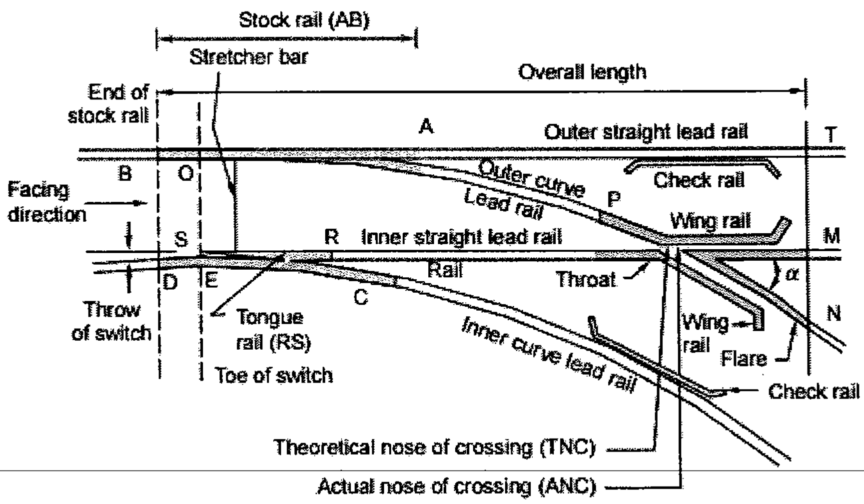


Fig. 14.1 (a) Constituents of a turnout

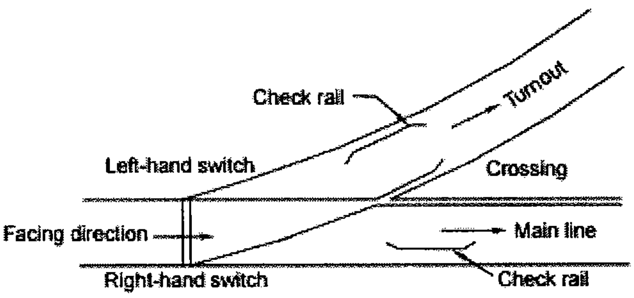


Fig. 14.1 (b) Left-hand turnout

Points or switch A pair of tongue and stock rails with the necessary connections and fittings forms a switch.

Crossing A crossing is a device introduced at the junction where two rails cross each other to permit the wheel flange of a railway vehicle to pass from one track to another.

Railway Engineering: Switches

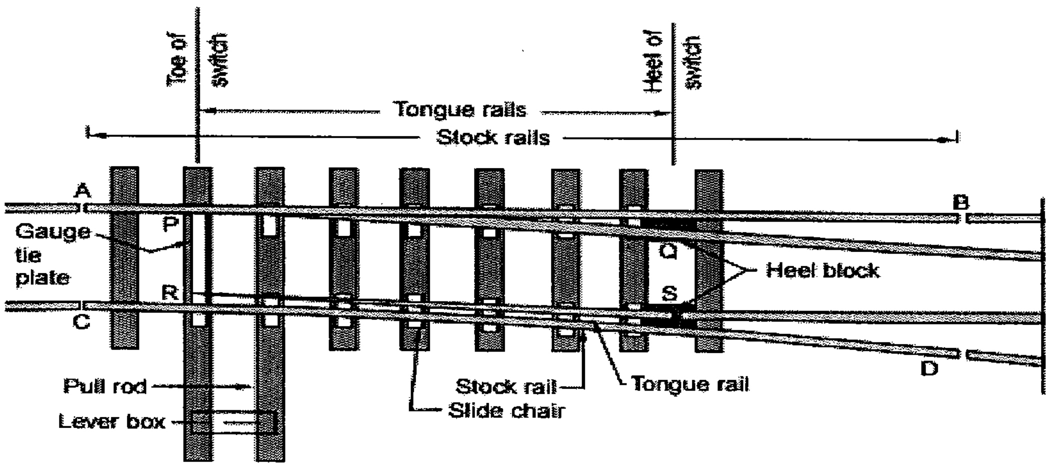


Fig. 14.2 Details of a switch

1.Types of Switches 2 Important Terms Pertaining to Switches

Switches

A set of points or switches consists of the following main constituents (Fig. 14.2).

(a) A pair of stock rails, AB and CD, made of medium-manganese steel.

(b) A pair of tongue rails, PQ and RS, also known as switch rails, made of medium-manganese steel to withstand wear. The tongue rails are machined to a very thin section to obtain a snug fit with the stock rail. The tapered end of the tongue rail is called the *toe* and the thicker end is called the *heel.*

(c) A pair of heel blocks which hold the heel of the tongue rails is held at the standard clearance or distance from the stock rails.

(d) A number of slide chairs to support the tongue rail and enable its movement towards or away from the stock rail.

(e) Two or more stretcher bars connecting both the tongue rails close to the toe, for the purpose of holding them at a fixed distance from each other.

(f) A gauge tie plate to fix gauges and ensure correct gauge at the points.

1.Types of Switches

Switches are of two types, namely, *stud switch* and *split switch.* In a stud type of switch, no separate tongue rail is provided and some portion of the track is moved from one side to the other side. Stud switches are no more in use on Indian Railways. They have been replaced by split switches. These consist of a pair of stock rails and a pair of tongue rails. Split switches may again be of two types-loose heel type and fixed heel type. These are discussed below.

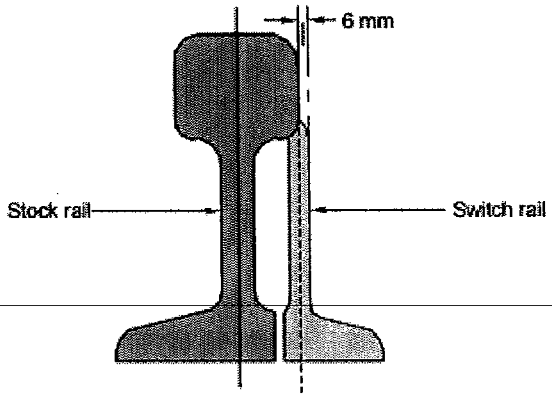
Loose heel type In this type of split switch, the switch or tongue rail finishes at the heel of the switch to enable movement of the free end of the tongue rail. The fish plates holding the tongue rail may be straight or slightly bent. The tongue rail is fastened to the stock rail with the help of a fishing fit block and four bolts. All the fish bolts in the lead rail are tightened while those in the tongue rail are kept loose or snug to allow free movement of the tongue. As the discontinuity of the track at the heel is a weakness in the structure, the use of these switches is not preferred.

Fixed heel type In this type of split switch, the tongue rail does not end at the heel of the switch but extends further and is rigidly connected. The movement at the toe of the switch is made possible on account of the flexibility of the tongue rail.

Toe of switches

The toe of the switches may be of the following types.

Undercut switch In this switch the foot of the stock rail is planed to accommodate the tongue rail (Fig. 14.3).



Overriding switch In this case, the stock rail occupies the full section and the tongue rail is planed to a 6-mm (0.25") -thick edge, which overrides the foot of the stock rail (Fig. 14.4). The switch rail is kept 6 mm (0.25") higher than the stock rail from the heel to the point towards the toe where the planing starts. This is done to eliminate the possibility of splitting caused by any false flange moving in the trailing direction. This design is considered to be an economical and superior design due to the reasons given below.

(a) Since the stock rail is uncut, it is much stronger.

(b) Manufacturing work is confined only to the tongue rail, which is very economical.

(c) Although the tongue rail has a thin edge of only 6 mm (0.25"), it is supported by the stock rail for the entire weakened portion of its length. As such, the combined strength of the rails between the sleepers is greater than that of the tongue rail alone in the undercut switch.

Overriding switches have been standardized on the Indian Railways.

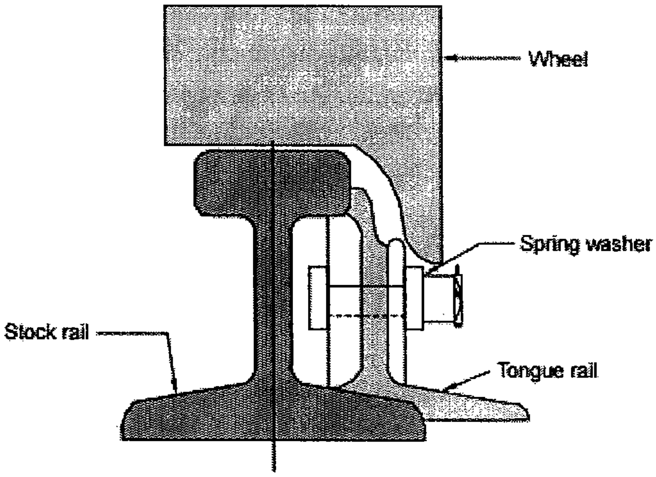


Fig. 14.4 Overriding switch

2 Important Terms Pertaining to Switches

The following terms are common when discussing the design of switches.

Switch angle This is the angle between the gauge face of the stock rail and that of the tongue rail at the theoretical toe of the switch in its closed position. It is a function of the heel divergence and the length of the tongue rail.

Flangeway clearance This is the distance between the adjoining faces of the running rail and the check rail/wing rail at the nose of the crossing. It is meant for providing a free passage to wheel flanges. Table 14.2 gives the minimum and maximum values of flangeway clearance for BG and MG tracks.

Table 14.2 Flangeway clearance

	Flangeway clearance	
Gauge	*Maximum value (mm)*	*Minimum value (mm)*
BG	48	44
MG	44	41

Heel divergence This is the distance between the gauge faces of the stock rail and the tongue rail at the heel of the switch. It is made up of the flangeway clearance and the width of the tongue rail head that lies at the heel.

Throw of the switch This is the distance through which the tongue rail moves laterally at the toe of the switch to allow movement of the trains. Its limiting values are 95-115 mm for BG routes and 89-100 mm for MG routes.

Design and Length of Tongue Rails

A tongue rail may be either straight or curved. Straight tongue rails have the advantage that they are easily manufactured and can be used for right-hand as well as left-hand turnouts.

Design of Tongue Rails :A tongue rail may be either straight or curved. Straight tongue rails have the advantage that they are easily manufactured and can be used for right-hand as well as left-hand turnouts. However, get jolted trains while negotiating with straight tongue rails turnouts because of the abrupt change in the alignment. Straight tongue rails are normally used for 1 in 8.5 and 1 in 12 turnouts on Indian Railways.

Curved tongue rails are shaped according to the curvature of the turnout from the toe to the heel of the switch. Curved tongue rails allow for smooth turning of trains, but can only be used for the specific curvature for which they are designed. Curved switches are normally used for 1 in 16 and 1 in 20 IRS (Indian Railway Standard) turnouts on Indian Railways. Recently Indian Railways has also started laying 1 in 8.5 and 1 in 12 turnouts with curved switches on important lines.

Length of Tongue Rails

The length of a tongue rail from heel to toe varies with the gauge and angle of the switch. The longer the length of the tongue rail, the smoother the entry to the switch because of the smaller angle the switch rail would make with the fixed heel divergence. The longer length of the tongue rail, however, occupies too much layout space in station yards where a number of turnouts have to be laid in limited space. The length of the tongue rail should be more than the rigid wheel base of a four-wheeled wagon to preclude the possibility of derailment in case the points move from their position when a train is running on the switch. Table 14.3 gives the standard lengths of switches (tongue rails) for BG and MG tracks.

