LECTURE NOTE

RAILWAY AND BRIDGE ENGINEERING

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Disclaimer

Lecture-1

History of Indian Railways

Introduction

In the year 1832 the first Railway running on steam engine, was launched in England.

Thereafter on 1st of August, 1849 the Great Indian Peninsular Railways Company was established in India. On 17th of August 1849, a contract was signed between the Great Indian Peninsular Railways Company and East India Company. As a result of the contract an experiment was made by laying a railway track between Bombay and Thane (56 Kms).

- On 16th April, 1853, the first train service was started from Bombay to Thane.
- On 15th August, 1854, the 2nd train service commenced between Howrah and Hubli.
- On the 1st July, 1856, the 3rd train service in India and first in South India commenced between Vyasarpadi and Walajah Road and on the same day the section between Vyasarpadi and Royapuram by Madras Railway Company was also opened.

Subsequently construction of this efficient transport system began simultaneously in different parts of the Country. By the end of 19th Century 24752 Kms. of rail track was laid for traffic. At this juncture the power, capital, revenue rested with the British. Revenue started flowing through passenger as well as through goods traffic.

Organizational structure

Railway zones

Indian Railways is divided into several zones, which are further sub-divided into divisions. The number of zones in Indian Railways increased from six to eight in 1951, nine in 1952 and sixteen in 2003. Each zonal railway is made up of a certain number of divisions, each having a divisional headquarters. There are a total of sixty-eight divisions. Each of the sixteen zones is headed by a general manager who reports directly to the Railway Board. The zones are further divided into divisions under the control of divisional railway managers (DRM).

Zonal railways details

Sl. No	Name	Abbr	Date Established	Route km	Headquarters	Divisions
1.	Central	CR	5 November 1951	3905	Mumbai	Mumbai, Bhusawal, Pune, Solapur, Nagpur
2.	East Central	ECR	1 October 2002	3628	Hajipur	Danapur, Dhanbad, Mughalsarai, Samastipur, Son pur
3.	East Coast	ECoR	1 April 2003	2677	Bhubaneswar	Khurda Road, Sambalpur and Waltair (Visakhapatnam)
4.	Eastern	ER	April 1952	2414	Kolkata	Howrah, Sealdah, Asansol, Malda
5.	North Central	NCR	1 April 2003	3151	Allahabad	Allahabad, Agra, Jhansi
6.	North Eastern	NER	1952	3667	Gorakhpur	Izzatnagar, Lucknow, Varanasi
7.	North Western	NWR	1 October 2002	5459	Jaipur	Jaipur, Ajmer, Bikaner, Jodhpur
8.	Northeast Frontier	NFR	15 January 1958	3907	Guwahati	Alipurduar, Katihar, Rangia, Lumding, Tinsukia
9.	Northern	NR	14 April 1952	6968	Delhi	Delhi, Ambala, Firozpur, Lucknow, Moradabad
10.	South Central	SCR	2 October 1966	5803	Secunderabad	Vijayawada, Hyderabad, Guntakal, Guntur, Nanded, Secunderabad
11.	South East Central	SECR	1 April 2003	2447	Bilaspur	Bilaspur, Raipur, Nagpur
12.	South Eastern	SER	1955	2631	Kolkata	Adra, Chakradharpur, Kharagpur, Ranchi
13.	South Western	SWR	1 April 2003	3177	Hubli	Hubli, Bangalore, Mysore
14.	Southern	SR	14 April 1951	5098	Chennai	Chennai, Trichy, Madurai, Salem,[12] Palakkad,Thiruvananthapuram
15.	West Central	WCR	1 April 2003	2965	Jabalpur	Jabalpur, Bhopal, Kota
16.	Western	WR	5 November 1951	6182	Mumbai	Mumbai central, Ratlam, Ahmedabad, Rajkot, Bhavnagar, Vadodara
17.	Kolkata Metro Railway	KNR	29 December 2010		Kolkata	Kolkata

Subsidiaries of Indian Railways

There also exist independent organisations under the control of the Railway Board for electrification, modernisation, research and design and training of officers, each of which is headed by an officer of the rank of general manager. A number of Public Sector Undertakings, which perform railway-related functions ranging from consultancy to ticketing, are also under the administrative control of the Ministry of railways.

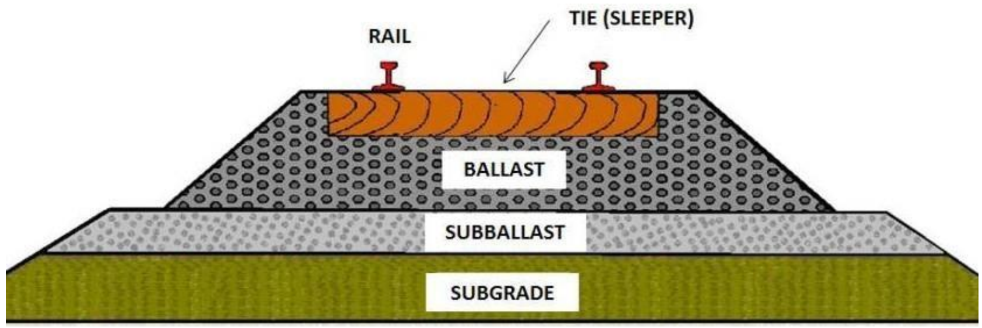
There are fourteen public undertakings under the administrative control of the Ministry of Railways:

- Bharat Wagon and Engineering Co. Ltd. (BWEL)
- Centre for Railway Information Systems (CRIS)[24]
- Container Corporation of India Limited (CONCOR)
- Dedicated Freight Corridor Corporation of India Limited (DFCCIL)
- Indian Railway Catering and Tourism Corporation Limited (IRCTC)
- Indian Railway Construction (IRCON) International Limited
- Indian Railway Finance Corporation Limited (IRFC)
- Konkan Railway Corporation Limited (KRCL)
- Mumbai Railway Vikas Corporation (MRVC)
- Railtel Corporation of India Limited (Rail Tel)
- Rail India Technical and Economic Services Limited (RITES)
- Rail Vikas Nigam Limited (RVNL)
- High Speed Rail Corporation of India (HSRC)
- Burn Standard Company
- Braithwaite and Co. Ltd

Lecture-2

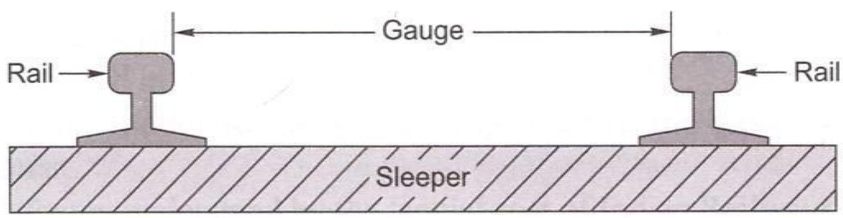
Component parts of railway track

The Typical components are – Rails, – Sleepers (or ties), – Fasteners, – Ballast (or slab track), – Subgrade



GAUGE

The clear minimum horizontal distance between the inner (running) faces of the two rails forming a track is known as Gauge. Indian railway followed this practice. In European countries, the gauge is measured between the inner faces of two rails at a point 14 mm below the top of the rail.



GAUGES ON WORLD RAILWAYS

Various gauges have been adopted by different railways in the world due to historical and other considerations. Initially British Railways had adopted a gauge of 1525 mm (5 feet), but the wheel flanges at that time were on the outside of the rails. Subsequently, in order to guide the wheels better, the flanges were made inside the rails. The gauge then became 1435 mm (4'8.5"), as at that time the width of the rail at the top was 45 mm (1.75 "). The 1435 mm gauge became the standard on most European Railways. The various gauges on world railways are given in Table 2.1.

Various gauges on world railways

Type of gauge	Gauge (mm)	Gauge (feet)	% of total length	Countries
Standard gauge	1435	4'8.5"	62	England, USA, Canada, Turkey, Persia, and China
Broad gauge	1676	5 '6"	6	India, Pakistan, Sri Lanka, Brazil, Argentina
Broad gauge	1524	5'0"	9	Russia, Finland
Cape gauge	1067	3 '6"	8	Africa, Japan, Java, Australia, and New Zealand
Metre gauge	1000	3 '3.5"	9	India, France, Switzerland, and Argentina
23 various other gauges	Different gauges	Different gauges	6	Various countries

DIFFERENT GAUGES ON INDIAN RAILWAYS

The East India Company intended to adopt the standard gauge of 1435 mm in India also. This proposal was, however, challenged by W. Simms, Consulting Engineer to the Government of India, who recommended a wider gauge of 1676 mm (5 '6 "). The Court of Directors of the East India Company decided to adopt Simms's recommendation and 5'6 " finally became the Indian standard gauge. In 1871, the Government of India wanted to construct cheaper railways for the development of the country and 1000 mm metre gauge was introduced. In due course of time, two more gauges of widths 762 mm (2 '6 ") and 610 mm (2 '0 ") were introduced for thinly populated areas, mountain railways, and other miscellaneous purposes. The details of the various gauges existing on Indian Railways are given in Table below.

Various gauges on Indian Railways as on 31.03.2011

Name of gauge	*Width (mm)*	*Route (km)*	*% of route (km)*
Broad gauge (BG)	1676	55,188	85.6
Metre gauge (MG)	1000	6809	10.6
Narrow gauge (NG)	762	2463	3.8
	610		
Total all gauges		64,460	100

Broad Gauge: - When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1676mm the gauge is called Broad Gauge (B.G)

This gauge is also known as standard gauge of India and is the broadest gauge of the world.

The Other countries using the Broad Gauge are Pakistan, Bangladesh, SriLanka, Brazil, Argentine, etc.50% India‘s railway tracks have been laid to this gauge.

Suitability: - Broad gauge is suitable under the following Conditions:-

(i) When sufficient funds are available for the railway project.

(ii) When the prospects of revenue are very bright.

This gauge is, therefore, used for tracks in plain areas which are densely populated i.e. for routes of maximum traffic, intensities and at places which are centers of industry and commerce.

2. **Metre Gauge**: - When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1000mm, the gauge is known as Metre Gauge (M.G) The other countries using Metre gauge are France, Switzerland, Argentine, etc. 40% of India‘s railway tracks have been laid to this gauge.

Suitability:- Metre Gauge is suitable under the following conditions:-

(i) When the funds available for the railway project are inadequate.

(ii) When the prospects of revenue are not very bright.

This gauge is, therefore, used for tracks in under-developed areas and in interior areas, where traffic intensity is small and prospects for future development are not very bright.

3. **Narrow Gauge**:- When the clear horizontal distance between the inner faces of two parallel rails forming a track is either 762mm or 610mm, the gauge is known as Narrow gauge (N.G) The other countries using narrow gauge are Britain, South Africa, etc. 10% of India‘s railway tracks have been laid to this gauge.

Suitability: - Narrow gauge is suitable under the following conditions:-

(i) When the construction of a track with wider gauge is prohibited due to the provision of sharp curves, steep gradients, narrow bridges and tunnels etc.

(ii) When the prospects of revenue are not very bright. This gauge is, therefore, used in hilly and very thinly populated areas. The feeder gauge is commonly used for feeding raw materials to big government manufacturing concerns as well as to private factories such as steel plants, oil refineries, sugar factories, etc.

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 runnels 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. Thus, the following points need to be considered.

(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. As a thumb rule, diameter of the wheel is kept 75 per cent of gauge width.

(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.

Lecture-3

PROBLEMS OF MULTI GAUGE SYSTEM

Introduction

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 the Indian Railways because of the multi-gauge system (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 along with their luggage, which causes inconvenience such as the following:

(a) Climbing stairs and crossing bridges

(b) Getting 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 from one platform to another.

***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 or engines 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

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

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, bridges and tunnels, as well as 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 in 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.

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. Following are the advantages of a uni-system:

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 be 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 turnaround

There will be a better turnaround 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 currently 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 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.

Planning of Uni-gauge Projects

The gauge-conversion programme has been accelerated on Indian Railways since 1992. In the eighth Plan (1993-97) itself, the progress achieved in gauge-conversion projects in five years was more than the total progress made in the past 45 years. The progress of gauge-conversion projects is briefly given in Table below.

Progress of gauge-conversion projects

Year	*Progress in gauge conversion (kms)*	*Remarks*
1947-1992	2500	Approx. figure
1993-1997	6897	Actual
1998-2004	3787	Actual
2005-2011	6564	Actual

The current position is that the gauge-conversion project still pending on Indian Railways is 8855 kms which is likely to be completed in next five years. Execution of a gauge conversion project is quite a tricky job and lot of planning is to be done for the same.

Lecture-4

WHEEL AND AXIS ARRANGEMENTS AND CONING OF WHEELS

Introduction

Wheels and axles we have the different types of the locomotives under wagons which are used for the hauling of the passengers and freight. All these wagons and locomotives have different specifications depending on the gauges for which they have been used. If you look at the various locomotives from the very starting of our history, we have been using steam locomotives and then they have been replaced by diesel locomotives and finally by the electric locomotives.

In the case of the steam locomotives, the wheels and axles are classified by on the basis of **Whyte system**. Traditionally, steam locomotives have been classified using either their wheel arrangements or sometimes they are also been classified on the basis of axle arrangements.
In the case of the wheel arrangements classification, they are being classified on the basis of Whyte system and other system locomotives have three different types of wheel basis. They have the wheel basis which are either coupled or which are having the driving conditions or detective power attached to them or the wheel basis on which no attractive power is attached.

In Indian practice, the Indian practice has been taken from the United Kingdom because British were the persons who introduced the Indian railways in our country and in this system we count wheels and we do not count the axles as far as the steam locomotives are concerned. In the case of steam locomotives, one examples is been taken here where it is been shown as **2-4-2**. Now this 2-4-2 has the significance in terms of the wheel basis as been defined earlier. The first 2 is the front wheels or the 2 number of wheels have been placed or what we can say is that there is one axle which is being placed in the front condition. Then the 4 part is to the 4 number of wheels which have been placed in the central condition where they are the powered wheels or the driving wheels and therefore they transforms into the 2 axles condition and then there are trailing wheels where we have 2 wheels at the back and again, if it transform them into the actual condition, it will be working to one axle.

The compound locomotive is a condition where there is a more attractive power which is required to haul the passenger or the freight. The heavy amount of the freight which is to be transported and the trailing conditions governs the conditions where we require to provide two locomotives together so as to haul them. Here, this is an example of compound locomotive where two locomotive of condition 2-8-2 or 2-8-4 have been joined together so as to haul the traffic or the passengers or the freight. Again, if we go by the Whyte condition, Whyte system of classification of the locomotives of the wheel configuration then 2-8-2 means they have 2 front wheels, 8 medium or central wheels and 2 trailer wheels, in case of the first locomotives whereas in the case of the second locomotives we have 2 front wheels, 8 central condition wheels which are electrically driven, which are driven for the movement of the locomotives and then in this case we have 4 trailing wheels.

Coning wheels has the following disadvantages:

1. In order to minimize the above below disadvantages the tilting of rails is done. i.e. the rails are not laid flat but tilted inwards by using inclined base plates sloped at 1 in 20 which is also the slope of coned surface of wheels.
2. The pressure of the horizontal component near the inner edge of the rail has a tendency to wear the rail quickly.
3. The horizontal components tend to turn the rail outwardly and hence the gauge is widened sometimes.
4. If no base plates are provided, sleepers under the outer edge of the rails are damaged.
5. In order to minimize the above mentioned disadvantages the tilting of rails is done. i.e. the rails are not laid flat but tilted inwards by using inclined base plates sloped at 1 in 20 which is also the slope of coned surface of wheels.

Advantages of Tilting of Rails

1. It maintains the gauge properly.
2. The wear at the head of rail is uniform.
3. It increases the life of sleepers and the rails.

Lecture-5

VARIOUS RESISTANCES AND THEIR EVALUATION

Introduction

Various forces offer resistance to the movement of a train on the track. These resistances may be the result of movement of the various parts of the locomotives as well as the friction between them, the irregularities in the track profile, or the atmospheric resistance to a train moving at great speed. The tractive power of a locomotive should be adequate enough to overcome these resistances and haul the train at a specified speed.

RESISTANCE DUE TO FRICTION

Resistance due to friction is the resistance offered by the friction between the internal parts of locomotives and wagons as well as between the metal surface of the rail and the wheel to a train moving at a constant speed. This resistance is independent of speed and can be further broken down into the following parts.

Journal friction This is dependent on the type of bearing, the lubricant used, the temperature and condition of the bearing, etc. In the case of roll bearings, it varies from 0.5 to 1.0 kg per tonne.

Internal resistance This resistance is consequential to the movement of the various parts of the locomotive and wagons.

Rolling resistance This occurs due to rail-wheel interaction on account of the movement of steel wheels on a steel rail. The total frictional resistance is given by the empirical formula

$$R_1 = 0.0016\, W$$

Where R_1 is the frictional resistance independent of speed and W *is* the weight of the train in tonnes.

RESISTANCE DUE TO WAVE ACTION

When a train moves with speed a certain resistance develops due to the wave action in the rail. Similarly, track irregularities such as longitudinal unevenness and differences in cross levels also offer resistance to a moving train. Such resistances are different for different speeds. There is no method for the precise calculation of these resistances but the following formula has been evolved based on experience:

$$R_2 = 0.00008\ WV$$

Where R_2 is the resistance (in tonnes) due to wave action and track irregularities on account of the speed of the train, W *is* the weight of the train in tonnes, and V is the speed of the train in kmph.