Table 14.3 Length of tongue rail

Table 14.3 Length of tongue rail

Gauge and type	*Length of tongue rail*				
	1 in 8.5 straight (mm)	*1 in 12 straight (mm)*	*1 in 12 curved (mm)*	*1 in 16 curved (mm)*	*1 in 20 curved (mm)*
BG (90 R)	4725	6400	7730	9750	1,1150
MG (75 R)	4116*	5485*	6700	7420	

* These dimensions hold good for NG tracks also.

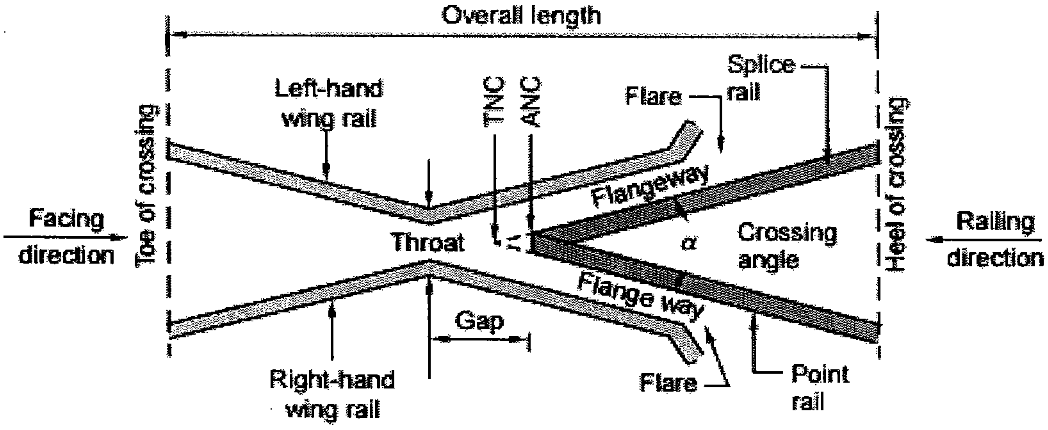


Fig. 14.5 Details of a crossing

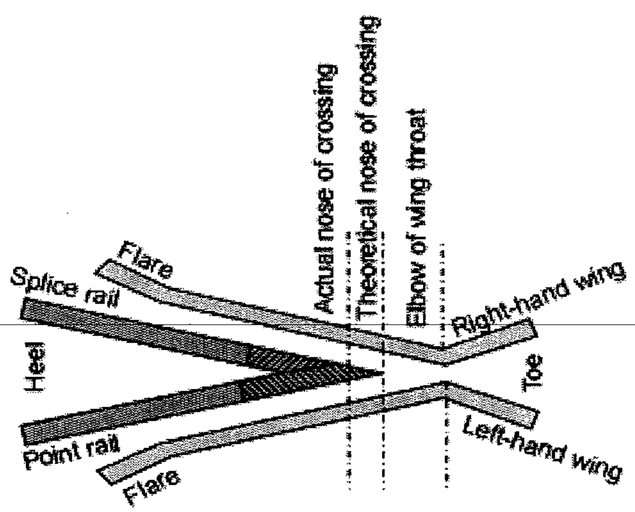


Fig. 14.6 Point rail and splice rail

A crossing or frog is a device introduced at the point where two gauge faces cross each other to permit the flanges of a railway vehicle to pass from one track to another.

Crossing

A crossing or *frog* is a device introduced at the point where two gauge faces cross each other to permit the flanges of a railway vehicle to pass from one track to another (Fig. 14.5). To achieve this objective, a gap is provided from the throw to the nose of the crossing, over which the flanged wheel glides or jumps. In order to ensure that this flanged wheel negotiates the gap properly and does not strike the nose, the other wheel is guided with the help of check rails. A crossing consists of the following components, shown in Fig. 14.6.

(a) Two rails, the *point rail* and *splice rail*, which are machined to form a nose. The point rail ends at the nose, whereas the splice rail joins it a little behind the nose. Theoretically, the points rail should end in a point and be made as thin as possible, but such a knife edge of the point rail would break off under the movement of traffic. The point rail, therefore, has its fine end slightly cut off to form a blunt nose, with a thickness of 6 mm (1/4"). The toe of the blunt nose is called the *actual nose of crossing* (ANC) and the theoretical point where gauge faces from both sides intersect is called the*theoretical nose of crossing* (TNC). The 'V' rail is planed to a depth of 6 mm (1/4") at the nose and runs out in 89 mm to stop a wheel running in the facing direction from hitting the nose.

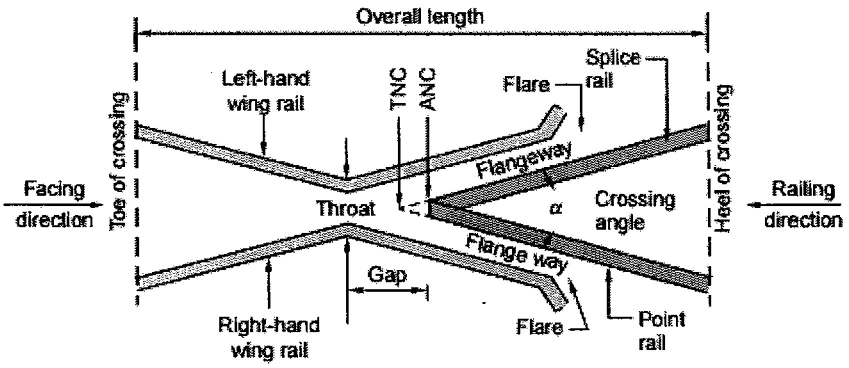


Fig. 14.5 Details of a crossing

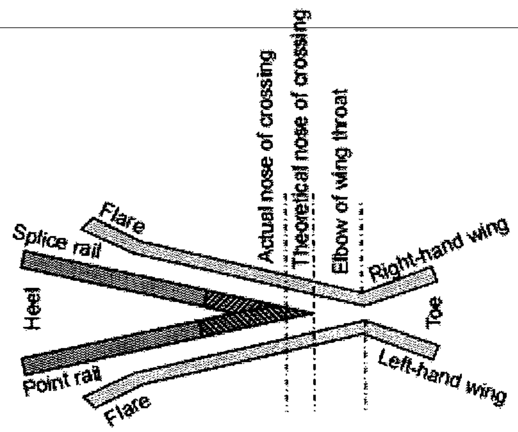


Fig. 14.6 Point rail and splice rail

(b) Two wing rails consisting of a right-hand and a left-hand wing rail that converge to form a throat and diverge again on either side of the nose. Wing rails are flared at the ends to facilitate the entry and exit of the flanged wheel in the gap.

(c) A pair of check rails to guide the wheel flanges and provide a path for them, thereby preventing them from moving sideways, which would otherwise may result in the wheel hitting the nose of the crossing as it moves in the facing direction.

1 Types of Crossings

A crossing may be of the following types.

(a) An *acute angle crossing* or 'V' crossing in which the intersection of the two gauge faces forms an acute angle. For example, when a right rail crosses a left rail, it makes an acute crossing. Thus, unlike rail crossings form an acute crossing (A and C of Fig. 15.9).

(b) An *obtuse* or *diamond crossing* in which the two gauge faces meet at an obtuse angle. When a right or left rail crosses a similar rail, it makes an obtuse crossing (B and D of Fig. 15.9).

A *square crossing* in which two tracks cross at right angles. Such crossings are rarely used in actual practice (Fig. 14.7).

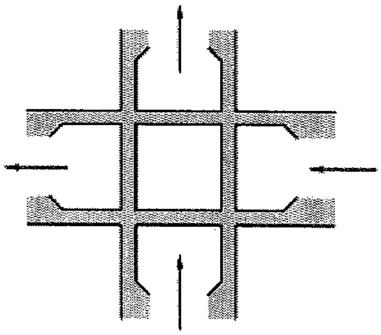


Fig. 14.7 Square crossing

For manufacturing purposes, crossings can also be classified as follows.

Built up crossing In a built-up crossing, two wing rails and a V section consisting of splice and point rails are assembled together by means of bolts and distance blocks to form a crossing. This type of crossing is commonly used on Indian Railways. Such crossings have the advantage that their initial cost is low and that repairs can be carried out simply by welding or replacing each constituent separately. A crossing becomes unserviceable when wear is more than 10 mm (3/8"). A built-up crossing, however, lacks rigidity. The bolts require frequent checking and sometimes break under fast and heavy traffic.

Cast steel crossing This is a one-piece crossing with no bolts and, therefore, requiring very little maintenance. Comparatively, it is a more rigid crossing since it consists of one complete mass. The initial cost of such a crossing is, however, quite high and its repair and maintenance pose a number of problems. Recently cast manganese steel (CMS) crossings, which have longer life, have also been adopted.

Combined rail and cast crossing This is a combination of a built-up and cast steel crossing and consists of a cast steel nose finished to ordinary rail faces to form the two legs of the crossing. Though it allows the welding of worn out wing rails, the nose is still liable to fracture suddenly.

2 CMS Crossing

Due to increase in traffic and the use of heavier axle loads, the ordinary built-up crossings manufactured from medium-manganese rails are subjected to very heavy wear and tear, specially in fast lines and suburban sections with electric traction. Past experience has shown that the life of such crossings varies from 6 months to 2 years, depending on their location and the service conditions. CMS crossings possess higher strength, offer more resistance to wear, and consequently have a longer life. The following are the main advantages of CMS crossings.

(a) Less wear and tear.

(b) Longer life: The average life of a CMS crossing is about four times more than that of an ordinary built-up crossing.

(c) CMS crossings are free from bolts as well as other components that normally tend to get loose as a result of the movement of traffic.

These days CMS crossings are preferred on Indian Railways. Though their initial cost is high, their maintenance cost is relatively less and they last longer. However, special care must be taken in their laying and maintenance. Keeping this in view, CMS crossings have been standardized on Indian Railways. On account of the limited availability of CMS crossings in the country, their use has, however, been restricted for the time being to group A routes and those lines of other routes on which traffic density is over 20 GMT. These should also be reserved for use on heavily worked lines of all the groups in busy yards.

3 Spring or Movable Crossing

In a spring crossing, one wing rail is movable and is held against the V of the crossing with a strong helical spring while the other wing rail is fixed (Fig. 14.8). When a vehicle passes on the main track, the movable wing rail is snug with the

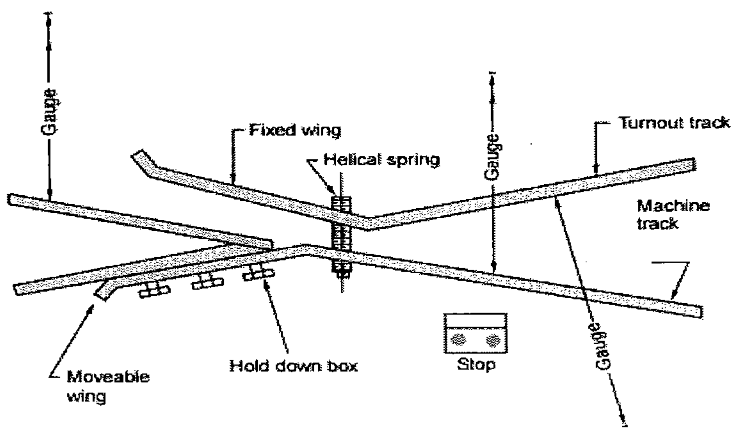


Fig. 14.8 Spring or movable crossing

crossing and the vehicle does not need to negotiate any gap at the crossing. In case the vehicle has to pass over a turnout track, the movable wing is forced out by the wheel flanges and the vehicle has to negotiate a gap as in a normal turnout.

This type of crossing is useful when there is high-speed traffic on the main track and slow-speed traffic on the turnout track.

4 Raised Check Rails for Obtuse Crossings

In order to provide a guided pathway in the throat portion of a 1 in 8.5 BG obtuse diamond crossing, the check rails are raised by welding a 25-mm-thick MS plate. This arrangement is considered satisfactory for BG as well as MG routes.

5 Position of Sleepers at Points and Crossings

Sleepers are normally perpendicular to the track. At points and crossings, a situation arises where the sleepers have to cater to the main line as well as to the turnout portion of the track. For this purpose, longer sleepers are used for some length of the track as shown in Fig. 14.9.

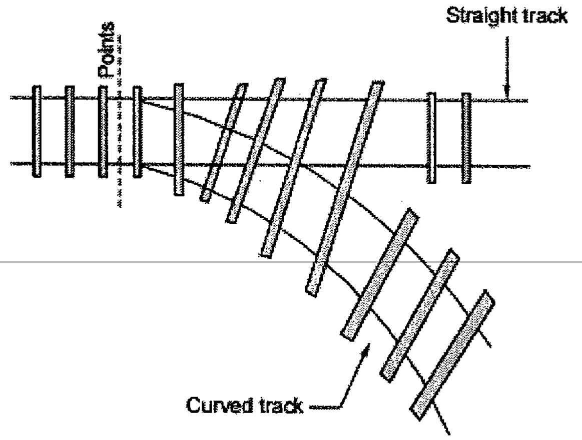


Fig. 14.9 Sleepers for points and crossings

Number and Angle of Railway Crossing

A crossing is designated either by the angle the gauge faces make with each other or, more commonly, by the number of the crossing, represented by N.

Number and Angle of Crossing

A crossing is designated either by the angle the gauge faces make with each other or, more commonly, by the number of the crossing, represented by *N*. There are three methods of measuring the number of a crossing, and the value of *N* also depends upon the method adopted. All these methods are illustrated in Fig. 14.10.

Centre line method

This method is used in Britain and the USA. In this method, *N* is measured along the centre line of the crossing.

Fig. 14.10 Different methods of measuring number (N) and angle of crossing

$$\cot\frac{\alpha}{2} = N \div \frac{1}{2}$$

or

$$N = \frac{1}{2}\cot\frac{\alpha}{2}$$

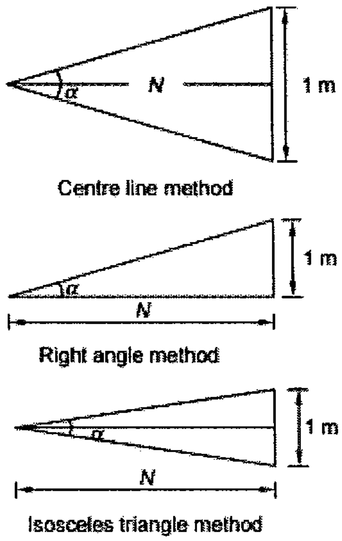


Fig. 14.10 Different methods of measuring number (N) and angle of crossing

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Right angle method

This method is used on Indian Railways. In this method, N is measured along the base of a right-angled triangle. This method is also called *Coles method.*

$$\cot\alpha = \frac{N}{1}$$

or

$$N = \cot\alpha$$

Isosceles triangle method

In this method, N is taken as one of the equal sides of an isosceles triangle.

$$\sin\frac{\alpha}{2} = \frac{1/2}{N} = \frac{1}{2N}$$

or

$$\operatorname{cosec}\frac{\alpha}{2} = 2N$$

$$N = \frac{1}{2}\operatorname{cosec}\frac{\alpha}{2}$$

The right angle method used by Indian Railways, in which *N* is the cotangent of the angle formed by two gauge faces, gives the smallest angle for the same value of *N*.

To determine the number of a crossing (*N*) on site, the point where the offset gauge face of the turnout track is 1 m is marked. The distance of this point (in metres) from the theoretical nose of crossing gives *N*.

Reconditioning of Worn Out Railway Crossings

Generally, noses of crossings and wing rails ungergo the maximum amount of wear in a turnout. The limiting wear for a crossing is 10 mm, after which it is required to be replaced.

Reconditioning of Worn Out Crossings

Generally, noses of crossings and wing rails ungergo the maximum amount of wear in a turnout. The limiting wear for a crossing is 10 mm, after which it is required to be replaced. A worn out crossing is generally reconditioned at the stage when the wear is only 6 mm (1/4"). In the case of tongue rails, the limit of vertical wear for 52-kg and 90 R rails is 6 mm (1/4") and that of lateral wear is 8 mm. Similarly, the limit of vertical wear for 60 R and 75 R rails is 6 mm and that of lateral wear is 5 mm. Normally gas welding is adopted to recondition crossings at the site itself. The sequence of operation is as follows.

1. An advance party carries out the preliminary work in which complete and detailed attention is paid to the turnout including through packing, replacement of worn out fittings, tightening of fittings, squaring, spacing of sleepers, etc.
2. Both the vertical and side wear are measured with the help of an 1.8-m straight edge. The area where welding is to be done is cleaned, and burns, etc., are removed using chalk.
3. The surfaces to be welded are also cleaned, and burns, etc. are removed using chisels.
4. Welding is done with the help of an oxyacetylene flame using suitable welding rods after pre-heating the surface for about 5 minutes. When the section is built up to the thickness required, the deposit metal is hammered to make a uniform level surface. The prepared surface is then checked with the help of a straight edge.
5. A caution order is sent out while the work is in progress and no speed restriction is necessary.
6. One welding party consisting of one permanent way mistry (craftsman), two welders, and six khalasis (labourers) including lookout men can weld one crossing or two pairs of switches every working day. The consumable items required for reconditioning work are ilsted in Table 14.4.

Table 14.4 Consumables required for reconditioning of crossings

Table 14.4 Consumables required for reconditioning of crossings

Component	*Requirement of oxygen (m^3)*	*Requirement of acetylene (m^3)*	*Requirement of welding rods (kg)*
One crossing	5.7	6.5	1.60
One pair of switches	2.3	3.0	0.75

Railway Engineering: Turnouts

The simplest arrangement of points and crossing can be found on a turnout taking off from a straight track. There are two standard methods prevalent for designing a turnout. These are the (a) Coles method and the (b) IRS method.

Turnouts

The simplest arrangement of points and crossing can be found on a turnout taking off from a straight track. There are two standard methods prevalent for designing a turnout. These are the (a) Coles method and the (b) IRS method.

These methods are described in detail in the following sections.

The important terms used in describing the design of turnouts are defined as follows.

Curve lead (CL) This is the distance from the tangent point (T) to the theoretical nose of crossing (TNC) measured along the length of the main track

Switch lead (SL) This is the distance from the tangent point (T) to the heel of the switch (TL) measured along the length of the main track.

Lead of crossing (L) This is the distance measured along the length of the main track as follows:

Lead of crossing (L) = curve lead (CL) - switch lead (SL)

Gauge (G) This is the gauge of the track.

Heel divergence (D) This is the distance between the main line and the turnout side at the heel.

Angle of crossing This is the angle between the main line and the tangent ofthe turnout line.

Radius of turnout (R) This is the radius of the turnout. It may be clarified that the radius of the turnout is equal to the radius of the centre line of the turnout (R_1) plus half the gauge width.

$$R = R_1 + 0.5G$$

As the radius of a curve is quite large, for practical purposes, R may be taken to be equal to R_1.

Special fittings with turnouts

Some of the special fittings required for use with turnouts are enumerated below.

Distance blocks Special types of distance blocks with fishing fit surfaces are provided at the nose of the crossing to prevent any vertical movement between the wing rail and the nose of the crossing.

Flat bearing plates As turnouts do not have any cant, flat bearing plates are provided under the sleepers.

Spherical washers These are special types of washers and consist of two pieces with a spherical point of contact between them. This permits the two surfaces to lie at any angle to each other. These washers are used for connecting two surfaces that are not parallel to one another.

Normally, tapered washers are necessary for connecting such surfaces. Spherical washers can adjust to the uneven bearings of the head or nut of a bolt and so are used on all bolts in the heel and the distance blocks behind the heel on the left-hand side of the track.**Slide chairs** These are provided under tongue rails to allow them to move laterally. These are different for ordinary switches and overriding switches

Grade off chairs These are special chairs provided behind the heel of the switches to give a suitable ramp to the tongue rail, which is raised by 6 mm at the heel.

Gauge tie plates These are provided over the sleepers directly under the toe of the switches, and under the nose of the crossing to ensure proper gauge at these locations.

Stretcher bars These are provided to maintain the two tongue rails at an exact distance

Coles method

This is a method used for designing a turnout taking off from a straight track (Fig. 14.11). The curvature begins from a point on the straight main track ahead of the toe of the switch at the theoretical toe of switch (TTS) and ends at the theoretical nose of crossing (TNC). The heel of the switch is located at the point where the offset of the curve is equal to the heel divergence. Theoretically, there would be no kinks in this layout, had the tongue rail been curved as also the wing rail up to the TNC. Since tongue rails and wing rails are not curved generally, there are the following three kinks in this layout.

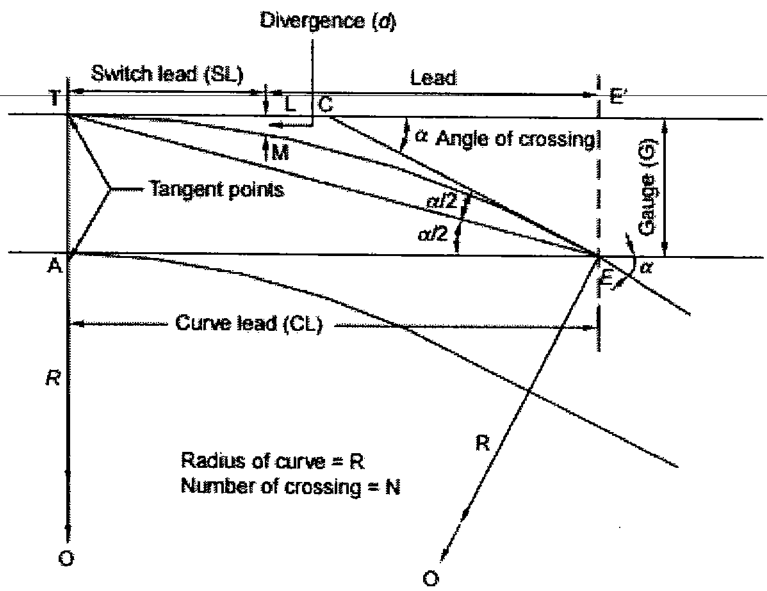

Fig. 14.11 Turnout from a straight track (Coles method)

(a) The first kink is formed at the actual toe of the switch.

(b) The second kink is formed at the heel of the switch.

(c) The third kink is formed at the first distance block of the crossing.

Switch lead (SL) TL is the length of the tangent with an offset LM = D = heel divergence.