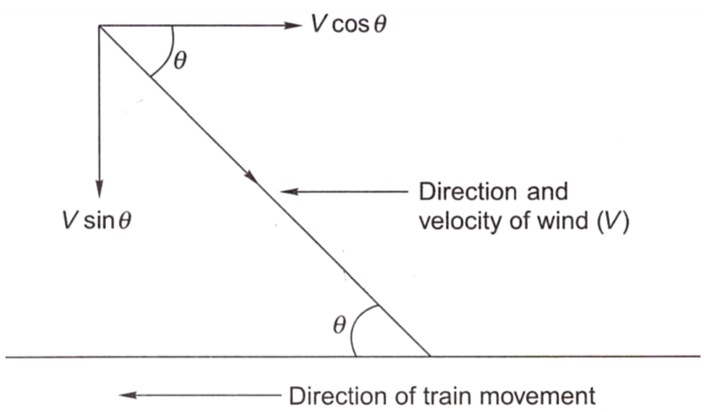
RESISTANCE DUE TO WIND

When a vehicle moves with speed, a certain resistance develops, as the vehicle has to move forward against the wind. Wind resistance consists of side resistance, head resistance, and tail resistance, but its exact magnitude depends upon the size and shape of the vehicle, its speed, and the wind direction as well as its velocity. Wind resistance depends upon the exposed area of the vehicle and the velocity and direction of the wind. In Fig. below, V *is* the velocity of wind at an angle θ. The horizontal component of wind, $V\cos\theta$, opposes the movement of the train. Wind normally exerts maximum pressure when it acts at an angle of 60° to the direction of movement of the train.

Wind resistance can be obtained by the following formula:

$$R_3 = 0.000017AV^2$$

Where A is the exposed area of vehicle (m^2) and V is the velocity of wind (kmph).



$$R_3 = 0.0000006\ W\ V^2$$

Where R_3 is the wind resistance in tonnes, V*is* the velocity of the train in km per hour, and W *is* the weight of the train in tonnes.

RESISTANCE DUE TO GRADIENT

When a train moves on a rising gradient, it requires extra effort in order to move against gravity as shown in Fig. below.

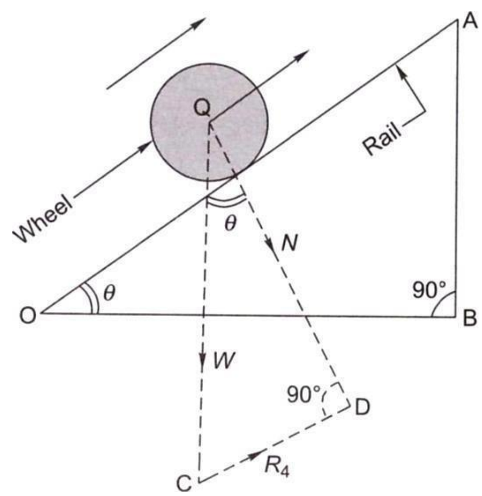
Assuming that a wheel of weight *W* is moving on a rising gradient OA, the following forces act on the wheel.

(a) Weight of the wheel *(W)*, which acts downward

(b) Normal pressure *N* on the rail, which acts perpendicular to OA

(c) Resistance due to rising gradient (R_4), which acts parallel to OA

These three forces meet at a common point Q and the triangle QCD can be taken as a triangle of forces. It can also be geometrically proved that the two triangles QCD and AOB are similar.



RESISTANCE DUE TO CURVATURE

When a train negotiates a horizontal curve, extra effort is required to overcome the resistance offered by the curvature of the track. Curve resistance is caused basically because of the following reasons (Fig. below):

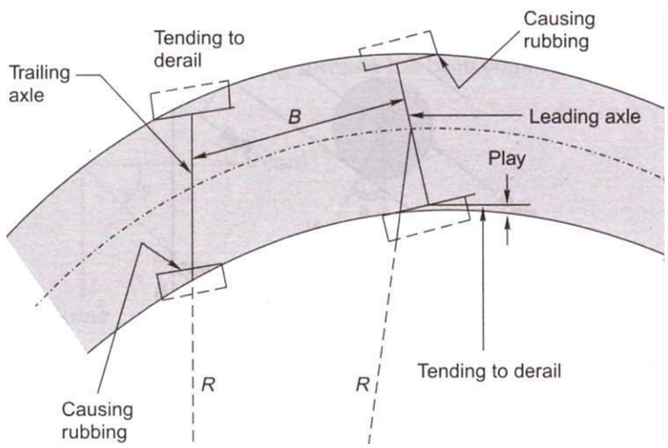
(a) The vehicle cannot adapt itself to a curved track because of its rigid wheel base. This is why the frame takes up a tangential position as the vehicle tries to move in a longitudinal direction along the curve as shown in Fig. below. On account of this, the flange of the outer wheel of the leading axle rubs against the inner face of the outer rail, giving rise to resistance to the movement of the train.

(b) Curve resistance can sometimes be the result of longitudinal slip, which causes the forward motion of the wheels on a curved track. The outer wheel flange of the trailing axle remains clear and tends to derail. The position worsens further if the wheel base is long and the curve is sharp.

(c) Curve resistance is caused when a transverse slip occurs, which increases the friction between the wheel flanges and the rails.

(d) Poor track maintenance, particularly bad alignment, worn-out rails, and improper levels, also increase resistance.

(e) Inadequate superelevation increases the pressure on the outer rail and, similarly, excess superelevation puts greater pressure on the inner rails, and this also contributes to an increase in resistance.



The value of curve resistance can be determined by the following equation:

***Curve resistance* = *C* x (FG/R)**

where *F* is the force of sliding friction, *G* is the gauge of the track, *R* is the mean radius of the curve, and *C* is the constant, which is dependent on various factors. This equation indicates that

(a) curve resistance increases with increase in gauge width and

(b) resistance is inversely proportional to the radius, i.e., it increases with an increase in the degree of the curve.

Empirical formulae have been worked out for curve resistance, which are as follows:

Curve resistance for BG (R_5) = 0.0004 *WD*

Curve resistance for MG (R_5) = 0.0003 *WD*

Curve resistance for NG (R_5) = 0.0002 *WD*

Compensated gradient for curvature

Curve resistance is quite often compensated or offset by a reduction in the gradient. In this way, the effect of curve resistance is translated in terms of resistance due to gradient. The compensation is 0.04 per cent on BG, 0.03 per cent on MG, and 0.02 per cent on NG lines for every 1° of the curve. This will be clear through the solved example given below.

RESISTANCE DUE TO STARTING AND ACCELERATING

Trains face these resistances at stations when they start, accelerate, and decelerate. The values of these resistances are as follows:

$$\textbf{Resistance on starting, } R_6 = 0.15\, W_1 + 0.005\, W_2$$

$$\textbf{Resistance due to acceleration, } R_7 = 0.028\, aW$$

where W_1 is the weight of the locomotive in tonnes, W_2 is the weight of the trailing vehicles in tonnes, W *is* the total weight of the locomotive and vehicle in tonnes. i.e. $W_1 + W_2$, and a is the acceleration, which can be calculated by finding the increase in velocity per unit time, i.e., $(V_2 - V_1)/t$, where V_2 is the final velocity. V_1 is the initial velocity, and t is the time taken.

Table below summarizes the various resistances faced by a train.

Lecture-6

HAULING CAPACITY AND TRACTIVE EFFORT

Introduction

The tractive effort of a locomotive is the force that the locomotive can generate for hauling the load. The tractive effort of a locomotive should be enough for it to haul a train at the maximum permissible speed. There are various tractive effort. Curves available for different locomotives for different speeds, which enable the computation of the value of tractive effort. Tractive effort is generally equal to or a little greater than the hauling capacity of the locomotive. If the tractive effort:-much greater than what is required to haul the train, the wheels of the locomotive may slip.

A rough assessment of the tractive effort of different types of locomotive.-provided in the following sections.

Steam Locomotive

The tractive effort of a steam locomotive can be calculated by equating the total power generated by the steam engine to the work done by the driving wheels.

Assume *P* to be the difference in steam pressure between the two sides of the inder, *A* the area of the piston of the engine, a' the diameter of the piston of the ;ine, *L* the length of the stroke of the engine, *D* the diameter of the wheel of locomotive, and Te the mean tractive effort of the locomotive. Work done by /o-cylinder steam engine

= 2 X difference in steam pressure X area of the piston x 2 X *length of the stroke* $= 2P \times A \times 2L$

$= 2P \times (\pi d^2/4) \times 2L = \pi d^2 L$

work done in one revolution of the driving wheel of the locomotive:

= tractive effort x circumference of the wheel

$= T_c \pi D$

squaring above two equations, $\pi d^2 L = T_c \pi D$

$$Tc = d^2 L/D$$

is clear from above Equation that tractive effort increases with an increase in n pressure difference and the diameter and length of the piston, but decreases an increase in the diameter of the driving wheel of the locomotive.

Diesel Locomotive

Tractive effort of a diesel-elective locomotive can be assessed by the following empirical formula.

$Te = (308 \text{ x RHP}) / V$

where Te is the tractive effort of a diesel-electric locomotive, RHP is the rated horsepower of the engine, and V is the velocity in km per hour.

Electric Locomotive

Tractive effort of an electric locomotive varies inversely with the power of speed. The empirical formulae for calculating the approximate value of tractive effort are as follows

For an dc electric locomotive: Te = a / V^3

For an ac electric locomotive: Te = a / V^5

where *a* is a constant depending upon the various characteristics of the locomotive.

.HAULING POWER OF A LOCOMOTIVE

Hauling power of a locomotive depends upon the weight exerted on the driving s and the friction between the driving wheel and the rail. The coefficient of friction depends upon the speed of the locomotive and the condition of the rail surface. The higher the speed of the locomotive, the lower will be the coefficient of friction, which is about 0.1 for high speeds and 0.2 for low speeds. The condition of the rail surface, whether wet or dry, smooth or rough, etc., also plays an important role in deciding the value of the coefficient of function. If the surface is very smooth, the coefficient of friction will be very low.

Hauling power = number of pairs of driving wheels x weight exerted on each driving axle

X coefficient of friction

Thus, for a locomotive with three pairs of driving wheels, an axle load of 20 tonnes, and a coefficient of friction equal to 0.2, the hauling power will be equal to 3 x 20 x 0.2 tonne, i.e., 12 tonnes.

Example : Calculate the maximum permissible load that a BG locomotive with three pairs of driving wheels bearing an axle load of 22 tonnes each can pull on a straight level track at a speed of 80 km/h. Also calculate the reduction in speed if the train has to run on a rising gradient of 1 in 200. What would be the further reduction in speed if the train has to negotiate a 4° curve on the rising gradient? Assume the coefficient of friction to be 0.2.

Lecture-7

RAIL

Introduction

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 withstand stresses, they are made of high-carbon steel. Standard rail sections, their specifications, and various types of rail defects are discussed in this section.

FUNCTION OF RAILS

Rails are similar to steel girders. They perform the following functions in a track:

(a) Rails provide a continuous and level surface for the movement of trains.

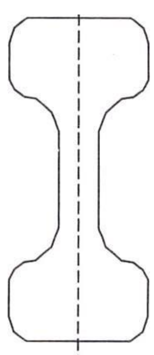
(b) They provide a pathway which is smooth and has very little friction. The friction between the steel wheel and the steel rail is about one-fifth of the friction between the pneumatic tyre and a metalled road.

(c) They serve as a lateral guide for the wheels.

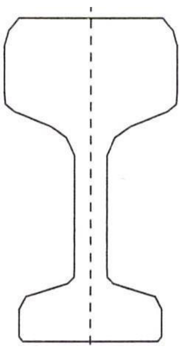
(d) They bear the stresses developed due to vertical loads transmitted to them through axles and wheels of rolling stock as well as due to braking and thermal forces.

(e) They carry out the function of transmitting the load to a large area of the formation through sleepers and the ballast.

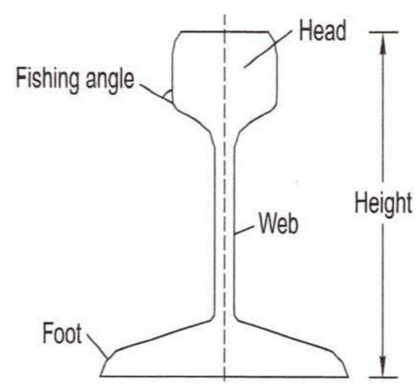
TYPES OF RAILS



DOUBLE HEADED RAIL



BULL HEADED RAIL



FLAT-FOOTED RAIL

REQUIREMENTS OF AN IDEAL RAIL SECTION

The requirements of an ideal rail section are as follows:

(a) The rail should have the most economical section consistent with strength, stiffness, and durability.

(b) The centre of gravity of the rail section should preferably be very close to the mid-height of the rail so that the maximum tensile and compressive stresses are equal.

(c) A rail primarily consists of a head, a web, and a foot, and there should be an economical and balanced distribution of metal in its various components so that each of them can fulfill its requirements properly.

The requirements, as well as the main considerations, for the design of these rail components are as follows:

Head The head of the rail should have adequate depth to allow for vertical wear. The rail head should also be sufficiently wide so that not only is a wider running surface available, but also the rail has the desired lateral stiffness.

Web The web should be sufficiently thick so as to withstand the stresses arising due to the loads bore by it, after allowing for normal corrosion.

Foot The foot should be of sufficient thickness to be able to withstand vertical and horizontal forces after allowing for loss due to corrosion. The foot should be wide enough for stability against overturning. The design of the foot should be such that it can be economically and efficiently rolled.

Fishing angles These must ensure proper transmission of loads from the rails to the fish plates. The fishing angles should be such that the tightening of the plate does not produce any excessive stress on the web of the rail.

Height of the rail The height should be adequate so that the rail has sufficient vertical stiffness and strength as a beam.

Weight of rails

Though the weights of a rail and its section depend upon various considerations, the heaviest axle load that the rail has to carrv olavs the most important role. The following is the thumb rule for denning the maximum axle load with relation to the rail section:

Maximum axle load = 560 x sectional weight of rail in Ibs per yard or kg per metre

- For rails of 90 Ibs per yard,

Maximum axle load = 560 x 90 Ibs = 50,400 Ibs or 22.5 tonnes

- For rails of 52 kg per m,

Maximum axle load = 560 x 52 kg = 29.12 tonnes

- For rail of 60 kg per m,

Max. axle load for 60 kg/m rail = 560 x 60 kg = 33.60 tonnes

Length of rails

Theoretically, the longer is the rail, the lesser would be the number of joints and fittings required and the lesser the cost of construction and maintenance. Longer rails are economical and provide smooth and comfortable rides. 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 39 m, and even longer rails in its track system. Now 65 m/78 m long rails are being produced at SAIL, Bhilai and it is planned to manufacture 130 m long rails.

Lecture-8

SLEEPERS

Introduction

Sleepers are the transverse ties that are laid to support the rails. They have an important role in the track as they transmit the wheel load from the rails to the ballast. Several types of sleepers are used on Indian Railways. The characteristics of these sleepers and their suitability with respect to load conditions are described in this section.

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 fulfill 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.

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,

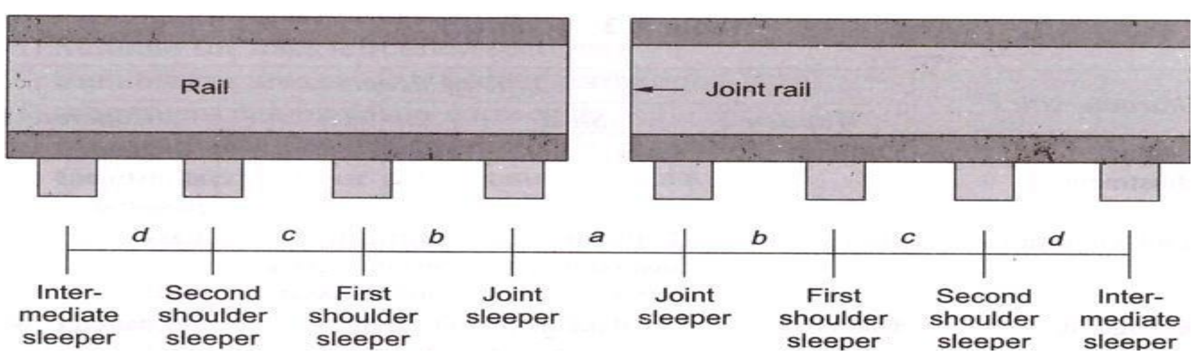
(c) type and strength of the sleepers,

(d) type of ballast and depth of 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 implies that 13 + 7 = 20 sleepers will be used per rail length of the track 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 on 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 sleepers. The standard spacing specifications adopted for a fish-plated-track on Indian Railways are given in Table below. The notations used in this table are explained in Fig. below.



TYPES OF SLEEPERS

The sleepers mostly used on Indian Railways are

(i) wooden sleepers,

(ii) cast iron (CI) sleepers,

(iii) steel sleepers, and

(iv) Concrete sleepers.