From the properties of triangles, SL *SL = d (2R - d)

$$SL \times SL = d(2R - d)$$

or

$$\text{Switch lead} = \sqrt{2Rd - d^2}$$

Lead of crossing (L)

L = curve lead - switch lead

L = curve lead – switch lead

$$= G \cot\frac{\alpha}{2} - \sqrt{2Rd - d^2}$$

Radius of curve (R) In □AOE ,

OE = OT = R, OA = R - G

$OE^2 = OA^2 + AE^2$

$OE^2 = (R - G)^2 + (\text{curve lead})^2$

or,

$$R^2 = (R - G)^2 + (GN + G\sqrt{1 + N^2})$$

$$= R^2 - 2RG + G^2 + G^2N + G^2(1 + N^2) + 2\,G^2N\,\sqrt{1 + N^2}$$

$$2RG = 2G^2(1 + N^2) + 2G^2N\,\sqrt{1 + N^2}$$

or

$$R = G(1 + N^2) + GN\,\sqrt{1 + N^2}$$

$$= 1.5G + 2GN^2 \text{ (approximately)}$$

Summarizing the formulae derived,

$$\text{Curve lead (CL)} = G \cot\frac{\alpha}{2} \text{ or } 2GN \text{ approx.} \qquad (14.1)$$

$$\text{Switch lead (SL)} = \sqrt{2Rd - d^2} \qquad (14.2)$$

$$\text{Lead of crossing } (L) = G \cot\frac{\alpha}{2} - \sqrt{2Rd - d^2}$$

$$= 2GN - \sqrt{2Rd - d^2} \qquad (14.3)$$

$$\text{Radius of curve } (R) = 1.5G + 2GN^2 \qquad (14.4)$$

$$\text{Heel divergence } (d) = \frac{(SL)^2}{2\left(R + \frac{G}{2}\right)} \qquad (14.5)$$

Example 14.1 Calculate the lead and radius of a 1 in 8.5 BG turnout for 90 R rails using Coles method.

Solution

$G = 1.676$ m $\quad d = 120$ mm

$\alpha = 6° 42' 35''$ $\quad N = 8.5$

(i) Curve lead (CL) $= \sqrt{1 + N^2}$

$$= 1.676 \times 8.5 + 1.676\sqrt{1 + 8.5^2}$$

$$= 28.6 \text{ m}$$

(ii) Radius of turnout curve (R) $= 1.5G + 2GN^2$

$$= 1.5 \times 1.676 + 2 \times 1.676 \times 8.5$$

$$= 245 \text{ m}$$

(iii) Switch lead (SL) $= \sqrt{2Rd - d^2}$

$$= \sqrt{2 \times 2.45 \times 0.12 - 0.12^2}$$

$$= 7.67 \text{ m}$$

(iv) Lead = CL − SL = 20.6 − 7.7 = 20.9 m

IRS method :In this layout (Fig. 14.12), the curve begins from the heel of the switch and ends at the toe of the crossing, which is at the centre of the first distance block. The crossing is straight and no kink is experienced at this point. The only kink occurs at the toe of the switch. This is the standard layout used on Indian Railways. The calculations involved in this method are somewhat complicated and hence this method is used only when precision is required.

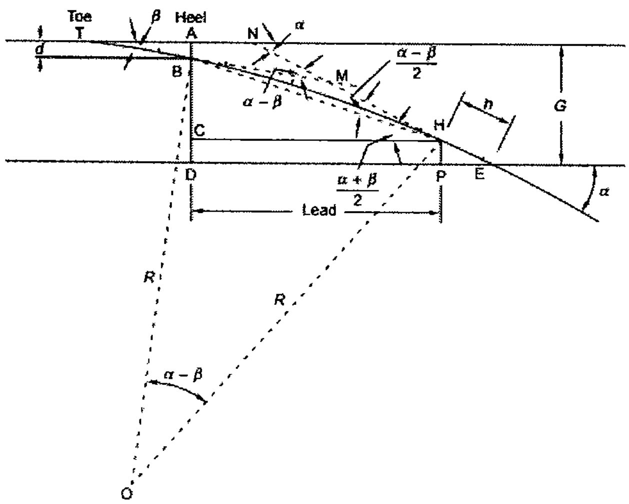

Fig. 14.12 Turnout from a straight track (IRS method)

Lead of crossing (L) In ΔBMH,

BM = MH (as both are tangents)

$$\angle MHB = \angle MBH = \frac{\alpha - \beta}{2}$$

$$BC = AD - (AB + CD) = G - (d + h\sin\alpha)$$

Therefore, crossing lead

$$L = (G - d - h\sin\alpha)\cot\frac{\alpha - \beta}{2} + h\cos\alpha \qquad (14.6)$$

Radius of curve (R) ΔOBH,

$$\angle BOH = \alpha - \beta$$

$$BH = 2R\sin\frac{\alpha - \beta}{2} \qquad (14.7)$$

In ΔBHC,

$$BH = \frac{BC}{\sin\frac{\alpha+\beta}{2}} = \frac{G - d - h\sin\alpha}{\sin\frac{\alpha + B}{2}} \qquad (14.8)$$

Equating Eqns (14.7) and (14.8)

$$2R\sin\frac{\alpha - \beta}{2} = \frac{G - d - h\sin\alpha}{\sin\frac{\alpha+\beta}{2}}$$

or

$$R = \frac{G - d - h\sin\alpha}{2\sin\frac{\alpha+\beta}{2} \times \sin\frac{\alpha-\beta}{2}}$$

$$= \frac{G - d - h\sin\alpha}{\cos\beta - \cos\alpha} \qquad (14.9)$$

Example 14.2 Calculate the lead and radius of a 1 in 8.5 BG turnout with straight switches. Use the IRS method.

Solution

G = 1676 mm, d = 136 mm, h = 864 mm

$\alpha = 6°\,42'\,35''$, $\beta = 1°\,34'\,27''$

(i) Lead $= (G - d - h\sin\alpha)\cot\frac{\alpha+\beta}{2} + h\cos\alpha$

$= (1676 - 136 - 864 \times 0.1168) \times 13.8089 + 864 \times 0.993$

$= 20{,}729.89$ mm or approx. 20,730 mm

(ii) Radius $= \frac{G - d - h\sin\alpha}{2\sin\frac{\alpha+\beta}{2} \times \sin\frac{\alpha-\beta}{2}}$

$= \frac{1676 - 136 - 864 \times 0.1168}{2 \times 0.7223 \times 0.0448} = 222{,}360$ mm

Example 14.3 A turnout is to be laid off a straight BG track with a 1 in 12 crossing. Determine the lead and radius of the turnout with the help of the following data: heel divergence (d) = 133 mm, crossing angle (□) = 4 o 45 ′49″, switch angle (□) = 1 o 8 ′00″, straight length between the theoretical nose of crossing and the tangent point of crossing (h) = 1.418 m.

Solution

$$\alpha = 4° 45' 49'', \ \beta = 1° 8' 0''$$
$$G = 1.676 \text{ m}, d = 0.133 \text{ m}$$
$$N = 12, h = 1.418 \text{ m}$$

(i) Radius $R = \dfrac{G - d - h \sin\alpha}{\cos\beta - \cos\alpha}$

$$= \frac{1.676 - 0.133 - 1.418 \sin 4°45'49''}{\cos 1°8'0'' - \cos 4°45'49''}$$
$$= 437.38 \text{ m}$$

(ii) Crossing lead (L) = $h \cos\alpha + (G - d - h \sin\alpha) \cot\dfrac{\alpha + \beta}{2}$

$$= 1.418 \cos 4° 45'49'' + (1.676 - 0.133 - 1.418 \sin 4° 45'49'') \times \cot 2° 56'54''$$
$$= 1.418 \times 0.9965 + 1.425 \times 19.415$$
$$= 29.084 \text{ m}$$

Standard turnouts and permissible speeds

On Indian Railways, normally 1 in 8.5 turnouts are used for goods trains while 1 in 12 and 1 in 16 turnouts are used for passenger trains. Recently 1 in 20 and 1 in 24 turnouts have also been designed by the RDSO, to be used to permit higher speeds for fast trains on the turnout side.

As per the Indian Railway way and works (IRWW) manual, a speed of 15 km/h was originally permitted on 1 in 8.5 turnouts. However, due to a subsequent number of derailments of passenger trains on turn-in curves, the speeds on these turnouts have row been reduced to 10 km/h only.

- The figures in the second row correspond to curved switches.
- A speed of 30 km/h is also permitted on 1 in 12 turnouts on those interlocked sections where all turnouts over which a running train may pass are 1 in 12 throughout the section and the locomotives are fitted with speedometers. In all other cases, speed is restricted to 15 km/h only.
- 60 km/h permitted only for high-speed turnouts to Drg. No. RDST/T-403.

Turnout with Curved Switches

The following formulae are used for the calculation of turnouts with curved switches

The following formulae are used for the calculation of turnouts with curved switches

$$R = \frac{G - t - h\sin\alpha}{2\sin\frac{\alpha+\beta}{2} \times \sin\frac{\alpha-\beta}{2}} = \frac{G - t - h\sin\alpha}{\cos\beta - \cos\alpha} \qquad (14.10)$$

$$I = R\sin\alpha - (G - t - h\sin\alpha)\cot\frac{\alpha+\beta}{2} \qquad (14.11)$$

$$V = G - \{h\sin\alpha + R(1 - \cos\alpha)\} \qquad (14.12)$$

$$\text{Switch lead} = \sqrt{2R(d-y) - (d-y)^2 - 1} \qquad (14.13)$$

$$\text{Lead} = (G - t - h\sin\alpha)\cot\frac{\alpha+\beta}{2} - \text{SL} - h\cos\alpha \qquad (14.14)$$

where R is the radius of the outer lead rail, G is the gauge, h is the lead of the straight leg of the crossing ahead of TNC up to the TP of the lead curve, t is the thickness of the switch at the toe, I is the distance from the toe of the switch to the point where the tangent drawn to the extended lead curve is parallel to the main line gauge face, V is the distance between the main line gauge face and the tangent drawn to the lead curve from a distance 1 from the toe, y is the vertical ordinate along the Y-axis, □ is the crossing angle, and □ is the switch angle.

Layout of Turnout

To lay out a turnout in the field, the values of offsets from the gauge face of the straight track to the gauge face of the turnout may be adopted from Table 14.6.

Trends in Turnout Design on Indian Railways

The main factors responsible for low speeds overturnouts on Indian Railways are as follows.

(a) A sudden change in the direction of the running edge upon entry onto the switch from a straight track
(b) Absence of a transition between the curved lead and the straight crossing
(c) Non-transitioned entry from the curved lead to the straight crossing
(d) Absence of superelevation over the turnout curve
(e) Gaps in the gauge face and the running table at the crossing
(f) Variation in cross level caused by raised switch rails

In order to achieve higher speeds on turnouts, it is necessary that all the limitations of the design of a turnout be overcome as far as possible. In European countries, the design of turnouts has been greatly improved and speeds of more than 100 km/ h are permitted on turnout curves. The main features of the design of these turnouts are the following.

(a) Long curved switches are provided to avoid the abrupt change in the direction of the vehicle at the entry to the switch.
(b) Switches and crossings are curved to the same radius as the lead curve or, alternatively, a transition curve is provided between the toe of the switch and the nose of the crossing. This provides a smooth passage to the trains on the turnout curve.

(c) Higher cant deficiency is permitted so that the disadvantage of not providing superelevation on the turnout curve is duly compensated.

In keeping with the trend in the railways of the world to permit higher speeds on turnouts, Indian Railways is considering standardization of high-speed turnouts for the following conditions of the track.

(a) For goods yards for a maximum permissible speed of 25 km/h and for passenger yards for maximum permissible speed of 50 km/h.
(b) In peripheries of big yards for bypass lines for a maximum permissible speed of 75 km/h.
(c) At junction joints of single-line and double-line sections for a maximum permissible speed of 100 km/h.

A design of 1 in 12 turnouts for passenger yards with thick web tongue rails and CMS crossings (RDSO Drg. no. T-2733) has already been finalized for enabling a maximum permissible speed of 50 km/h. Similarly, a new design of 1 in 24 turn outs for BG routes with curved switches and thick web tongue rails with a speed potential of 160 km/h is being finalized by Indian Railways.

Inspection and Maintenance of Railway Points and Crossings

Points and crossings should be inspected in detail, as the quality of a train ride greatly depends on their maintenance. The following important points should be checked.

Inspection and Maintenance of Points and Crossings

Points and crossings should be inspected in detail, as the quality of a train ride greatly depends on their maintenance. The following important points should be checked.

Condition of tongue rails and stock rails There should be no wear on the top as well as the gauge face side of the tongue rail. Badly worn out rails should be replaced. It should be ensured that the turnout side stock rail is provided with the requisite bend ahead of the toe of the switch; otherwise the alignment at this spot is bound to be kinky.

Condition of fittings of tongue and stock rails The fittings should be tight and the spherical washers must be placed at their correct locations. The slide chairs should be cleaned and greased with graphite for smooth operation of the points. The fish plates should be provided with the correct amount of bend at the loose heel joint. A gauge tie plate should be added if provisions for the same have not been made.

Gauge and cross level at switch assembly The gauge and cross levels should be checked for correctness at the following locations: (i) the stock joint, (ii) 150 mm (6") behind the toe of the switch, (iii) the mid-switch for the straight track and for the turnout side, and (iv) the heel of the switch for the straight track and for the turnout side.

Clearance between stock and tongue rails at the heel of the switch The correct divergence to be provided at heel of the switch should be as follows:

1 in 16 or 1 in 12	*1 in 8.5*
BG—133 mm (5.25")	120 mm (4.25")
MG—117 mm (4.65")	120 mm (4.75")

Throw of the switch The throw of the switch should be as follows

	Recommended	*Minimum*
BG	115 mm (4.5")	95 mm (3.25")
MG	100 mm (4")	89 mm (3.5")

Condition of crossing and tongue rail The condition of the crossings and of the fittings should be checked. The maximum vertical wear permitted on a point or wing rail is 10 mm and these should be reconditioned when the wear is 6 mm. The burn burrs should also be removed and the fittings should be tightened. The maximum vertical wear permitted on a tongue rail is 6 mm, whereas the permitted lateral wear is 8 mm for 90 R and 52-kg rails and 5 mm for 60 R and 75 R rails. The tongue rail should be replaced or reconditioned before this value is reached. The Railway Board has recently decided that the maximum vertical wear on wing rails and the nose of the crossings should be limited to 4 mm on the Rajdhani and Shatabdi routes and 6 mm on all other routes. The wear limits for CMS crossings are, however, 5.5 mm for Rajdhani and Shatabdi routes and 7.5 mm for all other routes.

Gauge and cross level of crossing assembly The gauge and cross level should be checked at the following locations and should always be correct: (i) 1 m ahead of the nose on straight tracks and on turnouts, (ii) 150 mm (6") behind the ANC on straight tracks and on turnouts, and (iii) 1 m behind the ANC on straight tracks and on turnouts.

Check rails The condition of check rails should be ascertained. Check rail clearances should be as follows:

	Maximum	Minimum
BG	48 mm	44 mm
MG	44 mm	41 mm

Lead curvature The curvature should be checked either by the offset method or by the versine method. The curvature should be correct and uniform.

Cross levels on straight tracks and turnouts The cross levels on straight tracks and turnouts should be checked to see that they are correct at all places.

Sleepers The condition of the sleepers and their fittings should be checked and unserviceable sleepers should be replaced. The squaring and spacing of sleepers should be proper and they should be well packed.

Ballast and drainage Enough quantity of ballast should be available so as to provide an adequate cushion. The drainage should be proper.

Any other defects If there are any other defects in the layout, these should be checked and corrected.

turnout: turnout of similar flexure is one that continues to run in the same direction as the main line curve even after branching off from it.
Track junctions are formed by the combination of points and crossings. Their main objective is to transfer rail vehicles from one track to another or to enable them to cross from one track to another. Depending upon the requirements of traffic, there can be several types of track junctions with simple track layouts. The most commonly used layouts are discussed in the following sections.

Turnout of Similar Flexure

A turnout of similar flexure (Fig. 15.1) is one that continues to run in the same direction as the main line curve even after branching off from it. The degree of the turnout curve is higher than that of the main line curve. The degree and radius of the turnout curve are given by the formulae

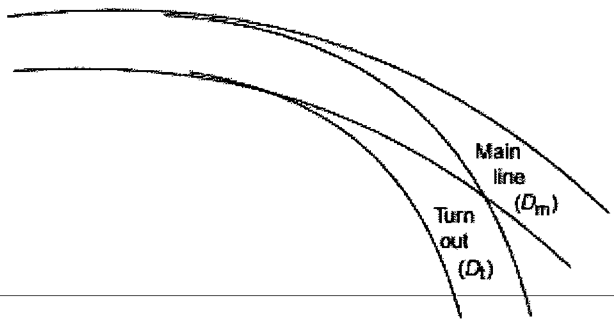

Fig. 15.1 Turnout of similar flexure

$$D_t = D_s + D_m \quad (15.1)$$

$$R_t = \frac{R_m R_s}{R_m + R_s} \quad (15.2)$$

where D_s is the degree of the outer rail of the turnout curve from the straight track, D_m is the degree of the rail of the main track on which the crossing lies, i.e., the inner rail in Fig. 15.1, D_t is the degree of the rail of the turnout curve on which the crossing lies, i.e., the outer rail, R_s is the radius of the outer rail of the turnout curve from the straight track, and R_t is the radius of the rail of the turnout curve on which the crossing lies, i.e., the outer rail.

Turnout of Contrary Flexure

A turnout of contrary flexure (Fig. 15.2) is one that takes off towards the direction opposite to that of the main line curve. In this case, the degree and radius of the turnout curve are given by the following formulae:

$$D_t = D_s - D_m \qquad (15.3)$$

$$R_t = \frac{R_s R_m}{R_m - R_s} \qquad (15.4)$$

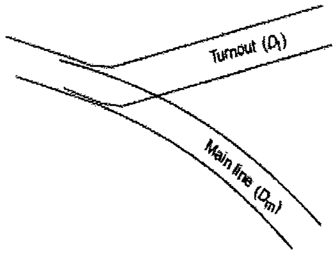

Fig. 15.2 Turnout of contrary flexure

Here D_m is the degree of the rail of the main track on which the crossing lies, i.e., the outer rail

Railway Track Junctions: Symmetrical Split

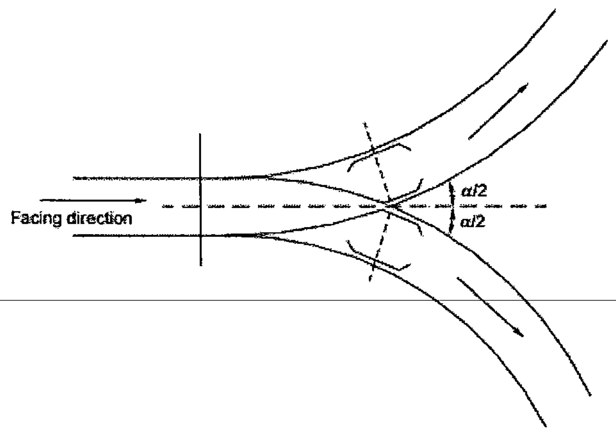

Fig. 15.3 Symmetrical split

When a straight track splits up in two different directions with equal radii, the layout is known as a symmetrical split.

Symmetrical Split

When a straight track splits up in two different directions with equal radii, the layout is known as a symmetrical split (Fig. 15.3). In other words, a symmetrical split is a contrary flexure in which the radii of the two curves are the same. The salient features of a symmetrical split are the following.

(a) The layout consists of a pair of points, one acute angle crossing, four curved lead rails, and two check rails.

(b) The layout is symmetrical about the centre line. This means that the radii of the main track as well as of the branching track are equal.

(c) The layout provides facilities for diverting vehicles both towards the left and the right.

(d) It is suitable for locations with space constraints, as it occupies comparatively much less space than a turnout from the straight track.

Railway Track Junctions: Three throw Switch

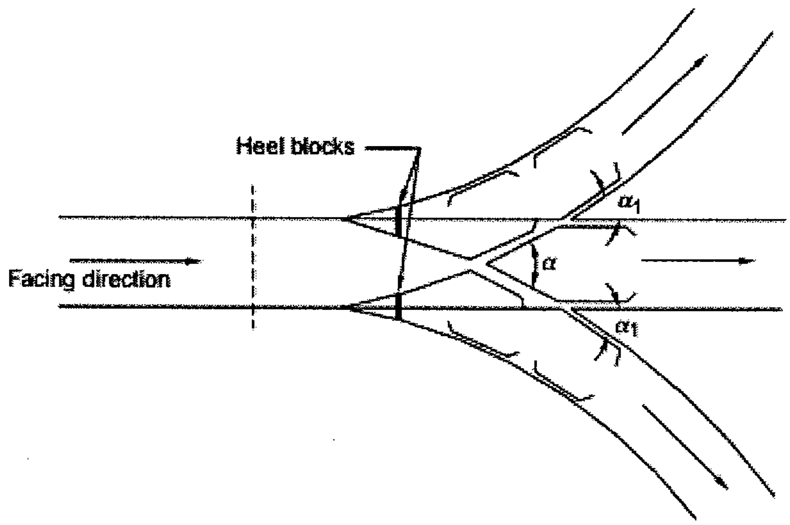

Fig. 15.4 Three-throw switch (contrary flexure)

In a three-throw arrangement, two turnouts take off from the same point of a main line track.

Three-throw Switch

In a three-throw arrangement, two turnouts take off from the same point of a main line track. A three-throw switch can have contrary flexure or similar flexure, as shown in Figs 15.4 and 15.5, respectively. Three-throw switches are used in congested goods yards and at entry points to locomotive yards, where there is a great limitation of space.

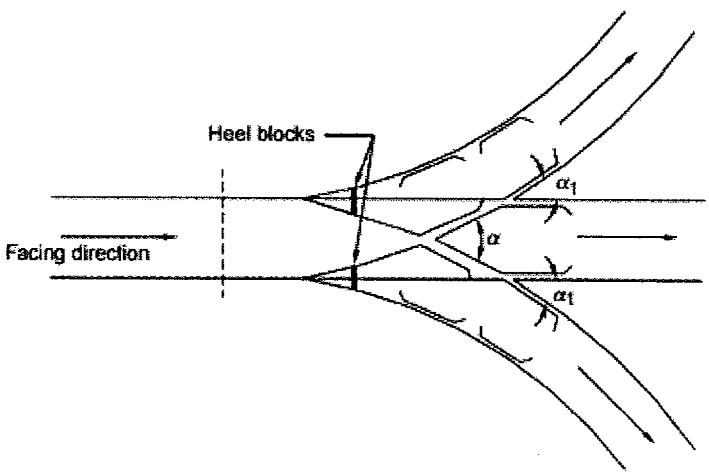

Fig. 15.4 Three-throw switch (contrary flexure)

A three-throw switch has two switches and each switch has two tongue rails placed side by side. There is a combined heel block for both the tongue rails of the switch. The switches can be operated in such a way that movement is possible in three different directions, i.e., straight, to the right, and to the left. Three-throw switches are obsolete now as they may prove to be hazardous, particularly at higher speeds, because the use of double switches may lead to derailments.