Comparison of different types of sleepers

Characteristics	**Type of sleeper**			
	Wooden	**Steel**	**'CI**	**Concrete**
Service life (years)	12-15	40-50	40-50	50-60
Weight of sleeper for BG (kg)	83	79	87	267
Handling	Manual handling; no damage to sleeper while handling	Manual handling; no damage to sleeper while handling	Manual handling; liable to break by rough handling	No manual handling; gets damaged by rough handling
Type of maintenance	Manual or mechanized	Manual or mechanized	Manual	Mechanized only
Cost of maintenance	High	Medium	Medium	Low
Gauge adjustment	Difficult	Easy	Easy	No gauge adjustment possible
Track circuiting	Best	Difficult; insulating pads are necessary	Difficult; insulating pads are necessary	Easy
Damage by white ants and corrosion	Can be damaged by white ants	No damage by white ants but corrosion is possible	Can be damaged by corrosion	No damage by white ants or corrosion
Suitability for fastening	Suitable for CF* and EF[f]	Suitable for CF and EF	Suitable for CF only	Suitable for EF only
Track elasticity	Good	Good	Good	Best
Creep	Excessive	Less	Less	Minimum
Scrap value	Low	Higher than wooden	High	None

Lecture-9

BALLAST AND BALLAST REQUIREMENTS

Introduction

Ballast is a layer of broken stones, gravel, rnoorum, 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. Different types of ballast materials and their specifications are discussed in this chapter.

FUNCTIONS OF BALLAST

The ballast serves the following functions in a railway track.

- It provides a level and hard bed for the sleepers to rest on.
- It holds the sleepers in position during the passage of trains.
- It transfers and distributes load from the sleepers to a large area of the formation.
- It provides elasticity and resilience to the track for proper riding comfort.
- It provides the necessary resistance to the track for longitudinal and lateral stability.
- It provides effective drainage to the track.
- It 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 here.

Sand ballast

Sand ballast is used primarily for cast iron (CI) pots. It is also used with wooden ir.d steel trough sleepers in areas where traffic densitv is verv 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. 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 it should be porous nor it flake off due to the weathering. 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.

The comparative advantages, disadvantages, and suitability of different types of ballast are given in Table below.

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 for metal sleepers such as CST-9 and trough sleepers. Now, to ensure uniformity, 50 mm (2") ballasts have been adopted universally for all types of sleepers.

Points and crossings are subjected to heavy blows of moving loads and hence are maintained to a higher degree of precision. A small sized, 25 mm (1") ballast: s. therefore, preferable because of its fineness for slight adjustments, better compaction, and increased frictional area of the ballast.

For uniformity sake, the Indian Railways has adopted the same standard size of ballast for the main line as well as for points and crossings.

This standard size of ballast should be as per Indian Railways specification. The specification provides grading of ballast from 25 mm to 65 mm, maximum quantity of ballast being in the range of 40 mm to 50 mm size.

Table Comparison of different types of ballast

Type of ballast	**Advantages**	**Disadvantages**	**Suitability**
Sand ballast	Good drainage properties	Causes excessive wear	Suitable for CI pot sleeper tracks
	Cheap	Blows off easily	Not suitable for
	No noise produced on the track	Poor retentivity of packing	high-speed tracks
	Good packing material for CI sleepers	Track cannot be maintained to high standards	
Moorum ballast	Cheap, if locally available	Very soft and turns into dust	Used as a sub-ballast
	Prevents water from percolating	Maintenance of track is difficult	Initial ballast for new construction
	Provides good aesthetics	Quality of track average	
Coal ash or cinder	Easy availability on railways	Harmful for steel sleepers	Normally used in yards and sidings
	Very cheap	Corrodes rail bottom and steel sleepers	Suitable for repairs of formations during floods and emergencies
	Good drainage	Soft and easily pulverized	Not fit for high-speed tracks
		Maintenance is difficult	
Broken stone ballast	Hard and durable when procured from hard rocks	Initial cost is high	Suitable for packing with track machines
	Good drainage properties	Difficulties in procurement	Suitable for high speed tracks
	Stable and resilient to the track	Angular shape may injure wooden sleepers	
.	Economical in the long run		

REQUIREMENTS OF GOOD BALLAST

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.

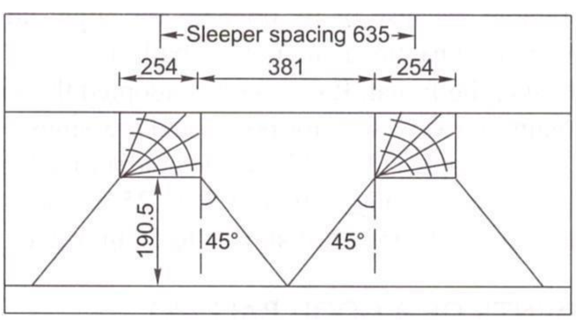
DESIGN OF BALLAST SECTION

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 as follows.

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 as discussed in, yet for simplicity, the dispersion of load can be assumed to be roughly 45° 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:

Sleeper spacing = width of the sleeper + 2 x depth of ballast



Minimum Depth of the Ballast Cushion

Lecture-10

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, along with sleeps 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) It provides a smooth and uniform bed for laying the track.

(b) It bears the load transmitted to it from the moving load through the balla

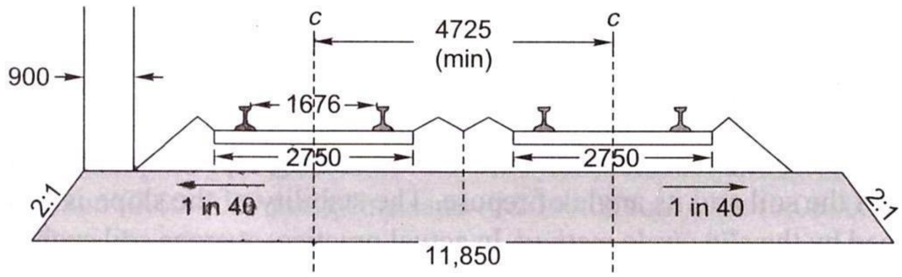
(c) It facilitates drainage.

(d) It provides stability to the track.

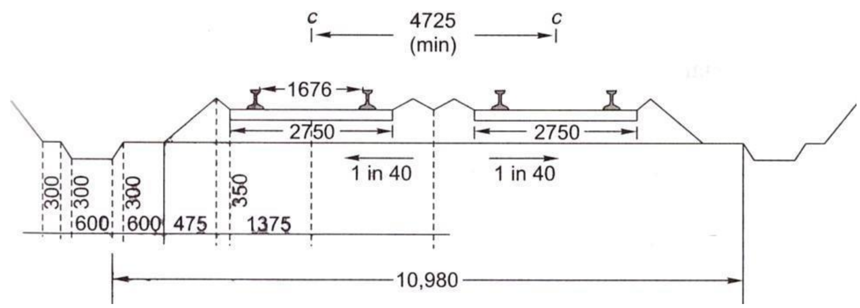
GENERAL DESCRIPTION OF FORMATION

The formation can be in the shape of an embankment or a cutting. When 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 an 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. below) 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 Railway BG MG. and NG are given in Table below.



(a) Cross section of bank



(b) Cross section of cutting

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

Table. Width of formation for different tracks

Gauge	*Type of sleepers*	*Single-line section*		*Double-line section*	
		Bank width (m)	*Cutting width (m)*	*Bank width (m)*	*Cutting width (m)*
BG	W,* ST,! and concrete	6.85	6.25	12.155	11.555
MG	W, ST, CST-9, and concrete	5.85	5.25	9.81	9.21
NG	W, ST, and CST-9	3.70	3.35	7.32	7.01

W stands for wooden sleepers. ST stands for steel trough sleeper.

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 in such cases.

Permanent way is the generic term for the track (rails, sleepers and ballast) on which railway trains run. Although the configuration of the track today would be recognized by engineers of the 19th century, it has developed significantly over the years as technological improvements became available, and as the demands of train operation increased.

Requirement of Good Track

A permanent way or track should provide comfortable and safe ride at the maximum permissible speed with minimum maintenance cost. To achieve these objectives, a sound permanet way should have the following characteristics:

- The gauge should be correct and uniform.
- The rail should have perfect cross levels. In curves, the outer rail should have proper super elevation to take into account the centrifugal force.
- The alignment should be straight and free of kinks. In the case of curves, a proper transition should be provided between the straight track and the curve.
- The gradient should be uniform and as gentle as possible. The change of gradient should be followed by a proper vertical curve to provide a smooth ride.
- The track should be resilient and elastic in order to absorb the shocks and vibration of running trains.
- The track should have a good drainage system so that the stability of the track is not effected by water logging.
- The track should have good lateral strength so that it can maintain its stability despite variations in temperature and other such factors.
- There should be provisions for easy replacement and renewal of the various track components.
- The track should have such a structure that not only is its initial cost low, but also its maintenance cost is minimum.

REQUIREMENTS OF AN IDEAL PERMANENT WAY

The following are the principal requirements of an ideal permanent way or of a good railway track :-

i. The gauge of the permanent way should be uniform, correct and it should not get altered.
ii. Both the rails should be at the same level on tangent (straight) portion of the track.
iii. Proper amount of *superelevation* should be provided to the outer rail above the inner rail on curved portion of the track.
iv. The permanent way should be sufficiently strong against lateral forces.
v. The curves, provided in the track, should be properly designed.
vi. An even and uniform gradient should be provided through out the length of the track.
vii. The *tractive resistance* of the track should be minimum.
viii. The design of the permanent way should be such that the load of the train is uniformly distributed on both the rails so as to prevent unequal settlement of the track.
ix. It Should provide adequate elasticity in order to prevent the harshness of impacts between the rails and the moving wheel loads of a train.
x. It should be free from excessive rail joints and all the joining should be properly designed and constructed.
xi. All the components parts such as *rails*, *sleepers*, *ballast, fixtures* and *fastenings*, etc. should satisfy the design requirements.
xii. All the fixtures and fastenings such as *chairs, bearing plates, fish plates, fish bolts, spikes* etc. should be strong enough to withstand the stresses occurring in the track.
xiii. All the **points and crossings*, laid in the permanent way, should be properly designed and carefully constructed.
xiv. It should be provided with fence near *level crossings* and also in urban areas.
xv. It should be provided with proper drainage facilities so as to drain off the rain water quickly away from the track.
xvi. It should be provided with safe and strong bridges coming in the alignment of the track.
xvii. It should be provided with safe and strong bridges coming in the alignment of the track.
xviii. It should be so constructed that repairs and renewals of any of its portion can be carried out without any difficulty.

Lecture-11

WEAR AND FAILURE IN RAILS

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 hitting the fish plate.

Types 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

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

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 as follows-

(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

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.

OTHER DEFECTS IN RAILS

Rail wear and 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 as follows:

Hogging of rails

Rail ends get hogged due to poor maintenance of the rail joint, yielding format, 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 she packing.

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 n 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 stress.

Corrugation of rail:

Corrugation consists of minute depressions on the surface of rails, varying in shape and size and occurring it 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

RAIL FAILURE

A rail is said to have failed if it is considered necessary to remove it immediately from the track on account of the defects noticed on it. The majority of rail failures originate from the fatigue cracks caused due to alternating stresses created in the rail section on account of the passage of loads. A rail section is normally designed to take a certain minimum GMT of traffic, but sometimes due to reasons such as an inherent defect in the metal, the section becomes weak at a particular point and leads to premature failure of the rail.

(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

The corrugation of rails is quite an undesirable feature. When vehicles pass over corrugated rails, a roaring sound is produced, possibly due to the locking of air in the corrugation. This phenomenon is sometimes called 'Roaring of rails'. This unpleasant and excessive noise causes great inconvenience to the passengers. Corrugation also results in the rapid oscillation of rails, which in turn loosens the keys, causes excessive wear to fittings, and disturbs the packing.

Causes of Rail Failures

The main causes of failure of rails are as follows:

Inherent defects in the rail These are due to manufacturing defects in the rail, such as faulty chemical composition, harmful segregation, piping, seams, laps, and guide marks.

Defects due to fault of the rolling stock and abnormal traffic effects Flat soots in tvres, engine burns, skidding of wheels, severe braking, etc.

Excessive corrosion of rails This generally takes place due to weather conditions, the presence of corrosive salts such as chlorides and constant exposure of the rails to moisture and humidity in locations near water columns, ashpits, tunnels, etc. Corrosion normally leads to the development of cracks in regions with a high concentration of stresses.

Badly maintained joints Poor maintenance of joints such as improper packing of joint sleepers and loose fittings.

Defects in welding of joints These defects arise either because of improper composition of the thermit weld metal or because of a defective welding technique.

Improper maintenance of track Ineffective or careless maintenance of the track or delayed renewal of the track.

Derailments The rails are damaged during derailment.

Classification of Rail Failures

The classification of rail failures on Indian Railways has been codified for easy processing of statistical data. The code is made up of two portions—the first portion consisting of three code letters and the second portion consisting of three or four code digits.

First portion of the code The three code letters make up the first portion and denote the following.

(i) Type of rail being used (O for plain rail and X for points and crossing rails) (ii) Reasons for withdrawal of rail (F for fractured, C for cracked, and D for defective)

(iii) Probable cause failure (S for fault of rolling stock, C for excessive corrosion, D for derailment, and O for others)

Second portion of code The second portion consisting of three or four digits gives the following information, (i) First digit indicate the location of the fracture on the length of the rail (1 for within fish plate limits and 2 for other portions on the rail), (ii) Second digit indicate the position in the rail section from where the failure started (0 for unknown, 1 for within rail head, 2 for surface of rail head, 3 for web, and 4 for foot).

(iii) Third digit indicate the direction of crack or fracture (0 to 9). (iv) Any other information about the fracture, where it is necessary to provide further subdivision. No specific system is recommended for this code.

Metallurgical Investigation

The following types of defective rails should normally be sent for metallurgical investigation, (i) Rails that have been removed from the track as a result of visual or ultrasonic detection

(ii) Rail failures falling in categories in which cracks or surface defects develop at specified locations

Lecture-12

CREEP OF RAIL

Introduction

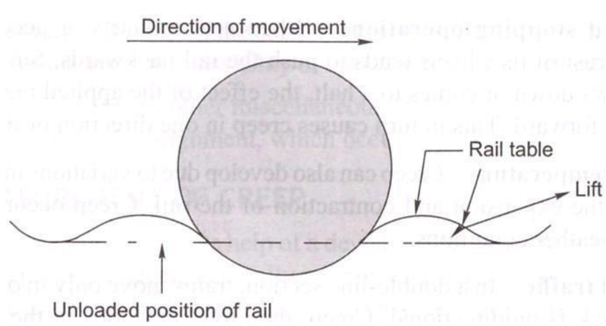
Creep is defined as the longitudinal movement of the rail with respect to the sleepers. Rails have a tendency to gradually move in the direction of dominant traffic. Creep is common to all railway tracks, but its magnitude varies considerably from place to place; the rail may move by several centimeters in a month at few places, while at other locations the movement may be almost negligible.

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.

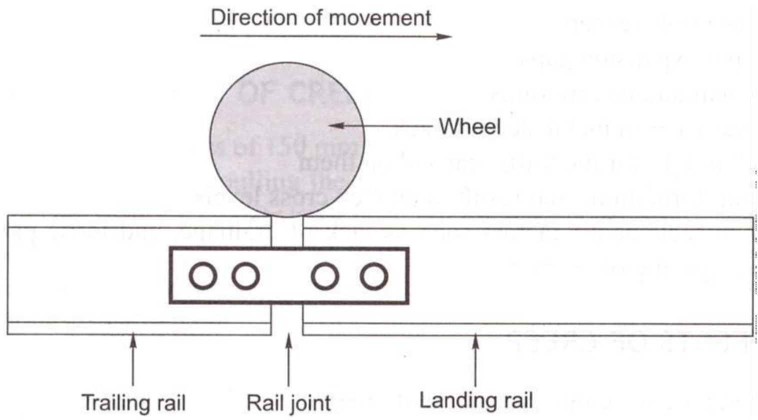
Wave Motion Theory

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. Therefore, the rails generally have a wavy formation.



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



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 and trailing wagons 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.

CAUSES OF CREEP

The main factors responsible for the development of creep are as follows.

Ironing effect of the wheel The ironing effect of moving wheels on the waves formed in the rail tends to cause the rail to move in the direction of traffic, resulting in creep.

Starting and stopping operations When a train starts or accelerates, the backward thrust of its wheels tends to push the rail backwards. Similarly, when the train slows down or comes to a halt, the effect of the applied brakes tends to push the rail forward. This in turn causes creep in one direction or the other.

Changes in temperature Creep can also develop due to variations in temperature resulting in the expansion and contraction of the rail. Creep occurs frequently during hot weather conditions.

Unbalanced traffic In a double-line section, trains move only in one direction, i.e., each track is unidirectional. Creep, therefore, develops in the direction of traffic. In a single-line section, even though traffic moves in both directions, the volume of traffic in each direction is normally variable. Creep, therefore, develops in the direction of predominant traffic.

Poor maintenance of track Some minor factors, mostly relating to poor maintenance of the track, also contribute to the development of creep. These are as follows:

• Improper securing of rails to sleepers

• Limited quantities of ballast resulting in inadequate ballast resistance to the movement of sleepers

• Improper expansion gaps

• Badly maintained rail joints

• Rail seat wear in metal sleeper track

• Rails too light for the traffic carried on them

• Yielding formations that result in uneven cross levels

• Other miscellaneous factors such as lack of drainage, and loose packing, uneven spacing of sleepers

EFFECTS OF CREEP

The following are the common effects of creep.

Sleepers out of square The sleepers move out of their position as a result of creep and become out of square. This in turn affects the gauge and alignment of the track, which finally results in unpleasant rides.

Expansion in gaps get disturbed Due to creep, the expansion gaps widen at some places and close at others. This results in the joints getting jammed. Undue stresses are created in the fish plates and bolts, which affect the smooth working of the switch expansion joints in the case of long welded rails.

Distortion of points and crossings Due to excessive creep, it becomes difficult to maintain the correct gauge and alignment of the rails at points and crossings.

Difficulty in changing rails If, due to operational reasons, it is required that the rail be changed, the same becomes difficult as the new rail is found to be either too short or too long because of creep.

Effect on interlocking The interlocking mechanism of the points and crossings pets disturbed bv creep.

Possible buckling of track If the creep is excessive and there is negligence in the maintenance of the track, the possibility of buckling of the track cannot be ruled out.

Other effects There are other miscellaneous effects of creep such as breaking of bolts and kinks in the alignment, which occur in various situations.

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. 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 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 as follows:

(i) A careful survey of the expansion gaps and of the current position of rail joints is carried out.

(ii) The total creep that has been proposed to be adjusted and the correct expansion gap that is to be kept are decided in advance.

(iii) 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.

(iv) 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.

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. 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 i 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 while using a creep adjuster:

(i) Expansion liners of the correct size are put in all the expansion gaps,

(ii) All the keys on the side (with wide joints) of the creep adjuster are removed and all fish bolts loosened,

(iii) 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 between the rail ends opposite the adjuster,

(iv) The corrected rails are then fastened with keys. After that, the rails on the other side of the adjuster are tackled,

(v) 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,

(vi) The corrected rails are then fastened and the adjuster is shifted to the new position,

(vii) 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.

Lecture-13

RAIL JOINTS

Introduction

Although a rail joint has always been an integral part of the railway track, it is looked upon as a necessary evil because of the various problems that it presents. Earlier, rails were rolled in short lengths due to difficulties in rolling and the problem of transportation. With increase in temperature, rails expand and this expansion needs to be considered at the joints. It was, therefore, felt that the longer the rail, the larger the required expansion gap, and this too limited the length of the rail. A rail joint is thus an inevitable feature of railway tracks, even though it presents a lot of problems in the maintenance of the permanent way. This chapter discusses the various types of rail joints and their suitability on a railway track.

ILL EFFECTS OF A RAIL JOINT

A rail joint is the weakest link in the track. At a joint, there is a break in the continuity of the rail in both the horizontal and the vertical planes because of the presence of the expansion gap and imperfection in the levels of rail heads. A severe jolt is also experienced at the rail joint when the wheels of vehicles negotiate the expansion gap. This jolt loosens the ballast under the sleeper bed, making the maintenance of the joint difficult. The fittings at the joint also become loose, causing heavy wear and tear of the track material. Some of the problems associated with the rail joint are as follows.

Maintenance effort

Due to the impact of moving loads on the joint, the packing under the sleeper loosens and the geometry of the track gets distorted very quickly because of which the joint requires frequent attention. It is generally seen that about 30 per cent extra labour is required for maintenance of a joint.

Bonded main line 6-bolt rail joint on a segment of 76.9 kg/m rail. Note how bolts are oppositely oriented to prevent complete separation of the joint in the event of being struck by a wheel during a derailment.

Lifespan

The life of rails, sleepers, and fastenings gets adversely affected due to the extra stresses created by the impact of moving loads on the rail joint. The rail ends particularly get battered and hogged and chances of rail fracture at joints are considerably high due to fatigue stresses in the rail ends.

Noise effect

A lot of noise pollution is created due to rail joints, making rail travel uncomfortable.

Sabotage chances

Wherever there is a rail joint, there is a potential danger of the removal of fish plates and rails by miscreants and greater susceptibility to sabotage.

Impact on quality

The quality of the track suffers because of excessive wear and tear of track components and rolling stock caused by rail joints.

Fuel consumption

The presence of rail joints results in increased fuel consumption because of the extra effort required by the locomotive to haul the train over these joints.

REQUIREMENTS OF AN IDEAL RAIL JOINT

An ideal rail joint provides the same strength and stiffness *a*s the parent rail. The characteristics of an ideal rail joint are briefly summarized here.

Holding the rail ends: An ideal rail joint should hold both the rail ends in their precise location in the horizontal as well as the vertical planes to provide as much continuity in the track as possible. This helps in avoiding wheel jumping or the deviation of the wheel from its normal path of movement.

Strength: An ideal rail joint should have the same strength and stiffness as the parent rails it joins.

Expansion gap: The joint should provide an adequate expansion gap for the free expansion and contraction of rails caused by changes in temperature

Flexibility It should provide flexibility for the easy replacement of rails, whenever required.

Provision for wear: It should provide for the wear of the rail ends, which is likely to occur under normal operating conditions.

Elasticity: It should provide adequate elasticity as well as resistance to longitudinal forces so as to ensure a trouble-free track.

Cost: The initial as well as maintenance costs of an ideal rail joint should be minimal.

TYPES OF RAIL JOINTS

The nomenclature of rail joints depends upon the position of the sleepers or the joints.

Classification According to Position of Sleepers

Three types of rail joints come under this category.

Supported joint

In this type of joint, the ends of the rails are supported directly on the sleeper. It was expected that supporting the joint would reduce the wear and tear of the rails, as there would be no cantilever action. In practice, however, the support tends to slightly raise the height of the rail ends. As such, the run on a supported joint is normally hard. There is also wear and tear of the sleeper supporting the joint and its maintenance presents quite a problem. The duplex sleeper is an example of a supported joint (Fig. below).

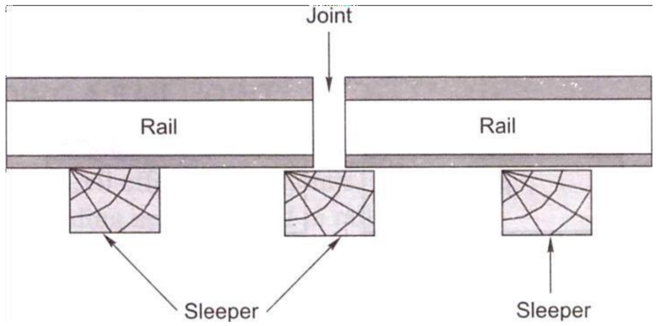


Fig. Supported rail joint

Suspended joint

In this type of joint, the ends of the rails are suspended between two sleepers and some portion of the rail is cantilevered at the joint. As a result of cantilever action, the packing under the sleepers of the joint becomes loose particularly due to the hammering action of the moving train loads. Suspended joints are the most common type of joints adopted by railway systems worldwide, including India (Fig. 16.2).

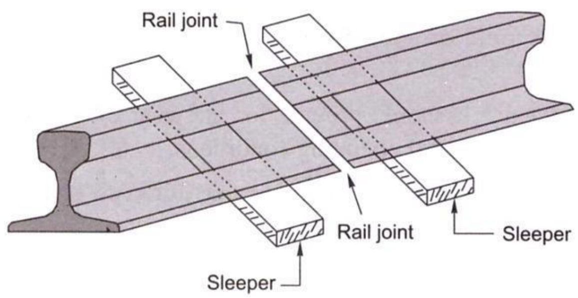


Fig. Suspended joint

Bridge joints

The bridge joint is similar to the suspended joint except that the two sleepers on either side of a bridge joint are connected by means of a metal flat [Fig. (a)] or a corrugated plate known as a bridge plate [Fig. 16.3(b)]. This type of joint is generally not used on Indian Railways.

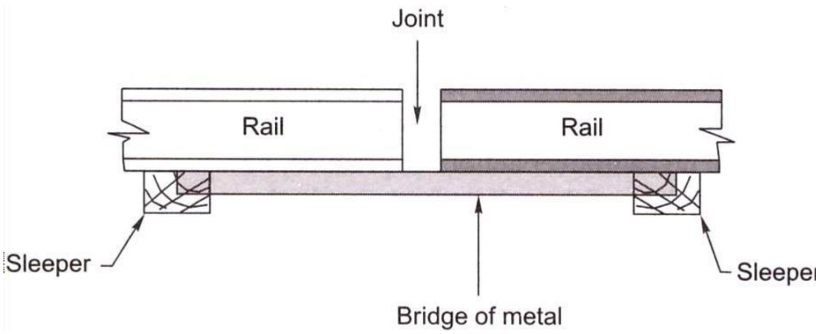


Fig. (a) Bridge joint with metal flat Joint

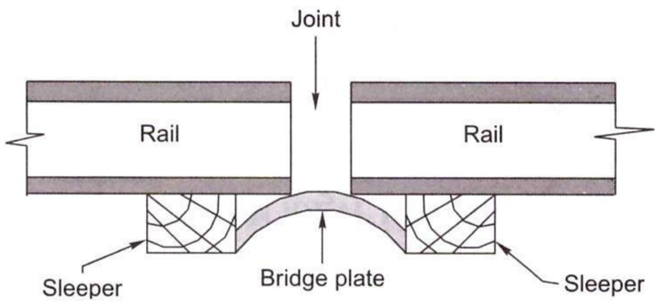
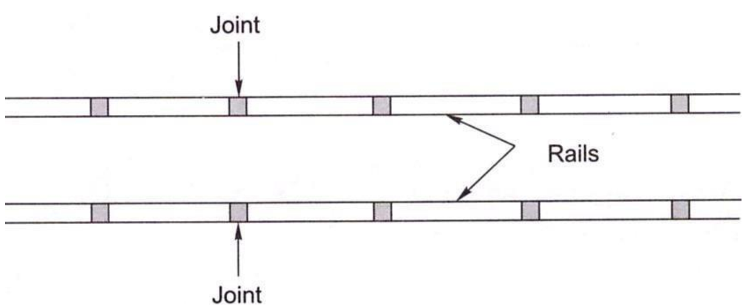


Fig. (b) Bridge joint with bridge plate

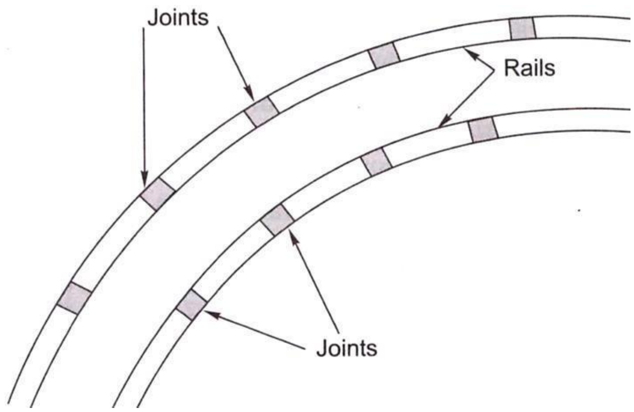
Classification Based on the Position of the Joint

Two types of rail joints fall in this category.

Square joint In this case, the joints in one rail are exactly opposite to the joints in the other rail. This type of joint is most common on Indian Railways (Fig. below).



Staggered joint In this case, the joints in one rail are somewhat staggered and are not opposite the joints in the other rail. Staggered joints are normally preferred on curved tracks because they hinder the centrifugal force that pushes the track outward (Fig. below).



WELDING A RAIL JOINT

The purpose of welding is to join rail ends together by the application of heat and thus eliminate the evil effects of rail joints.

There are four welding methods used in railways.

a) Gas pressure welding

b) Electric arc or metal arc welding

c) Flash butt welding

d)Thermit welding

Lecture-14

BEARING PLATES, ANTI-CREEP DEVICES

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 as follows:

(v) A careful survey of the expansion gaps and of the current position of rail joints is carried out.

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(vii) 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.

(viii) 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.

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(viii) Expansion liners of the correct size are put in all the expansion gaps,

(ix) All the keys on the side (with wide joints) of the creep adjuster are removed and all fish bolts loosened,

(x) 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 between the rail ends opposite the adjuster,

(xi) The corrected rails are then fastened with keys. After that, the rails on the other side of the adjuster are tackled,

(xii) 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,

(xiii) The corrected rails are then fastened and the adjuster is shifted to the new position,

(xiv) 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

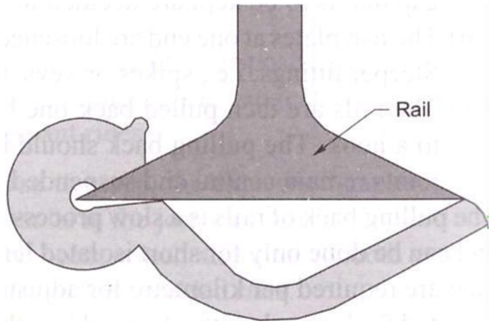
The following locations of a track are normally more susceptible to creep.

- The point where a steel sleeper track or CST-9 sleeper track meets a wooden sleeper track
- Dips in stretches with long gradients
- Approaches to major girder bridges or other stable structures
- Approaches to level crossings and points and crossings
- Steep gradients and sharp curves

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 creep anchors 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. below. The creep anchor should fit snugly against the sleeper for it to be full;-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°C) in the case of zones III and IV. Regular adjustment may be necessitated on girder bridges.

(c) Anticreep bearing plates should be provided on wooden sleepers to arrest creep, but joints sleepers should have standard canted bearing plates with rail screws.

Lecture-15

RAILWAY ALIGNMENT

INTRODUCTION

Geometric design of a railway track discusses all those parameters which 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

DETAILS OF GEOMETRIC DESIGN OF TRACK

The geometric design of the track deals with alignment of railway track and Curves Details regarding curves and their various aspects.

GRADIENTS

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 movement of traffic and in a down or falling gradient the track loses elevation the direction of 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 per cent.

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

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.

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.

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 Railway and the Darjeeling Himalayan Railway section.

Momentum Gradient

The momentum gradient is also 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.

Gradients in Station Yards

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

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

(b) It reduces 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 cent per degree of the curve or 70/R, whichever is minimum

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

(c) On NG tracks, 0.02 per cent 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.

Lecture-16

HORIZONTAL CURVES

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 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 super elevation.

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 denned 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 arc.

The value of the degree of the curve can be determined as indicated below.

Circumference of a circle = $2\pi R$

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

Angle subtended at the centre by a 30.5 m arc, or degree of curve = $360°/2\pi R \times 30.5$

$= 1750/R$ (approximately R is in meter)

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

Relationship between radius and versine of a curve

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. Below. 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.

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

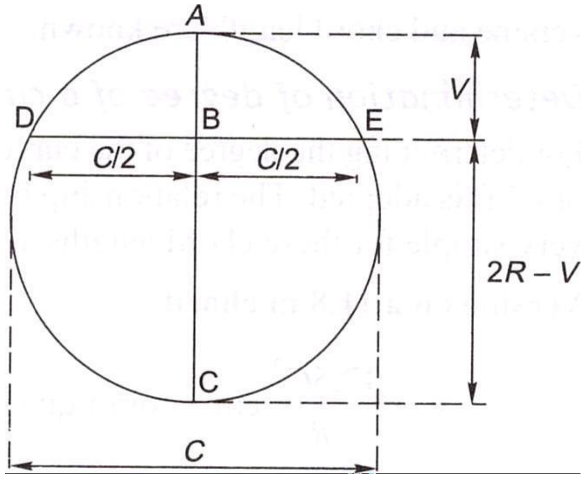


Fig. Relation between radius and versine of a curve

AB x BC = DB x BE or $V(2R-V)$ =(C/2) x (C/2) or $2RV - V^2 = C^2/4$

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

$2RV = C^2/4$ or $V = C^2/8R$

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

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 below.

Table 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. below, AO and BO are two tangents of a circular curve which meet or intersect at a point O, called *the point of inter section* 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* (∟ ϕ). The following are some of the important relations between these elements:

∟1 + ∟ ϕ =180^0

Tangent $OT_1 = OT_2 = R \tan (\phi/2)$

T_1T_2 = length of long cord = $2R \sin (\phi/2)$

Length of the curve = $2\pi R/360 \times \phi = \pi R \phi / 180$

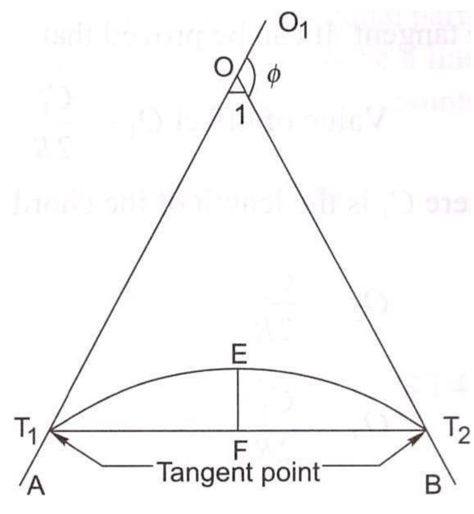


Fig. Elements of a circular curve

Lecture-17

SUPERELEVATION

The following terms are frequently used in the design of horizontal curves.

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

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 curves 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 (C_d) It 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 (C_e) It 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.