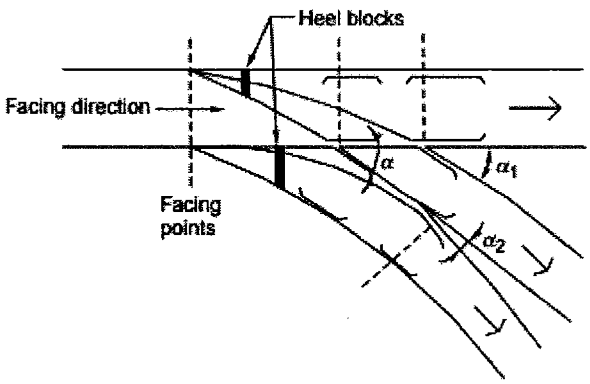

Fig. 15.5 Three-throw switch (similar flexure)

Railway Track Junctions: Double Turnout

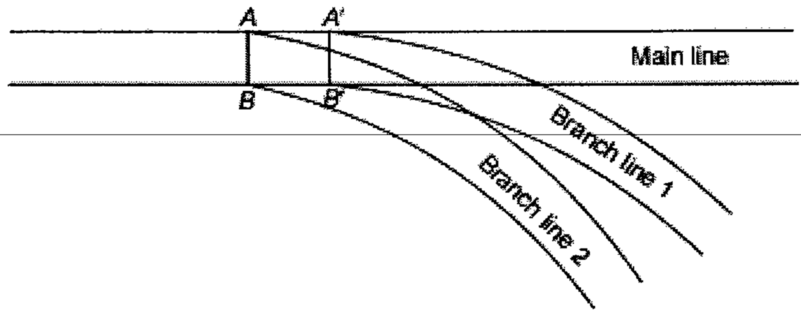

Fig. 15.6 Double turnout with similar flexure

A double turnout or tandem is an improvement over a three-throw switch. In a double turnout, turnouts are staggered and take off from the main line at two different places.

Double Turnout

A double turnout or *tandem* is an improvement over a three-throw switch. In a double turnout, turnouts are staggered and take off from the main line at two different places. This eliminates the defects of a three-throw switch, as the heels of the two switches are kept at a certain distance from each other. The distance between the two sets of switches should be adequate to allow room for the usual throw of the point.

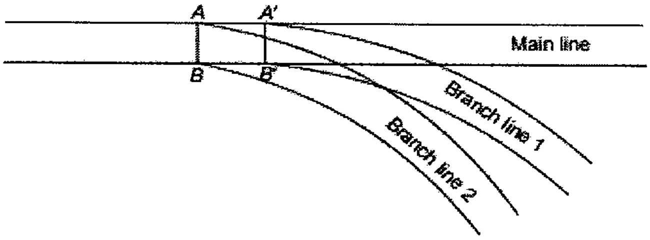

Fig. 15.6 Double turnout with similar flexure

Double turnouts can be of similar flexure, when the two turnouts take off on the same side of track (Fig. 15.6) or of contrary flexure, when the two turnouts take off in two different directions (Fig. 15.7).

Double turnouts are mostly used in congested areas, particularly where traffic is heavy, so as to economize on space.

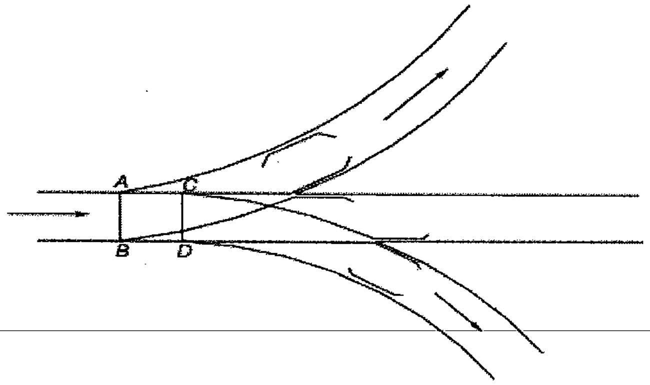

Fig. 15.7 Double turnout with contrary flexure

Crossover Between Two Parallel Railway Tracks with an Intermediate Straight Length

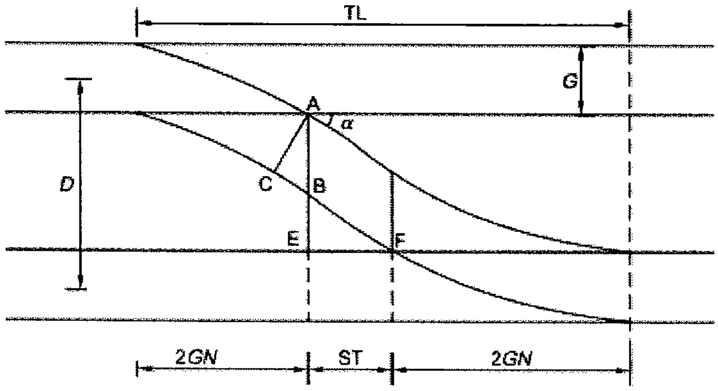

Fig. 15.8 Crossover between two parallel tracks

The crossover between two parallel tracks with an intermediate straight length can be designed by applying any one of two methods.

Crossover Between Two Parallel Tracks with an Intermediate Straight Length

The crossover between two parallel tracks with an intermediate straight length can be designed by applying any one of two methods.

Coles design

Coles design is a simple layout. In this case, two parallel tracks at a distance D from each other are connected by a crossover with a small length of the straight portion of the track lying between the two theoretical noses of the crossing. The straight portion of the track (ST) can be calculated using the formula

$$\text{Straight track (ST)} = (D - G)N - G\sqrt{1 + N^2} \qquad (15.5)$$

where G is the gauge of the track and N is the number of the crossing. The overall length (OL) of the crossover from the tangent point of one track to the tangent point of the other track is found by adding the lengths of the curve leads of the two turnouts and the length of the straight portion in between the two TNC (Fig. 15.8).

Overall length = OL of one turnout + ST + OL of other turnout

$$= 2GN + (D - G)N - G\sqrt{1 + N^2} + 2GN$$

$$= (D - G)N + G(4N - \sqrt{1 + N^2}) \qquad (15.6)$$

Since the value of N^2 is very large as compared to 1, the value $\sqrt{1 + N^2}$ can be taken approximately as N. Simplifying Eqn (15.6),

$$\text{Total length (TL)} = (D + 2G)N$$

$$= 2GN + \text{ST} + 2GN$$

$$= 4GN + \text{ST} \qquad (15.7)$$

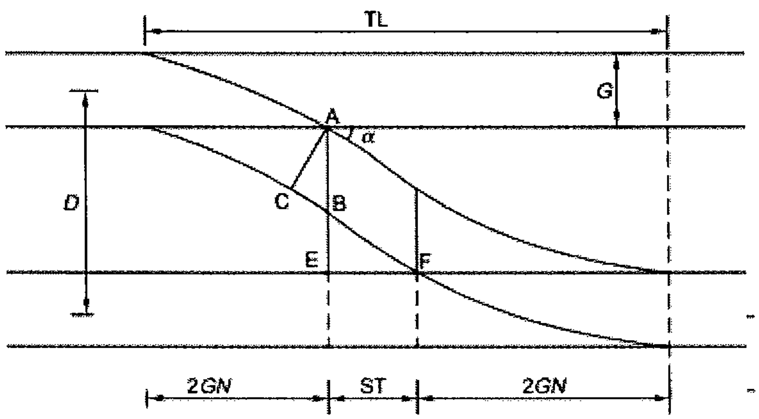

Fig. 15.8 Crossover between two parallel tracks

Example 15.1 A 1 in 8.5 crossover exists between two BG parallel tracks with their centres 5 m apart. Find the length of the straight track and the overall length of the crossover. Use Coles method. Given $D = 5$ m, $N = 8.5$, $G = 1.676$ m.

Solution

(i) $ST = (D - G)N - G\sqrt{1 + N^2}$

$= (5 - 1.676)8.5 - 1.676\sqrt{1 + N^2}$

$= 13.91$ m

(ii) $OL = ST + 4GN$

$= 13.91 + 4 \times 1.676 \times 8.5 = 70.89$ m

Example 15.2 A crossover is laid between two BG straight tracks placed at a distance of 5 m c/c. Calculate the (i) overall length, (ii) radius of the curved lead, (iii) lead distance. Heel divergence of 1 in 12 crossing = 133 mm.

Solution The crossing number is equal to 12 and the intermediate portion is straight.

(i) $ST = (D - G)N - G\sqrt{1 + N^2}$

where $D = 5$ m, $G = 1.676$ m, and $N = 12$,

$ST = (5 - 1.676)\ 12 - 1.676\ \sqrt{1 + 144}$

$= 39.88 - 20.18 = 19.69$ m

(ii) $OL = ST + 4GN$

$= 19.69 + 4 \times 1.676 \times 12$

$= 100.13$ m

(iii) Radius of the turnout curve (R):

$R = 1.5G + 2GN^2$

$= 1.5 \times 1.676 + 2 \times 1.676 \times 12 \times 12$

$= 485$ m

(iv) Lead of crossing (L) = curve lead – switch lead

$= 2GN - \sqrt{2Rd - d^2}$

$= 2 \times 1.676 \times 12 - \sqrt{2 \times 485 \times 0.133 - (0.133)^2}$

$= 40.2 - 11.4 = 28.8$ m

IRS design

In IRS design, the distance from the TNC measured along the straight track is given by the formula

$ST = (D - G - G \sec a) \cot a$

On simplification

$ST = D \cot a - G \cot a/2$

where ST is the distance from TNC to TNC along the straight track, D is the distance from centre to centre of two tracks, G is the gauge, and a is the angle of crossing.

Similarly, the distance from TNC to TNC along the crossover is given by the formula (Fig. 15.8)

CF = (D - G - G sec$a$) cosec$a$ + G tan$a$

where CF is the distance from TNC to TNC along the crossover, D is the distance from centre to centre of two tracks, G is the gauge, and a is the angle of crossing.

Example 15.3 A 1 in 12 crossover of IRS type is laid between two BG parallel tracks with their centres 5 m apart. Calculate ST and the distance from TNC to TNC along the crossover.