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 = $a = V^2/R$

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 x $(V^2/R) = (W/g) x (V^2/R)$

where F *is* the centrifugal force (Kilo newton), W *is* the weight of the vehicle (tonnes), V is the speed (m/s), g *is* the acceleration due to gravity (m/s^2), and R is the radius of the curve in 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 is known as *equilibrium superelevation.*

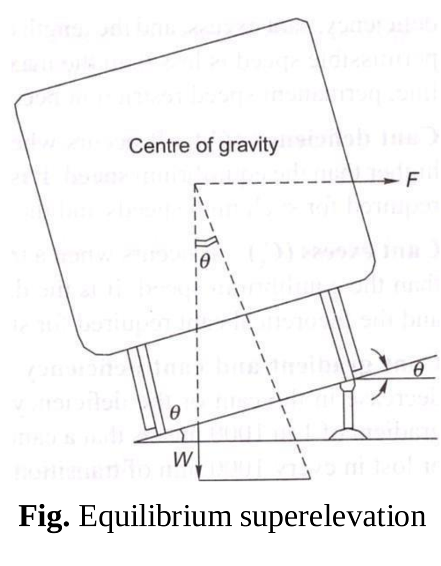


Fig. Equilibrium superelevation

Equilibrium Superelevation

In Fig. above, if θ *is* the angle that the inclined plane makes with the horizontal line, then superelevation tan θ = *Superelevation / Gauge = e/* G

tan θ = *Centrifugal force/weight = F/W*

From these equations

$e/G = F/W$

$e = f \times G/W$

$e = W/g \times V^2/R \times G/R = GV^2 / gR$

Here, *e is* the equilibrium superelevation, G is the gauge, *Vis* 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:

$e = GV^2 / 127R$

where *e* is the superelevation in millimetres, *V is* the speed in km per hour, *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 ermal to 1750 mm for BG tracks and 1058 mm for MG tracks.

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 superelevation generally adopted on on many railways around the world is one-tenth to one-twelfth of the gauge. The values of maximum superelevation prescribed on Indian Railways are given in Table below.

Table 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	All routes	90	100
NG		65	75

Lecture-18

CANT DEFICIENCY AND NEGATIVE SUPERELEVATION

Introduction

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:

1. Higher cant deficiency causes greater discomfort to passengers

2. Higher cant deficiency leads to greater unbalanced centrifugal force, which in turn leads to the requirement of stronger tracks and fastenings to withstand the resultant greater lateral forces. The maximum values of cant deficiency prescribed on Indian Railways are given in Table below.

Table Allowable cant deficiency

Gauge	*Group*	*Normal cant deficiency (mm)*	*Remarks*
BG	AandB	75	For BG group
BG	C, D, and E	75	For A and B routes; 1 00 mm cant deficiency permitted only for nominated rolling stock and routes with the approval of the CE
MG	All routs	50	
NG	-	40	

The limiting values of cant excess have also been prescribed. Cant excess should not be more than 75 mm on BG and 65 mm on MG 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 below lists the limiting values of the various parameters that concern a curve.

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**. below, AB, which is the outer rail of the main line curve, must he 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.

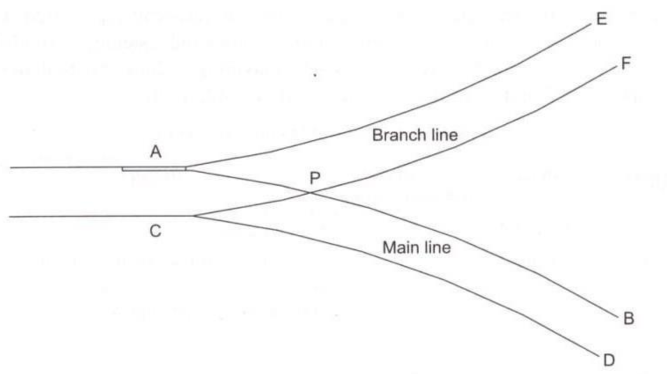


Fig: Negative superelevation

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

$e = GV^2 / 127R$

(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 the 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 refers to 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*

$V = 3.65(R - 6)^{1/2}$

where V is the speed in km per hour and R is the radius in metres.

Non-transitioned curves

Safe speed = four-fifths of the speed calculated using Eqn. above

For NG *Transitioned curves*

$V = 3.65(R - 6)^{1/2}$ (subject to a maximum of 50 kmph).

Non-transitioned curves

$V = 2.92(R - 6)^{1/2}$ (subject to a maximum of 40 kmph).

Indian Railways no longer follows this concept of safe speed on curves or the stipulations given here.

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:

ForBG

$V = ((C_a + C_d) \times R/ 13.76)^{1/2} = 0.27((C_a + C_d) \times R)^{1/2}$

where *V is* the maximum speed in km per hour, C_a is the actual cant in millimetres, C_d is the permitted cant deficiency in millimetres, and *R* is the radius in millimetres. This equation is derived from Eqn for equilibrium superelevation and is based on the assumption that G = 1 750 mm, which is the centre-to-centre distance between the rail heads of a BG track with 52 g rails.

For MG

$V = 0.347((C_a + C_d) \times R)^{1/2}$

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.

For NG (762 **mm.)**

$V = 3.65(R - 6)^{1/2}$ (subject to a maximum of 50 kmph)

(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 based on cant deficiency This is the speed calculated using the formula given in Table above. 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 superelevation ($C_a + C_d$).

(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 per hour for BG and 50 km per hour 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 considering the various lengths of transition curves given by the formulae listed in Table below.

Example 1: Calculate the superelevation and maximum permissible speed for a 2° BG transitioned curve on a high-speed route with a maximum sanctioned speed of 110 kmph. The speed for calculating the equilibrium superelevation as decided by the chief engineer is 80 kmph and the booked speed of goods trains is 50 kmph.

Example 2: Calculate the superelevation, maximum permissible speed, and transition length for a 3° curve on a high-speed BG section with a maximum sanctioned speed of 110 kmph. Assume the equilibrium speed to be 80 kmph and the booked speed of the goods train to be 50 kmph.

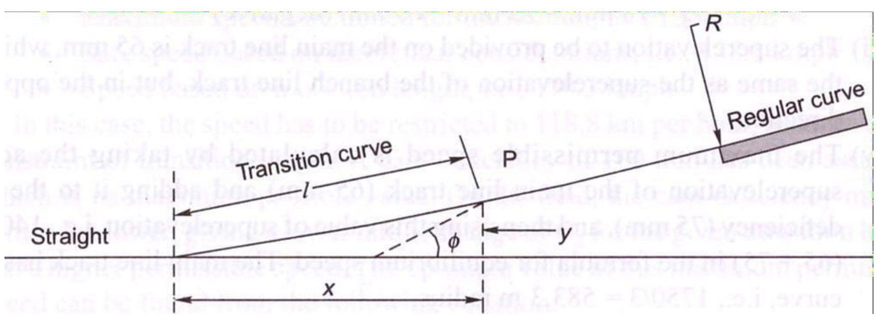
Lecture-19

LENGTH OF TRANSITION CURVES

Introduction

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. below). 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.

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.

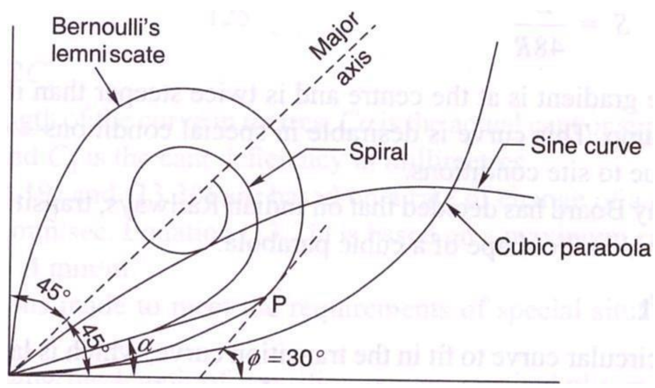
(b) It should join the circular curve tangentially, i.e., it should finally have the same curvature as that of the circular curve.

(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.

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. below.



Euler's spiral This is an ideal transition curve, but is not preferred due to mathematical complications. The equation for Euler's spiral is:

$$\phi = \frac{l^2}{2RL}$$

Cubical spiral This is also a good transition curve, but quite difficult to set on the field.

$$y = \frac{l^2}{6RL}$$

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° 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: $y = \frac{x^3}{6RL}$

In this curve, both the curvature and the cant increase at a linear rate. The can: 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 throughout the length of the curve. A straight line ramp is provided for such transition curves.

The notations used in above Eqs are as follows: ϕ 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:

$S = L^2/48R$

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.

LENGTH OF TRANSITION CURVE

The length of the transition curve is length along the centre line of the track from its meeting point with the straight to that of the circular curve. This length is inserted at the junction half in the straight and half in the curve. Let, L = Length of transition curve in metres *e* = Actual cant or superelevation in cm. *D* = Cant deficiency for maximum speed in cm and *V* = Maximum speed in kmph.

Indian Railways specify that *greatest* of the following lengths should be taken as the length of the transition curve.

$L = 7.20\, e$

where e = actual superelevation in centimetres. This is based on Arbitrary gradient (1 in 720)

$L = 0.073\, D \times V_{max}$

The length of the transition curve prescribed on Indian Railways is the maximum of the following three values:

$L = 0.008C_a \times V_m = C_a \times V_m /125$

$L = 0.008C_d \times V_m = C_d \times V_m /125$

$L = 0.72C_a$

Where L is the length of the curve in metres, C_a is the actual cant or superelevation in millimetres, and C_d is the cant deficiency in millimetres. Above first two equations are based on a rate of change of a cant or cant deficiency of 35 mm/sec. Third equation is based on a maximum cant gradient of 1 in a 720 or 1.4 mm/m.

.

Example: 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 kmph.

Lecture-20

VERTICAL CURVES

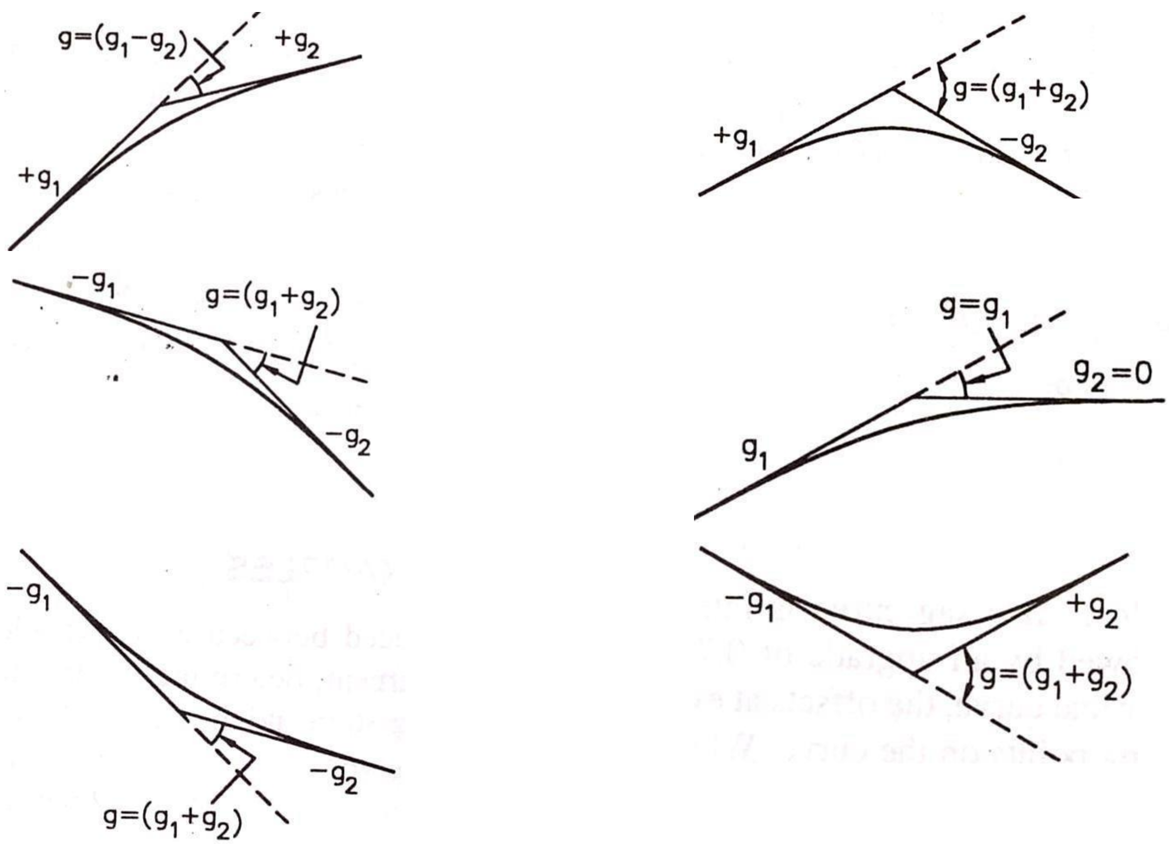
Introduction

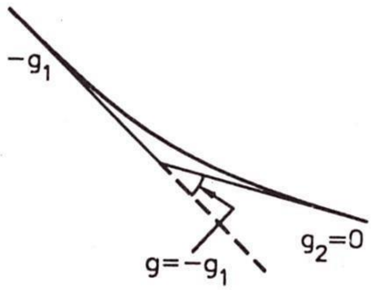
Vertical Curves. They are of two types :

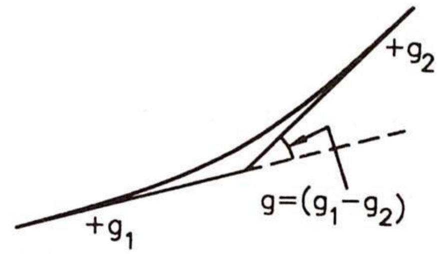
(i) Summit curves. (ii) Sag or Valley curves.

Whenever, there is a change in the gradient of the track, an angle is formed at the junction of the gradients. This vertical kink at the junction is smoothened by the use of curve, so that bad lurching is not experienced. The effects of change of gradient cause variation in the draw bar pull of the locomotive.

When a train climbs a certain upgrade at a uniform speed and passes over the summit of the curve, an acceleration begins to act upon it and makes the trains to move faster and increases the draw bar pull behind each vehicle, causing a variation in the tension in the couplings.







When a train passes over a sag, the front of the train ascends an up-grade while rear vehicles tend to compress the couplings and buffers, and when the whole train has passed the sag, the couplings are again in tension causing a jerk. Due to above reasons, it is essential to introduce a vertical curve at each sag and at each summit or apex.

A parabolic curve is set out, tangent to the two intersecting grades, with its apex at a level halfway between the points of intersection of the grade line and the average elevation of the two tangent points. The length of the vertical curve depends upon the algebraic difference in grade as shown in figure above and determined by the rate of change gradient of the line.

Lecture-21

POINT AND CROSSING-I

Points and crossings are provided facilitates the change of railway vehicles from one track to another. The tracks may be parallel, diverging, or converging to each other. Points and crossings are necessary due to the inside flanges of wheels of railway vehicles and, therefore require special arrangement 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 (a) shows the various constituents of a turnout. The details of these constituents are given in Table below.

Table: Parts of a turnout

Name of the main assembly	*Various constituents of the assembly*
Set of switches	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 wing rails, and two check rails
Lead rails	Four sets of lead rails

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. (a), the turnout is a right-hand turnout because it diverts the traffic towards the right side. Figure (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, that is, 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.*

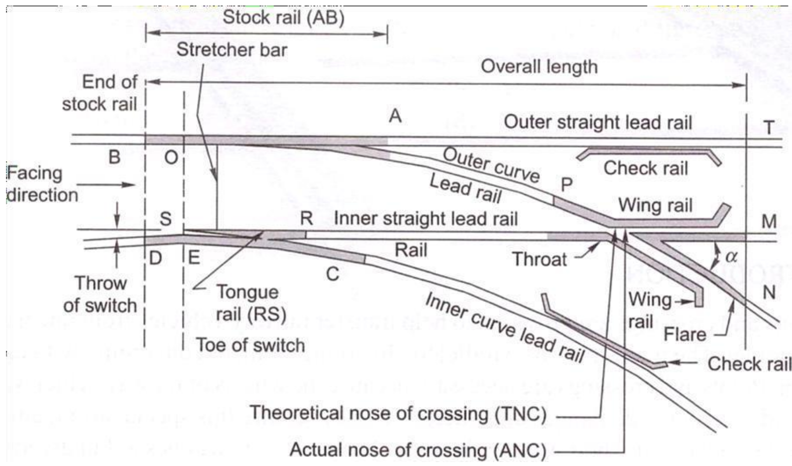


Fig. (a) Constituents of a turnout

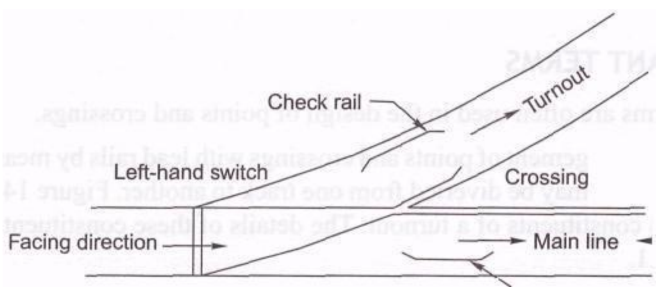


Fig. (b) Left-hand turnout

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.

Points or switch A pair of tongue and stock rails with the necessary connections and fittings forms a switch.

Crossing It 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.

SWITCHES

A set of points or switches consists of the following main constituents (Fig. below).

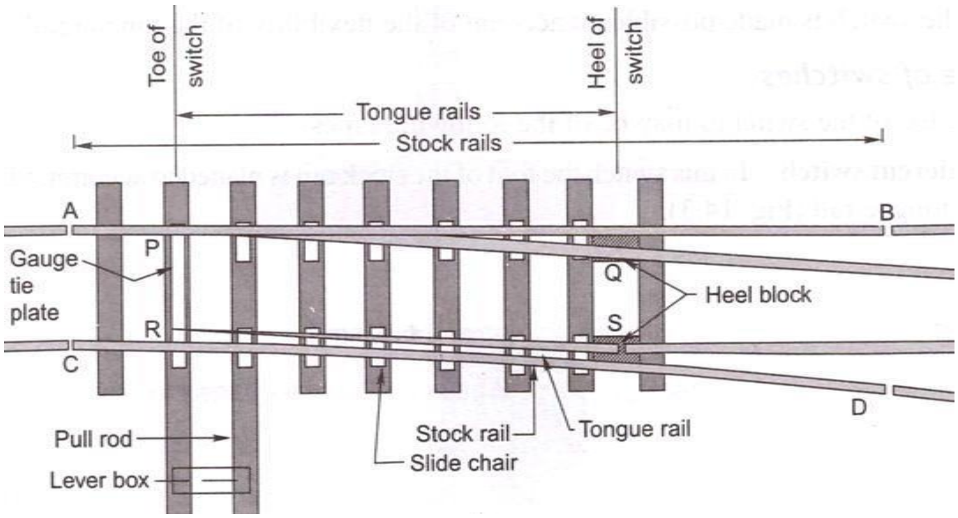


Fig. Details of a switch

(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.

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 also be of two types—loose heel type and fixed heel type. These are discussed below.

Loose heel type

Fixed heel type

The toe of the switches may be of the following types.

Undercut switch In this switch the foot of the stock rail is planned to accommodate the tongue rail (Fig. below).

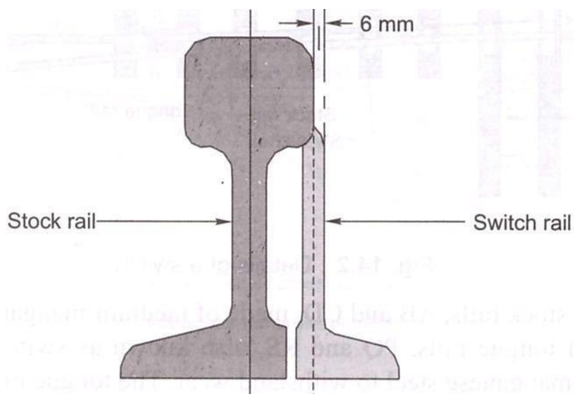


Fig. Undercut switch

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. below).

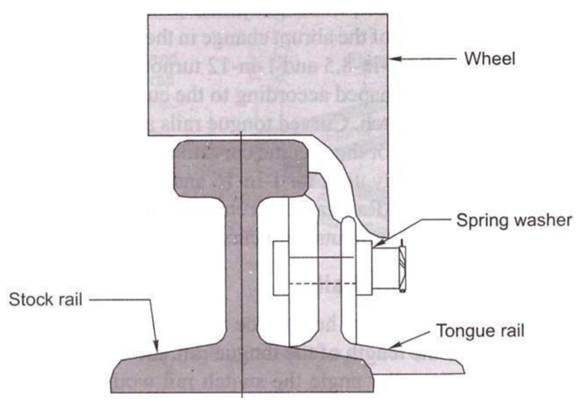


Fig. Overriding switch

Lecture-22

POINT AND CROSSING-II

Introduction

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, trains get jolted while negotiating with tongue rail turnouts because of the abrupt change in the alignment. Straight rails are normally used for l-in-8.5 and l-in-12 turnouts on Indian Railways.

Curved tongue rails are shaped according to the curvature of the turnout ft the toe to the heel of the switch. Curved tongue rails allow for smooth trains, but can only be used for the specific curvature for which they are Curved switches are normally used for 1-in-16 and 1-in-20 IRS (Indian Standard) turnouts on Indian Railways. Recently Indian Railways has also laying 1-in-8.5 and 1-in-12 turnouts with curved switches on important li

Length of Tongue Rails

The length of a tongue rail from heel to toe varies with the gauge and 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 space. The length of the tongue rail should be more than the rigid wheel a four-wheeled wagon to preclude the possibility of derailment in case the move from their position when a train is running on the switch. Table below the standard lengths of switches (tongue rails) for BG and MG tracks.

Table: Length of tongue rail

Gauge and type	Length of tongue rail (mm)				
	1-in-8.5 straight	1-in-12 straight	1-in-12 curved	1-in-16 Curved	
BG (90 R)	4725	6400	7730	9750	1.1150
MG (75 R)	4116*	5485*	6700		

* These dimensions hold good for NG tracks also.

CROSSING

A crossing or frog is a device introduced at the point where two gauge faces across each other to permit the flanges of a railway vehicle to pass from one tract to another (Fig. below). 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. below.

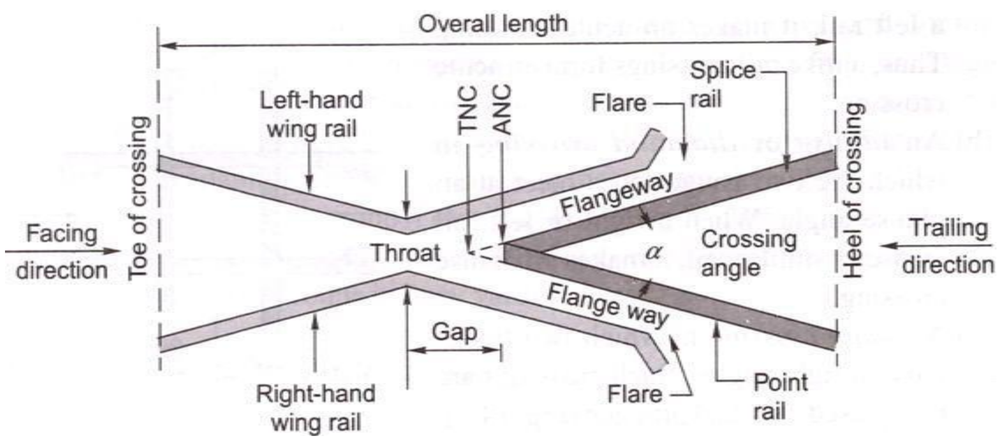


Fig. Details of a crossing

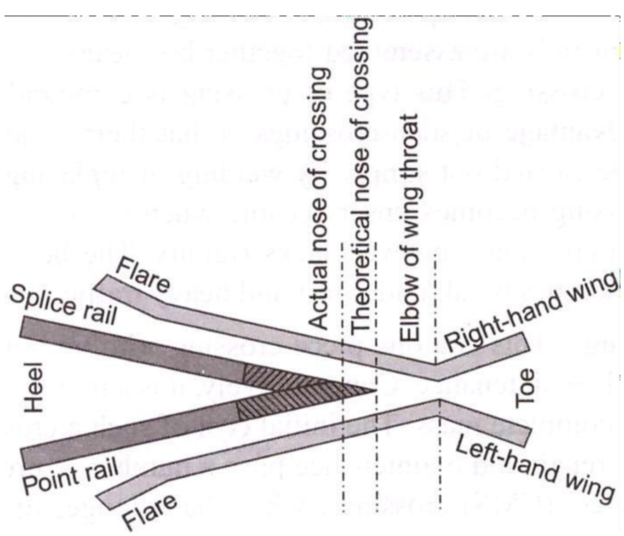


Fig. Point rail and splice rail

(a) Two rails, point rail and splice rail, which are machined to form a nose. Tic point rail ends at the nose, whereas the splice rail joins it a little behind the nose. Theoretically, the point 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 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 the 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.

(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.

Types of Crossings

A crossing may be of the following types.

(a) ***An acute angle crossing*** or 'V crossing

(b) ***An obtuse or diamond crossing***.

(c) ***A square crossing*** (**Fig**. below).

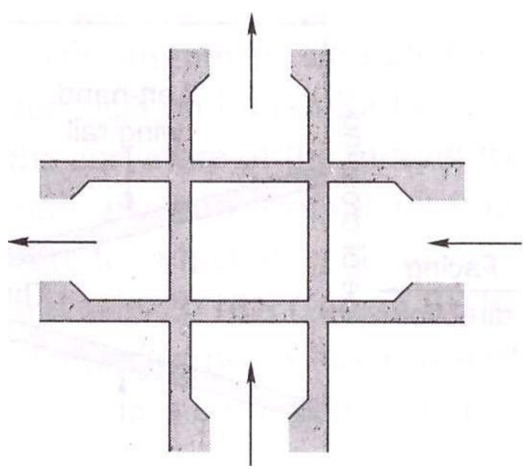


Fig. Square crossing also be classified as follows.

For manufacturing purposes, crossings can also be classified as follows.

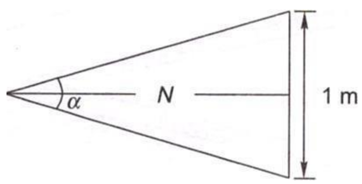
- Built-up crossing
- Cast steel crossing
- Combined rail and cast crossing

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 below.

Centre line method

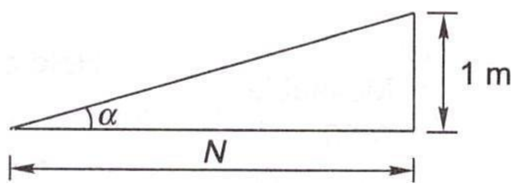
This method is used in Britain and the US. In this method, N is measured along the centre line of the crossing.



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.

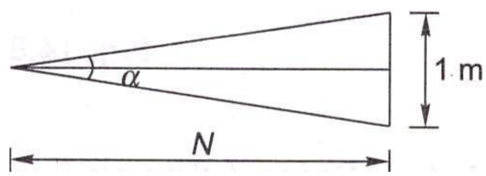
Cot α/2 – N = N /1/2 or N = 1/2 Cot α/2



Cot α = N /1 or N = Cot α

Isosceles* triangle *method

In this method, *N* is taken as one of the equal sides of an isosceles triangle.



Sin α/2 = ½ /N or N = 1/2N

Cosec α/2 = 2N

N = ½ Cosec α/2

The right angle method used on Indian Railways, in which TV 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-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*.

Lecture-23

TURNOUTS

Introduction

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 (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 (a) This is the angle between the main line and the tangent of the 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 (/?,) plus half the gauge width.

$R = R_{}$+ 0.5,G

As the radius of a curve is quite large, for practical purposes, *R* may be taken to be equal to .ft,.

Special fittings with turnouts

Some of the special fittings required for use with turnouts are enumerated as follows:

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.

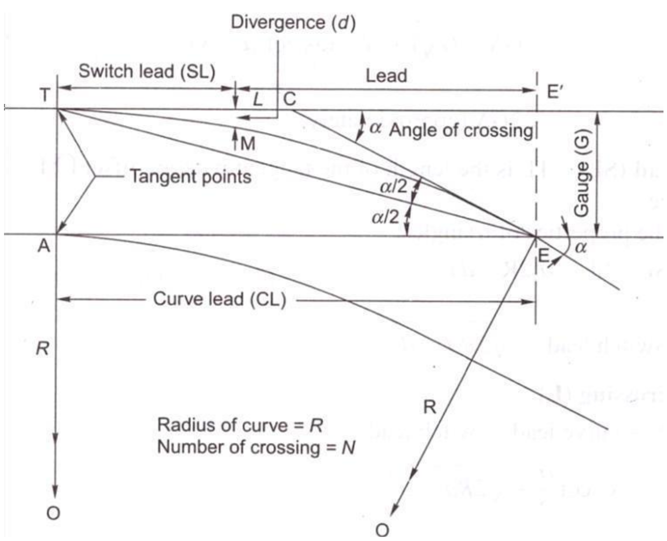
Grade off chairs These are special chairs provided behind the heel of the switches to give a suitable ramp to the tongue rail, which is raised by 6 mm at the heel.

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.



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. The maximum speeds permitted on these turnouts are given in Table below.

Table: Permissible speeds on turnouts

Gauge	*Type of turnout*	*Switch angle*	*Permissible speed (kmph)*
BG	1 in 8.5	1°34'27"	10* for straight switch and 15 for curved switch for 52/60 kg rails on PSC sleepers
BG[f]	l-in-8.5	Symmetrical split (SS) 0°27'35"	30 for curved switch as well as SS with 52/60 kg on PSC sleepers; 15* for curved switch for 52/60 kg on PSC sleepers*
BG	l-in-16	1°8'0" 0°24'27"	50 or 60[1]
MG	l-in-8.5	1°35'30" 0°29'14"	10 for straight as well as curved switch
MG[f]	l-in-12	1°09'38" 0°24'27"	1 5 for straight switch and 1 5 for partly curved switch
MG	l-in-16	0°24'27"	30

Lecture-24

DESIGN OF TURNOUTS

A turnout, after branching off from the main track, may run into various directions of which running parallel to the original track is most common. The design calculation of various turnout are based on following three factors:

(i) Method of calculating various leads
(ii) Method employed for crossing angle
(iii)Type of tongue rail used

Notation used in design calculation

Following notation have been used in various methods for design of turnouts:

CL = Curve lead
= Distance between theoretical nose of the crossing (T.N.C.) and the tangent point ―T‖ measured along the length of main track.

SL = Switch lead
= Distance between tangent point ―T‖ and the heel of the switch (H.S.) measured along the length of the track

L = Lead or crossing lead
= Distance between T.N.C. and the heel of the switch (H.S.) measured along the length of the track

Lead rails, being curved rails, are not measured along their curve length, long their projected length along the straight rail.

Therefore, CL, SL and L, it is clear that

CL = SL + L or L = CL - SL

β = Angle of the switch, i.e. the angle between the gauge faces of switch rail and stock rail

α = Angle of the crossing

d = Heel divergence or clearance

R_0 = Radius of the outer turnout

R = Radius of centre line of the turnout

G = Gauge of the track

N = Number of the crossing

D = Distance between T.N.C. and tangent point of crossing curve

Different method of the turnout design

Three methods are used for design of turnouts

Method-I

The important steps of this method are

(i) All three leads, CL, SL, and L are calculated. The CL and SL are particularly calculated in this method.

(ii) Crossing angle (α) calculated using right angle method

(iii) Crossing curve is considered to start from an imaginary tangent point ahead of actual toe of the switch and end at T.N.C. This arrangement results formation of three kinks,

a) Kinks at the toe of the switch. Due to straight tongue rail.

b) Kink at heel of the switch. Due to non tangential of tongue rail to the curve.

c) Kinks at toe of the crossing. Because the curve is carried theoretically upto T.N.C. but crossing actually is straight.

This design method all three kinds of kinks and was common in the past. But now a days used in unimportant lines and sidings.

Design calculation of method I

Value of gauge (G), Heel divergence (d) and Angle of the crossing (α) are given

Curve lead (CL)

CL= 2GN

R-Radius

Hence $R = R_0 – G/2$

$R_0 = 1.5G + 2GN^2$

$SL = (2 R_0 d)^{1/2}$ AS d^2 is very small Comair to $2R_0d$

Lead or crossing lead (L)

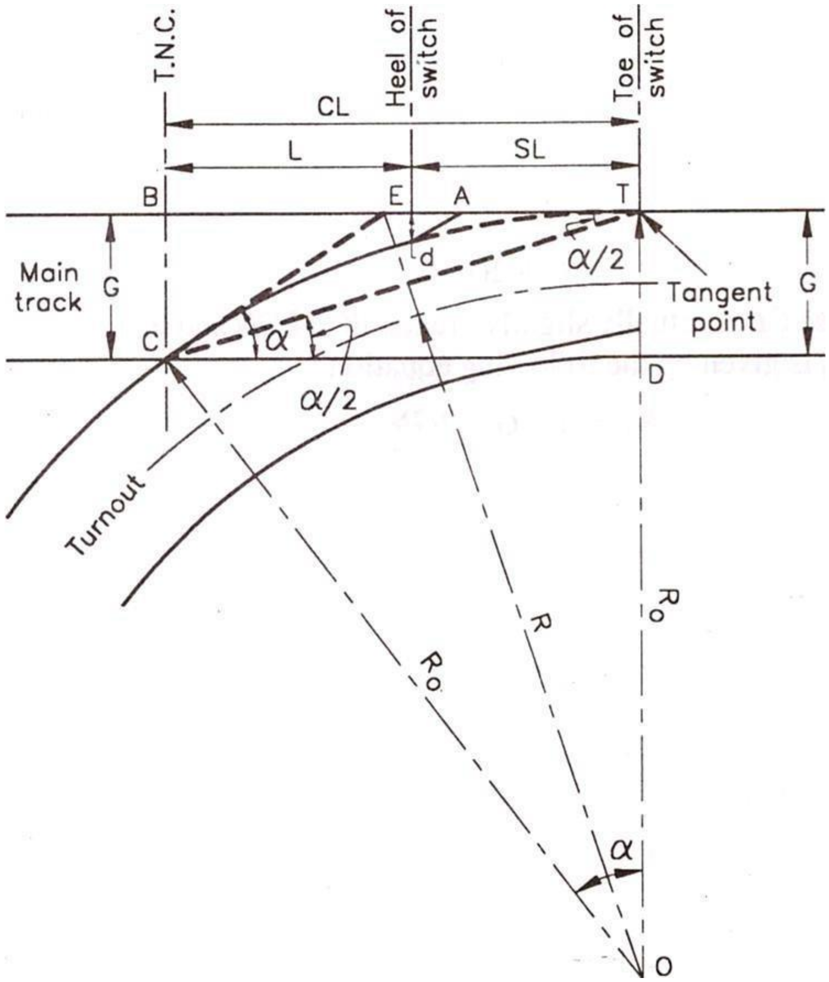
$L = CL – SL$

$= G \cot \alpha/2 – (2 R_0 d)^{1/2} = (2 R_0 G)^{1/2} – (2 R_0 d)^{1/2}$

$= 2GN - (2 R_0 d)^{1/2}$

Heel Divergence (d)

From equation $SL = (2 R_0 d)^{1/2}$ $d = (SL)^2 / 2 R_0$



Method II

The important features of this method are

(i) Only the cross lead ―L‖ is calculated

(ii) The curve is tangential to the tongue rail. It springs up from heel of switch and ends at T.N.C.