Solution

G = 1.676 m, N = 12, D = 5.0 m, α = 4° 45' 49"

(i) $ST = D \cot\alpha - G \cot\alpha/2$

$= 5 \times 12 - 1.676 \times 24.04$

$= 19.7$ m

(ii) $CF = (D - G - G \sec\alpha) \operatorname{cosec}\alpha + G \tan\alpha$

$= (5.0 - 1.676 - 1.682) \times 12.04 + 1.676 \times (1/12)$

$= 19.91$ m

Railway Track Junctions: Diamond Crossing

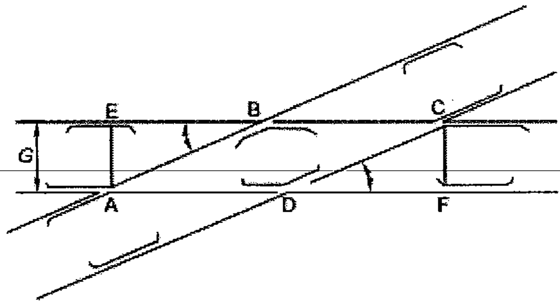

Fig. 15.9 Diamond crossing

A diamond crossing is provided when two tracks of either the same gauge or of different gauges cross each other. It consists of two acute crossings (A and C) and two obtuse crossings (B and D).

Diamond Crossing

A diamond crossing is provided when two tracks of either the same gauge or of different gauges cross each other. It consists of two acute crossings (A and C) and two obtuse crossings (B and D). A typical diamond crossing consisting of two tracks of the same gauge crossing each other, is shown in the Fig. 15.9.

In the layout, ABCD is a rhombus with four equal sides. The length of the various constituents may be calculated as follows.

EB = DF = AE cot a = GN

AB = BC = G cosec$a$

Diagonal AC = G cosec$a$/2

Diagonal BD = G sec$a$/2

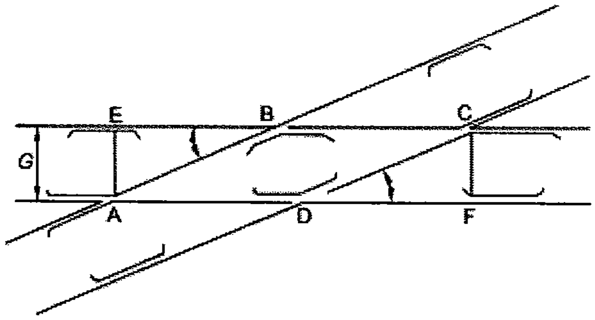

Fig. 15.9 Diamond crossing

It can be seen from the layout that the length of the gap at points B and D increases as the angle of crossing decreases. Longer gaps increase the chances of the wheels, particularly of a small diameter, being deflected to the wrong side of the nose. On Indian Railways, the flattest diamond crossing permitted for BG and MG routes is 1 in 8.5.

Along with diamond crossings, single or double slips may also be provided to allow the vehicles to pass from one track to another.

1 Single Slip and Double Slip

In a diamond crossing, the tracks cross each other, but the trains from either track cannot change track. Slips are provided to allow vehicles to change track.

The slip arrangement can be either single slip or double slip. In single slips, there are two sets of joints, the vehicle from only one direction can change tracks. In the single slip shown in Fig. 15.10, the train on track A can change to track D, whereas the train on track C remains on the same track, continuing onto track D.

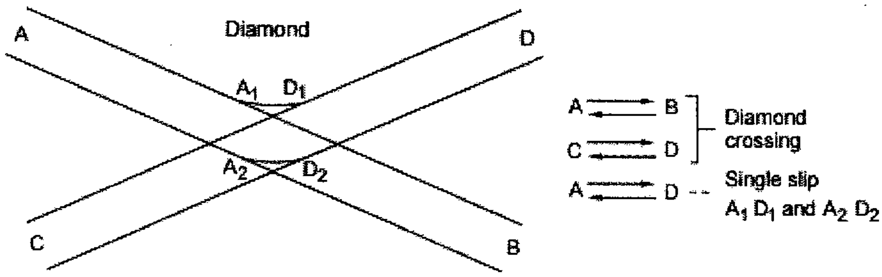

Fig. 15.10 Single slip

In the case of double slips, there are four sets of points, and trains from both directions can change tracks. In the double slip shown in Fig. 15.11, the trains on both tracks A and C can move onto either track B or D.

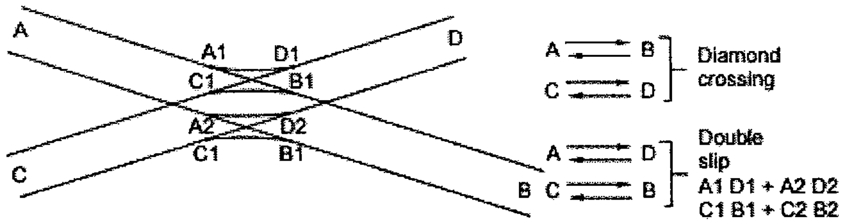

Fig. 15.11 Double slip

2 Improvements in the Design of Diamond Crossings

In order to smoothen the ride over a diamond crossing, the following improvements are generally made.

(a) Provision of 25 mm higher check rails

(b) Reduction in the check rail clearance by 3 mm in the case of obtuse crossings

Example 15.4 Two BG tracks cross each other at an angle of 1 in 10. Calculate the important dimensions of the diamond crossing.

Solution The data given are as follows (Fig. 15.9):

(i) Number of the crossing (*N*) = 10 Gauge (*G*) = 1.676 m

(ii) *N* = cot *a* or 10 = cot *a*

Therefore, *a* = 5 o 42*38

(iii) EB = DF = AE cot*a* = *GN*

= 1.676 * 10 = 16.76 m

(iv) AB = BC = G cosec*a*

=1.676 * 10.05 = 16.85 m

(v) AC = *G* cosec*a*/2

= 1.676 * 20.10 = 33.70 m

(vi) BD = *G* sec *a*/2

= 1.70 m

Railway Track Junctions: Scissors Crossover

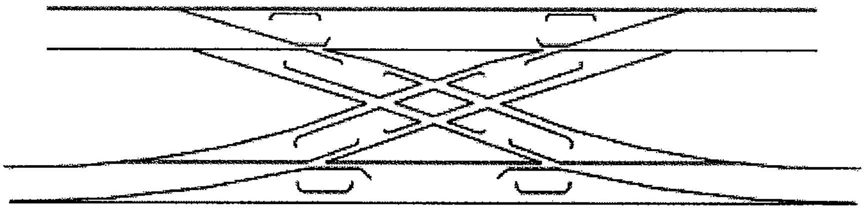

Fig. 15.12 Scissors crossover

A scissors crossover is meant for transferring a vehicle from one track to another track and vice versa.

Scissors Crossover

A scissors crossover (Fig. 15.12) is meant for transferring a vehicle from one track to another track and vice versa. It is provided where lack of space does not permit the provision of two separate crossovers. It consists of four pairs of switches, six acute crossings, two obtuse crossings, check rails, etc.

The scissors crossovers commonly used are of three types depending on the distance between the two parallel tracks they join. A brief description of these crossovers follows.

(a) In the first type, the acute crossing of the diamond falls within the lead of the main line turnout. In this case, the lead of the main line turnout is considerably reduced and hence this is not a satisfactory arrangement.

(b) In the second type, the acute crossing of the diamond falls opposite the crossing of the main line turnout. Here, both the crossings lie opposite each other, resulting in a simultaneous drop of the wheel and this results in jolting. This is also not a desirable type of layout.

(c) In the third type of scissors crossover, the acute crossing falls outside the lead of the main crossing. Thus, the acute crossing of the diamond is far away from the crossing of the main line track. This is the most satisfactory arrangement out of these three layouts.

Gauntletted Railway TrackThis is a temporary diversion provided on a double-line track to allow one of the tracks to shift and pass through the other track. Both the tracks run together on the same sleepers.

Gauntletted Track

This is a temporary diversion provided on a double-line track to allow one of the tracks to shift and pass through the other track. Both the tracks run together on the same sleepers. It proves to be a useful connection when one side of a bridge on a double-line section is required to be blocked for major repairs or rebuilding. The speciality of this layout is that there are two crossings at the ends and no switches [Fig. 15.13 (a)].

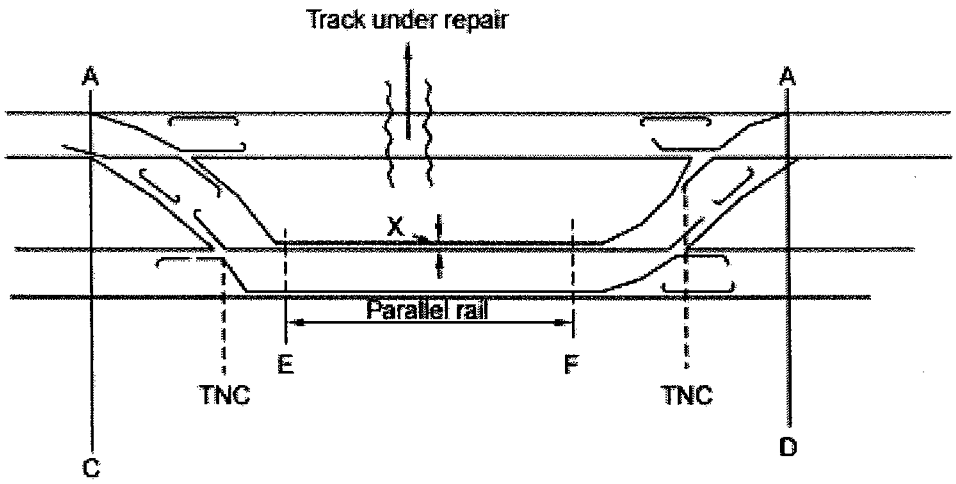

Fig. 15.13 (a) Gauntletted track

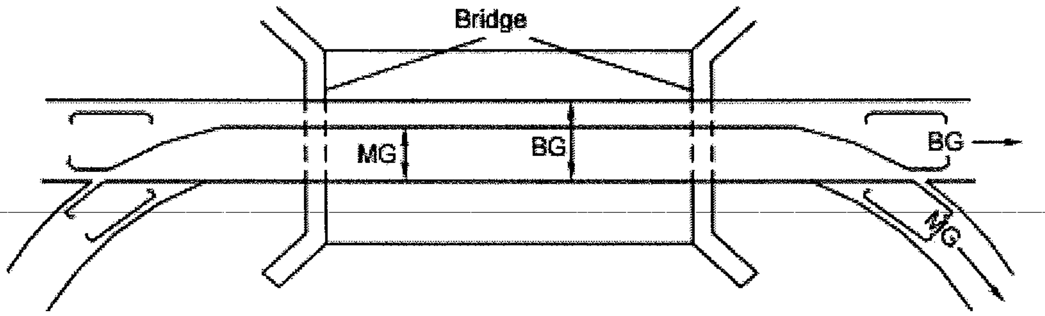

Fig. 15.13 (b) Gauntletted track for mixed gauge

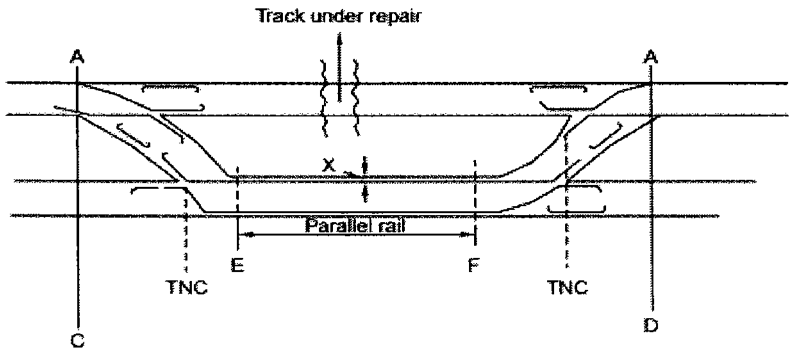

Fig. 15.13 (a) Gauntletted track

Gauntletted tracks are also used on sections where trains have to operate on mixed gauges, say, both BG and MG, for a short stretch. In such cases both the tracks are laid on the same set of wooden sleepers [Fig. 15.13(b)].