(iii) Out of three kinks, kinks formed at heel of the switch is removed

This method was common in UK in past

Design Calculation

With given value of gauge (G), d, β (angle of switch) and α, the turnout is designed:

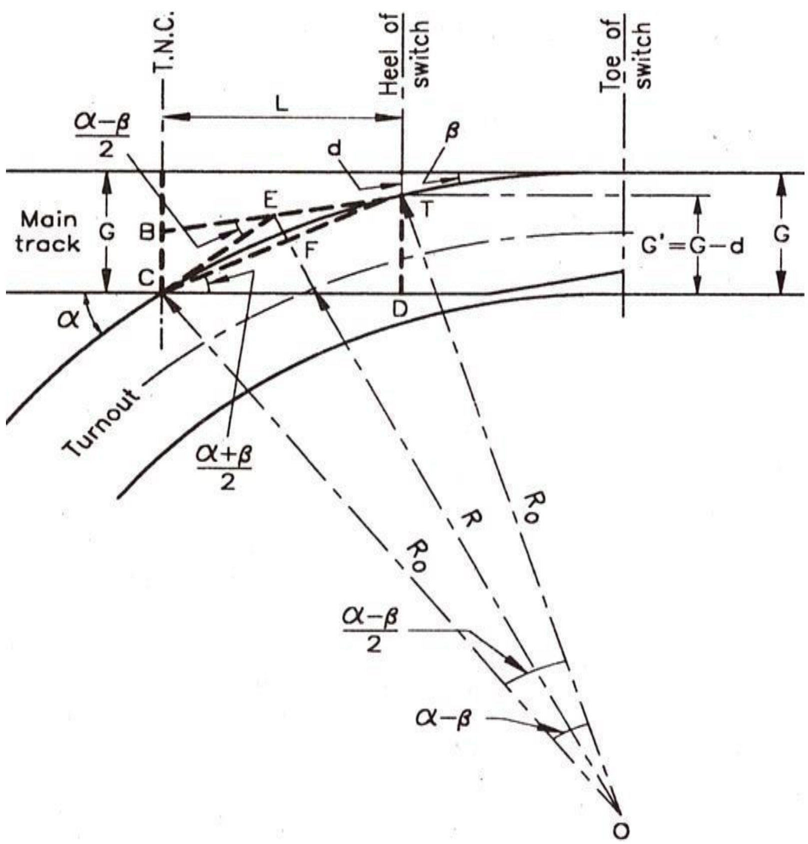
Lead or crossing lead (L):

$$L = (G - d)/ \tan (\alpha + \beta)/2 = (G - d) \cot (\alpha + \beta)/2$$

R-Radius:

$R_0 = (G - d) / 2 \sin (\alpha + \beta)/2 \sin (\alpha - \beta)/2 = (G - d) / (\cot \beta - \cot \alpha)$

and $R = R_0 - G/2$



Method III

The important features of this method are

(i) This method is very similar to method II. But here the straight length at crossing is provided.

(ii) So one end of the curve is tangential to tongue rail and spring up from the toe of the crossing and is tangential to the straight length of the crossing.

(iii) In this method kinks at toe of the switch and kinks at heel of the switch are removed.

(iv) It is suitable where tongue rails and crossing are straight. This method permits the

* Under revision

Design Calculation

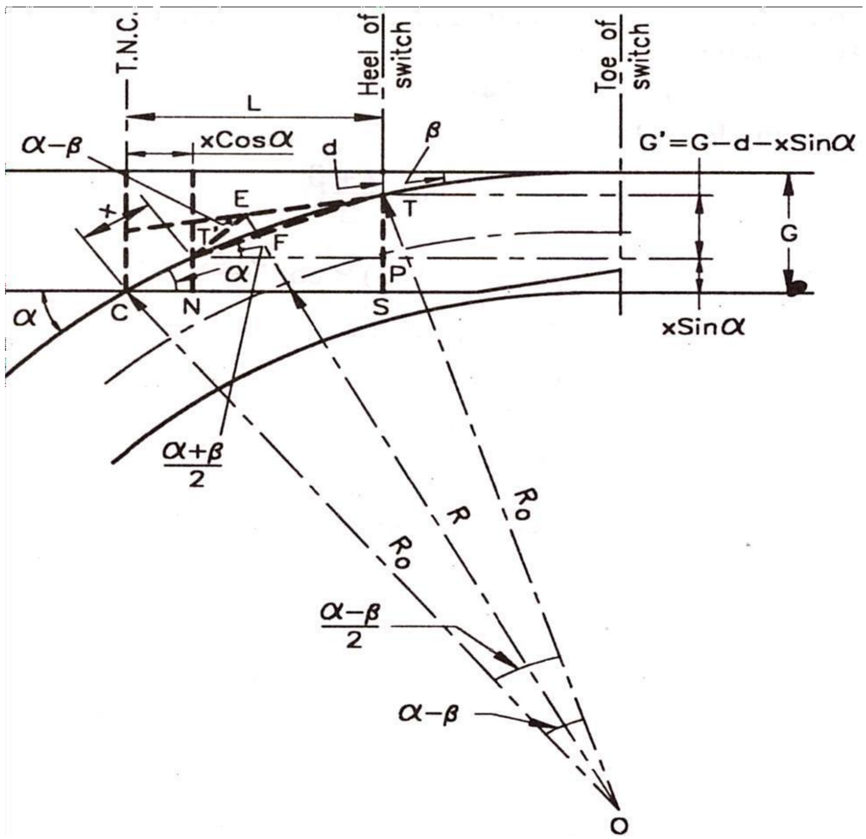
Let the straight length of the arms at crossing be $x = T'C$

R-Radius:

With given G, D, α, β and x

$R_0 = (G – d – x \sin α)/(\cos β – \cos α)$

$R = R_0 – G/2$



Crossing Lead (L)

$L = CN + NS = ON + T'P = x \cos α + TP \cot (\frac{α+β}{2})$

$L = x \cos α + G' \cot (\frac{α+β}{2}) = x \cos α + (G – d – x \sin α) \cot (\frac{α+β}{2})$

$d = x \sin α - G – ((L– x \cos α) / \cot (\frac{α+β}{2}))$

To get value of method II put x =0

* Under revision

Lecture-25

TRACK JUNCTION

Introduction

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.) continues to run in the same direction as the main line curve even after branching off from it. The degree of the turnout curve will be higher than that of the main line curve. The degree and radius of the turnout curve are given by the formulae:

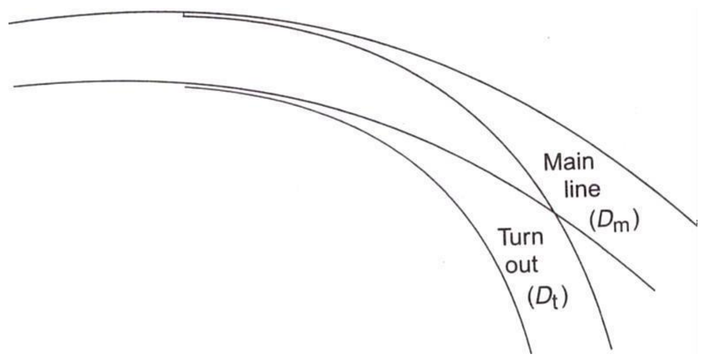


Fig Turnout of similar flexure

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. above, 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 .ft, 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) 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:

$D_t = D_s - D_m$

* Under revision

$R_t = R_s R_m / (R_m - R_s)$

Here, D_m is the degree of the rail of the main track on which the crossing lies, i.e., the outer rail in Fig. below.

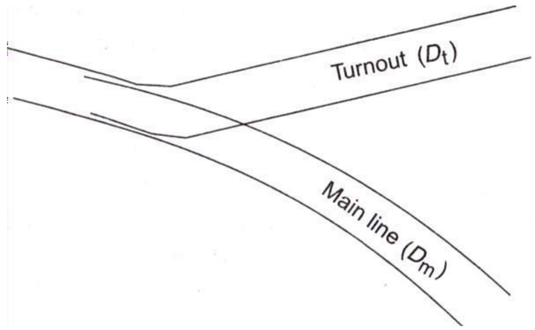


Fig. Turnout of contrary flexure

SYMMETRICAL SPLIT

"Alien a straight track splits up in two different directions with equal radii, the layout is known as a symmetrical split (Fig. below). In other words, a symmetrical spat is a contrary flexure in which the radii of the two curves are the same.

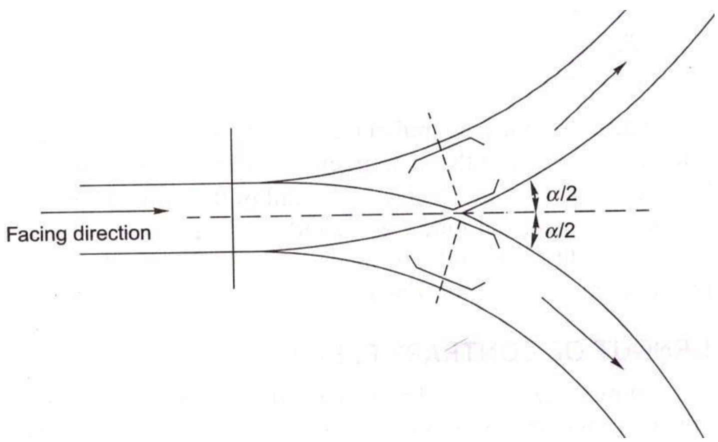


Fig. Symmetrical split

THREE-THROW SWITCH

In a three-throw arrangement, two turnouts take off from the same point of a main line track. Three-throw switches are used in congested goods yards and at entry points to locomotive yards, where there is much limitation of space. 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, that is, straight, to the right, and to the left. Three-throw switches are

* Under revision

obsolete now as they may prove to be hazardous, particularly at higher speeds, because the use of double switches may lead to derailments.

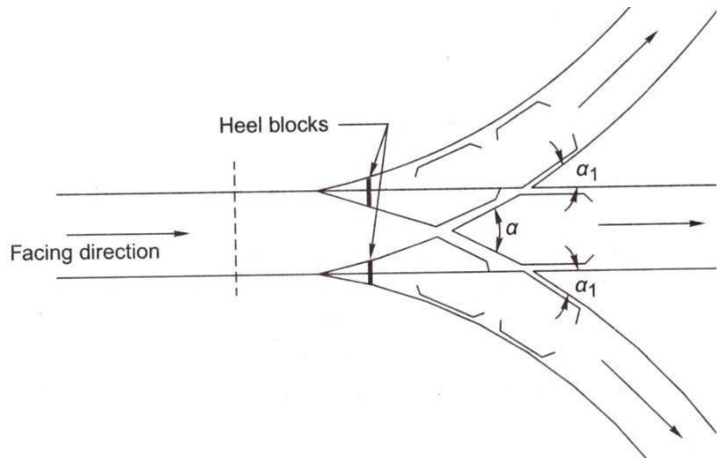


Fig Three-throw switch (contrary flexure)

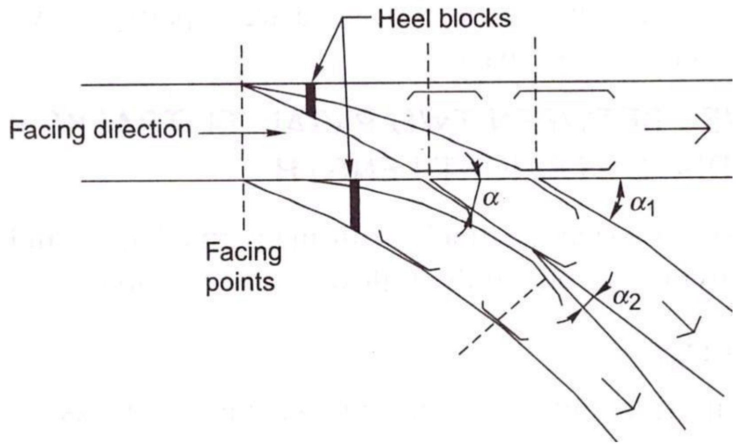


Fig. Three-throw switch (similar flexure)

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.

* Under revision

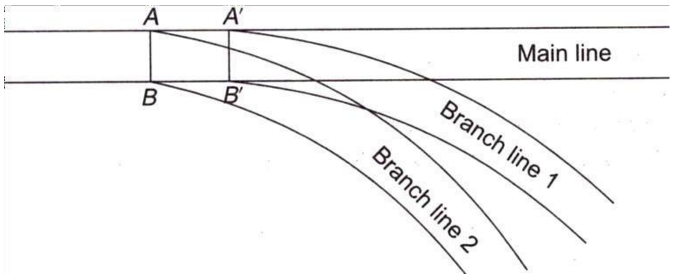


Fig. Double turnout with similar flexure

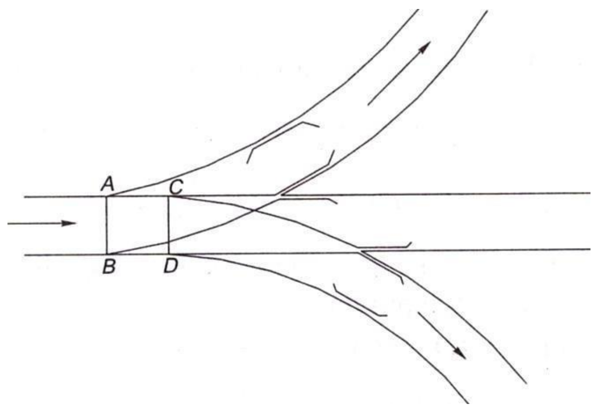


Fig. Double turnout with contrary flexure

Double turnouts are mostly used in congested areas, particularly where traffic is heavy, so as to economize on space.

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).

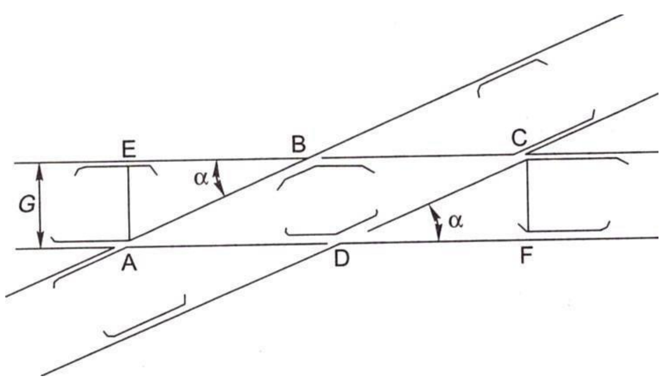


Fig. Diamond crossing

* Under revision

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.

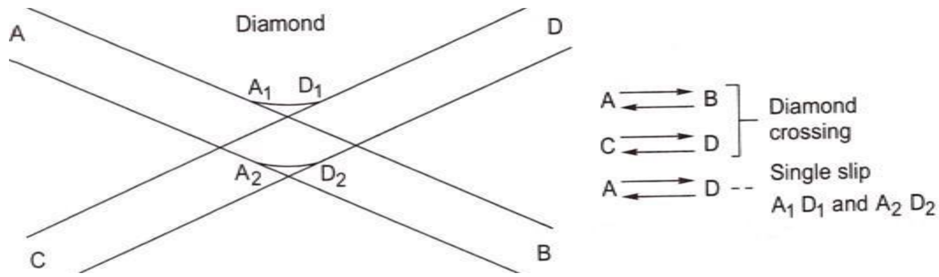


Fig. Single slip

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. the trains on both tracks A and C can move onto either track B or D.