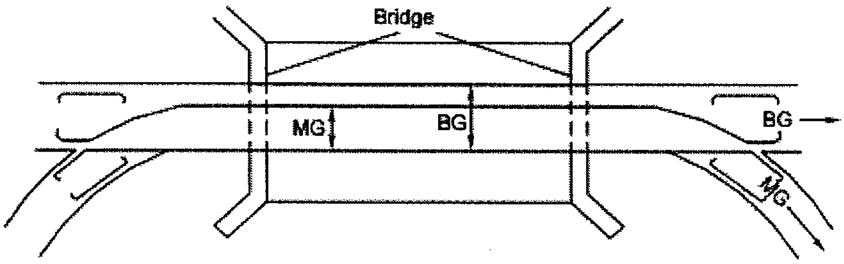

Fig. 15.13 (b) Gauntletted track for mixed gauge

The salient features of the gauntletted track are as follows.

(a) Two tracks are laid on the same sleepers with two sets of crossings without any switches.

(b) Gauntletted tracks can be economically used for mixed gauge, i.e., say, for tracks with both BG and MG.

(c) This layout is used when part of a double-line bridge is under repair. It is also used to economize the cost of a double-line bridge

Railway Track Junctions: Gathering Line

A gathering line (also called a ladder track) is a track where a number of parallel tracks gather or merge. Alternatively, a number of parallel tracks also branch off from a gathering line.

Gathering Line

A gathering line (also called a *ladder track*) is a track where a number of parallel tracks gather or merge. Alternatively, a number of parallel tracks also branch off from a gathering line. A gathering line is defined by the turnout angles and the angle of inclination of the ladder track to the parallel tracks (Fig. 15.14).

Gathering line at crossing angle

When the angle of inclination of the gathering line is the same as that of the turnout, it is said to be laid at the angle of crossing. In this situation, there is some gap between the back leg of the crossing of the turnout and the stock joint of the next turnout and a closure rail has to be used. The angle of the ladder track being equal to the angle of crossing, the two tracks intersect at the theoretical nose of crossing and no curve is introduced at the turnout crossing to connect the parallel tracks.

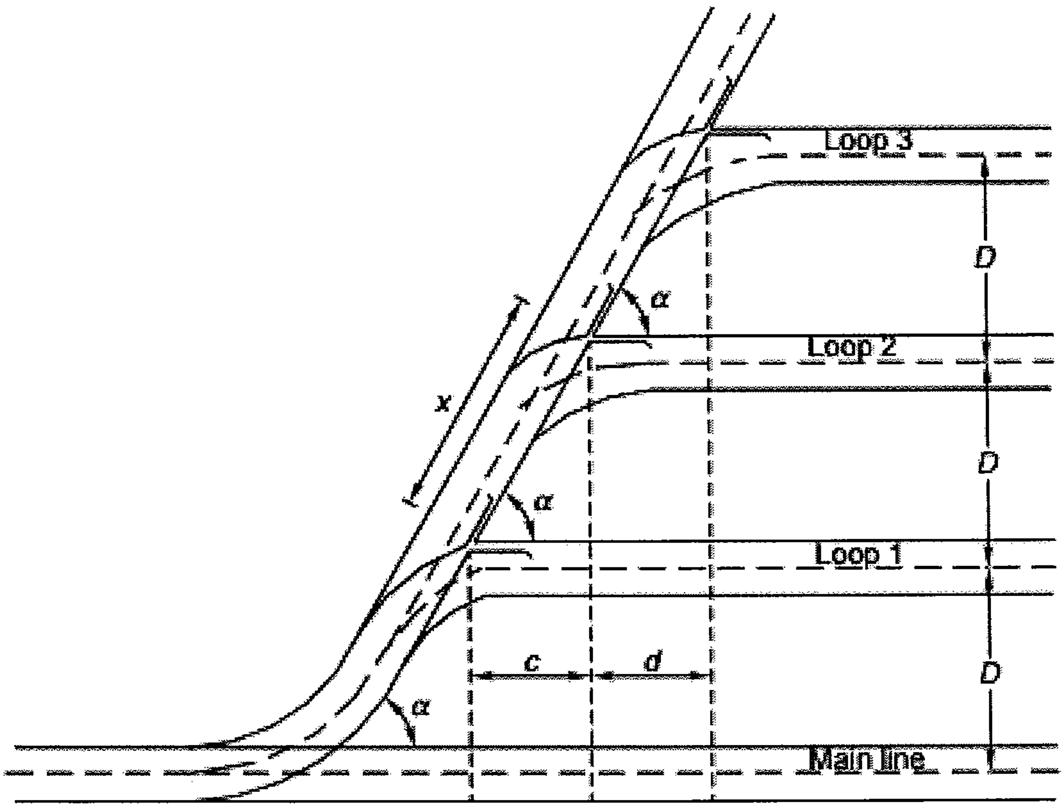

Fig. 15.14 Gathering line

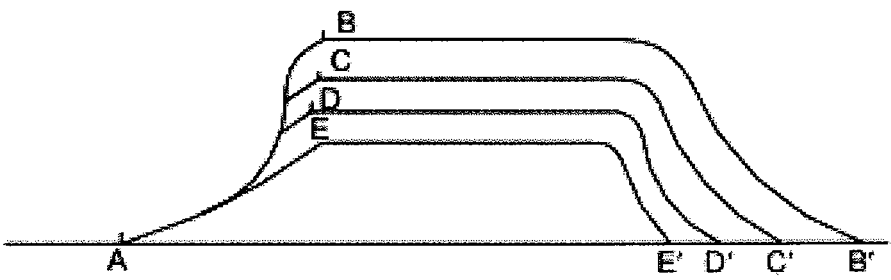

Fig. 15.15 Herringbone grid

Gathering line at limiting angle

In this case the angle of the gathering line is greater than the crossing angle and a curve follows the back leg of the crossing. The back leg of the crossing is followed by the stock joint of the next turnout and no space is wasted. The limiting angle of the gathering line is given by following formula:

Sine of limiting angle = Space between two adjacent parallel tracks / Overall length of turnout

= D/x

Gathering lines can also be laid at $2a$ or $3a$, i.e., at twice or thrice the crossing angle. Such gathering lines are generally found in marshalling yards and are known as *balloon layouts*. This layout of a marshalling yard based on the *Herringbone grid* is used when the various sidings of the marshalling yard are almost of equal length.

Railway Track Junctions: Triangle

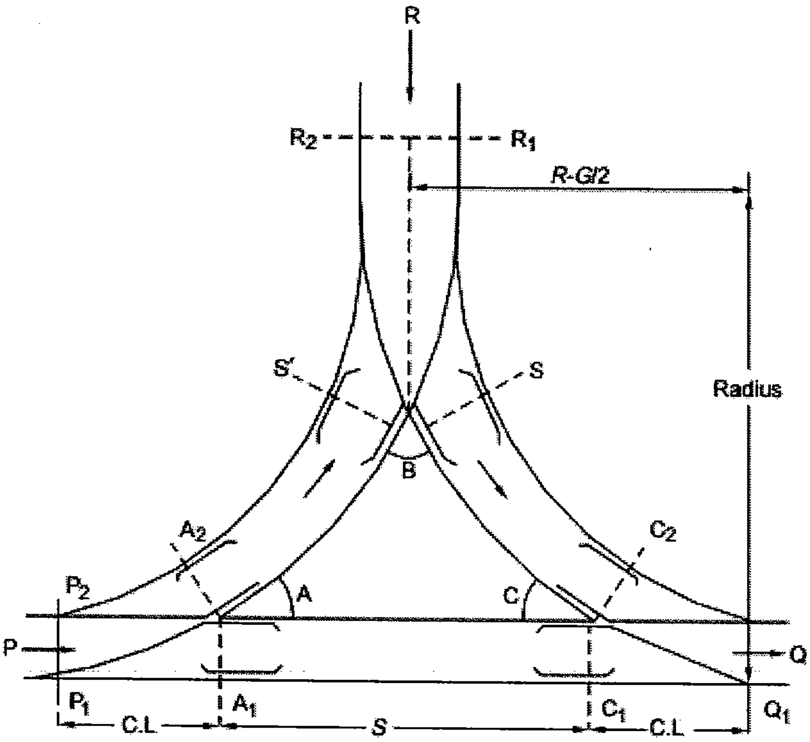

Fig. 15.16 Triangle

A triangle is mostly provided in terminal yards for changing the direction of an engine.

Triangle

A triangle (Fig. 15.16) is mostly provided in terminal yards for changing the direction of an engine. Turntables are also used for this purpose, but are costly, cumbersome, and present a lot of problems in maintenance. Normally, a triangle is provided if enough land is available. A triangle consists of one symmetrical split at R and two turnouts at P and Q along with lead rails, check rails, etc.

To change the direction of an engine standing at P, it is first taken to R, then to Q, and then back to P. By following these movements, the direction of the engine gets changed. The concept of change of direction of the engine was more relevant in the case of steam locomotives and is not applicable to electric and diesel locomotives, which can be operated conveniently from both sides. With the phasing out of steam locomotive on Indian Railways, the triangle is mostly redundant.

Railway Track Junctions: Double Junctions

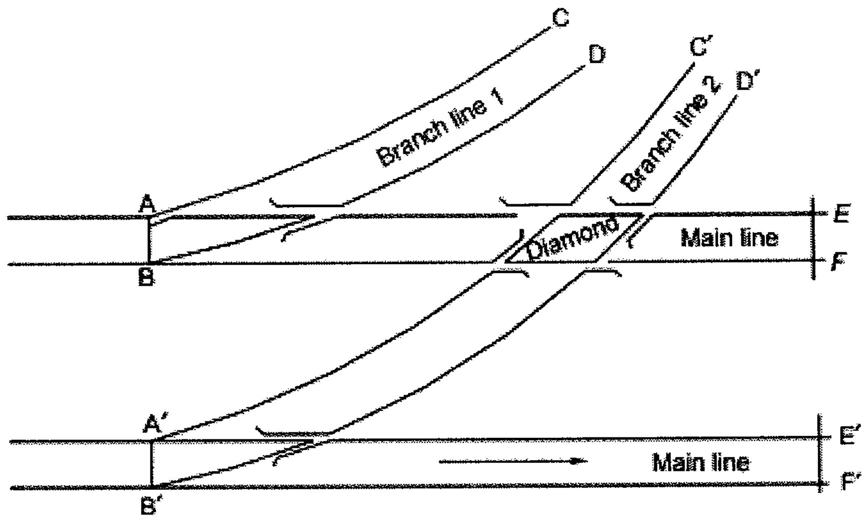

Fig. 15.17 Double junction

A double junction is required when two or more main line tracks are running and other tracks are branching off from these main line tracks in the same direction.

Double Junctions

A double junction (Fig. 15.17) is required when two or more main line tracks are running and other tracks are branching off from these main line tracks in the same direction. The layout of a double junction consists of ordinary turnouts with one or more diamond crossings depending upon the number of parallel tracks.

Double junctions may occur either on straight or curved main lines and the branch lines may also be either single or double lines. These types of junctions are quite common in congested yards.