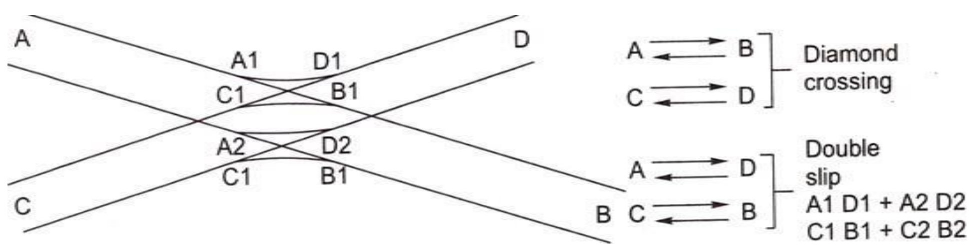


Fig. Double slip

SCISSORS CROSSOVER

A scissors crossover enables 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.

* Under revision

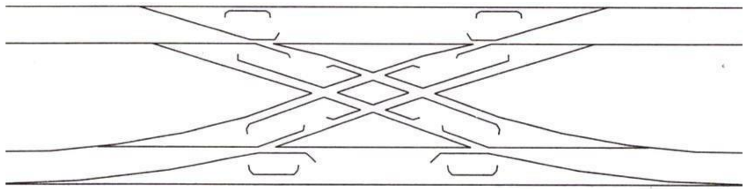


Fig. Scissors crossover

GAUNTLETTED TRACK

Gauntletted track 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 [(a)].

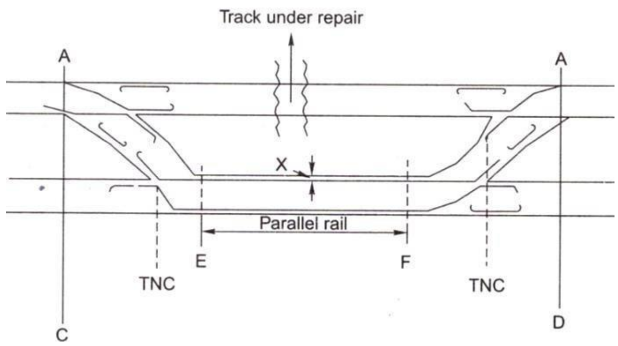


Fig. (a) Gauntletted track

Gauntletted tracks are also used on sections where trains have to operate on mixed gauges, say, both BG and MG, for short stretches. In such cases, both the tracks are laid on the same set of wooden sleepers [(b)].

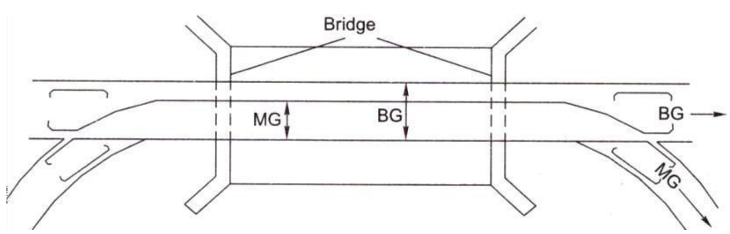
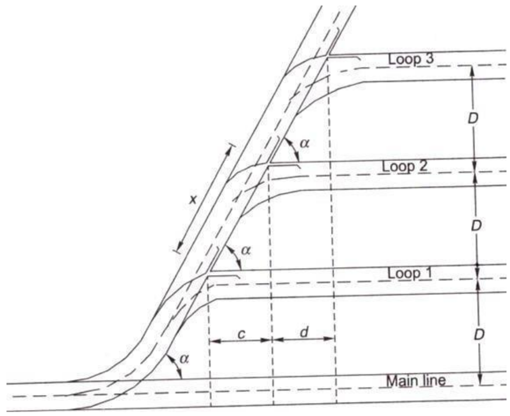


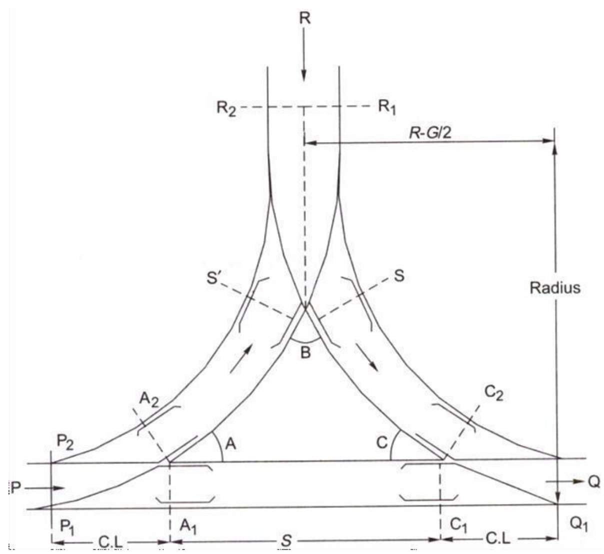
Fig. (b) Gauntletted track for mixed gauge

* Under revision

GATHERING LINE



TRIANGLE



DOUBLE JUNCTIONS

A double junction (Fig. below) 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.

*Under revision

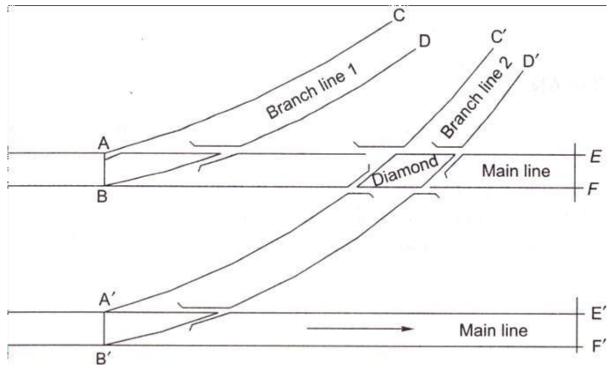


Fig. Double junction

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.

*Under revision

Lecture-26

SIGNAL-I

Introduction

In the early days of railway operation, there was seldom need for more than one train to operate on a section of track at any given time. As traffic increased, it became necessary to operate trains in both directions over single track. The purpose of signalling and interlocking is primarily to control and regulate the movement of trains safely and efficiently. Signalling includes operations and interlocking of signals, points, block instruments, and other allied equipment in a predetermined manner for the safe and efficient running of trains. Signalling enables the movement of trains to be controlled in such a way that the existing tracks are utilized to the maximum.

In fact, in railway terminology signalling is a medium of communication between the station master or the controller sitting in a remote place in the office and the loco pilot (As per latest instructions of the Railway Board, 'drivers' are now called 'Loco Pilots') of the train.

OBJECTIVES OF SIGNALLING

The objectives of signalling are as follows:

To regulate the movement of trains so that they run safely at maximum permissible speeds

To maintain a safe distance between trains those are running on the same line in the same direction

To ensure the safety of two or more trains that has to cross or approach each other

To provide facilities for safe and efficient shunting

To regulate the arrival and departure of trains from the station yard

To ensure the safety of the train at level crossings when the train is required to cross the path of road vehicles

CLASSIFICATION OF SIGNALS

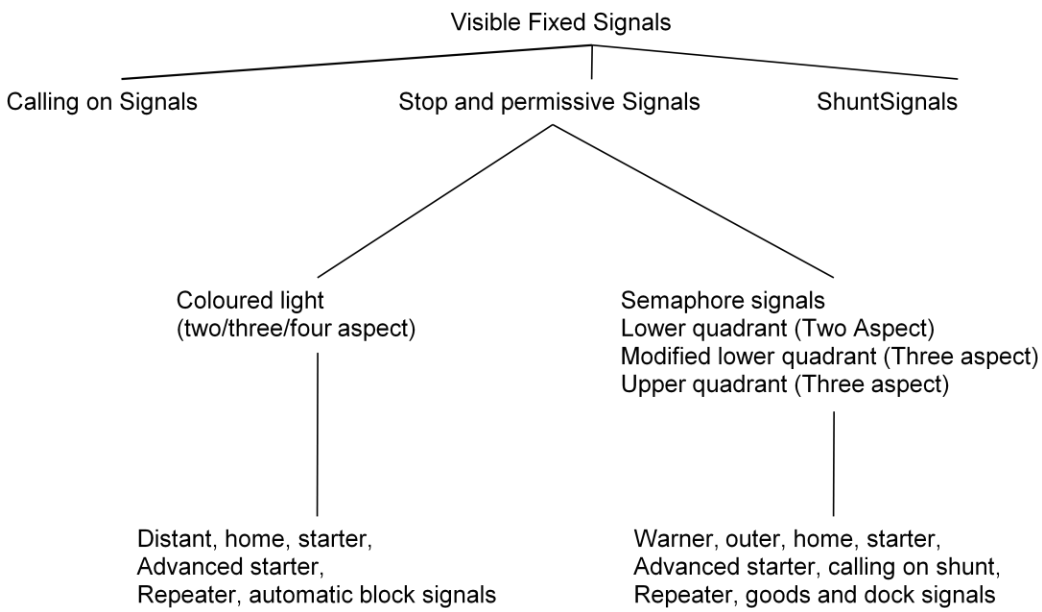
Railway signals can be classified based on different characteristics as presented in Table below.

Table: Classification of signals based on different characteristics

Characteristics	*Basis of classification*	*Examples*
Operational	Communication of message in visual form	Fixed signals
Functional	Signaling the loco pilot to stop, move cautiously, proceed, or carry out shunting operations	Stop signals, permissive Signals, shunt signals
Locational	Reception or departure signals	Reception: Outer, home, Departure: Starter, and advanced starter signals
Constructional	Semaphore or colour light signals	Semaphore: Lower quadrant or upper quadrant. Colour light: Two aspects or multiple aspects.
Special characteristics	Meant for special purposes	Calling-on signals, repeater signals, coaching signals, etc.

*Under revision

Figure. below shows further classification of signals and Table below lists the signalling requirements of various classes of stations.



Signals required at stations

Classification of station	Minimum requirement of signals	Remarks
A class	Warner, home, and starter	An outer signal can be provided after obtaining special permission
B class	Outer and home	In multiple-aspect upper quadrant (MAUQ) areas, distant home and outer signals are provided
C class	Warner and home	In MAUQ areas, the warner signal is replaced by a distant signal

FIXED SIGNALS

The various types of fixed signals used on railways are as follows.

Semaphore signals

The word 'semaphore' was first used by a Greek historian. 'Sema' means sign and 'phor' means to bear. A semaphore signal consists of a movable arm pivoted on a vertical post through a horizontal pin as shown in Fig. below.

*Under revision

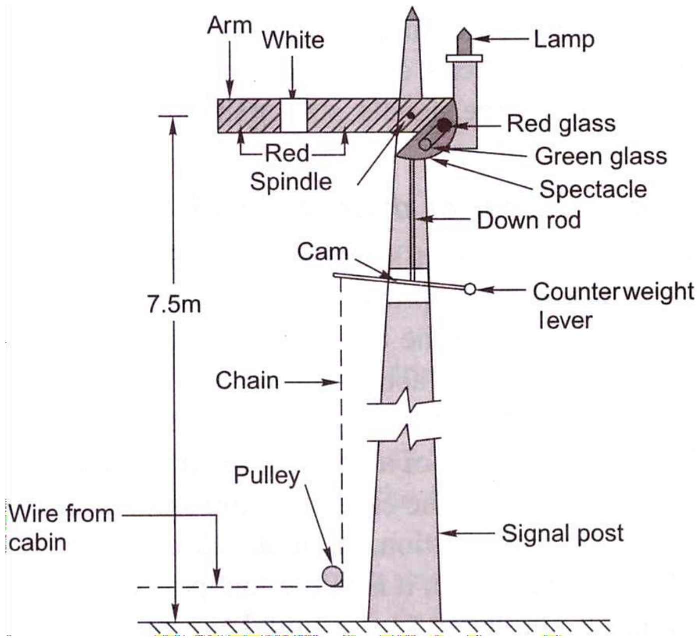


Fig. Semaphore signal

Lower quadrant semaphore signals move only in the fourth quadrant of a circle and have only two colour aspects. In order to provide the drivers with further information, multi-aspect upper quadrant signalling (MAUQ) is sometimes used on busy routes. In this system, the arms of the semaphore signals rest in three positions and the signals have three colour aspects, namely red, yellow, and green associated with the horizontal, 45° above horizontal and vertical directions, respectively. Details of MAUQ are given in subsequent paras.

Stop *signal in MAUQ, Signaling*

In case of multi-aspect upper quadrant (MAUQ) signaling of semaphore stop signal with a square ended arm, there may be three situations (Figure below) as indicated below in Table below:

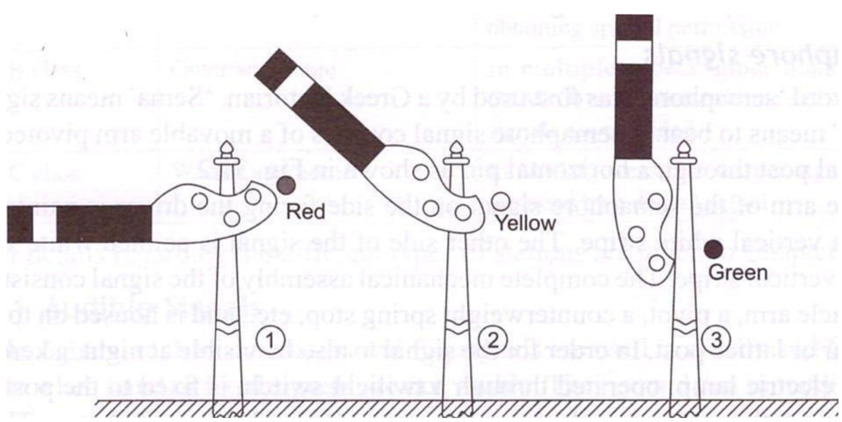


Fig. Semaphore stop signal in MAUQ signaling

*Under revision

Table Aspects and indications of stop signal in MAUQ signaling

Position	Aspect of signal	Position of arm	Colour during night	Indication
1.	ON-Stop	Horizontal	Red	Stop dead
2.	OFF-Caution	45° above Horizontal	Yellow	Proceed with caution and be prepared to stop at next signal
3.	OFF-Proceed	90° above Horizontal	Green	Proceed at maximum permitted speed

The signals are designed to be fail-safe so that if there is any failure in the working of the equipment, they will always be in the stop position. These signals are operated by hand levers or buttons located in a central cabin, which is normally provided near the station master's office. Semaphore stop signals are normally provided as outer signals, home signals, starter signals, advanced starter signals, and warner signals.

Permissive signal—warner or distant signal

In order to ensure that trains speed up safely, it is considered necessary that warning be given to drivers before they approach a stop signal. This advance warning is considered necessary, otherwise the drivers may confront a 'stop signal' when they least expect it and take abrupt action, which can lead to perilous situations. A warner or distant signal has, therefore, been developed, which is to be used ahead of a stop signal and is in the form of a permissive signal that can be passed even in most restricted conditions. In the case of a stop signal, the driver has to stop the train when it is in the 'on' position, but in the case of a permissive signal, the driver can pass through even when it is in the 'on' position.

***Distant signal in MAUQ,* signaling**

In case of multi-aspect upper quadrant (MAUQ) signaling for semaphore distant signal, there is a fish tailed arm, painted yellow with a black band near the edge of the arm (Fig. below). There are three aspects and indications of the same are presented in Table below.

*Under revision

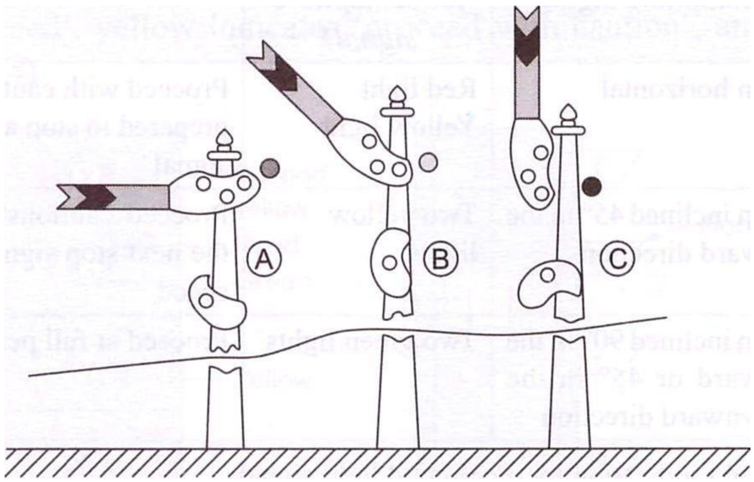


Fig. Semaphore distant signal in MAUQ signaling

Table Aspects and indications of distant semaphore signal in MAUQ signaling

Case	*Aspect of signal*	*Position of arms*	*Colour during night*	*Indications*
A	ON — Caution	Horizontal	Yellow light	Proceed and be prepared to stop at next stop signal.
B	OFF	45° above horizontal	Two yellow lights in vertical alignment	Proceed and be prepared to pass the next signal at caution.
C	OFF — Proceed	90° above horizontal	Green light	Proceed at maximum permitted speed.

In the case of signaling using colored light, the permissive signal is distinguished from the stop signal by the provision of a P marker disc on the signal post.

The warner signal is intended to warn the driver of a train regarding the following aspects as explained in Table below.

(a) To inform that the driver is approaching a stop signal

(b) To inform the driver as to whether the approach signal is in 'on' or 'off position

The warner signal can be placed at either one of the following locations.

(a) Independently on a post with a fixed green light 1.5 m to 2 m above it for night indication

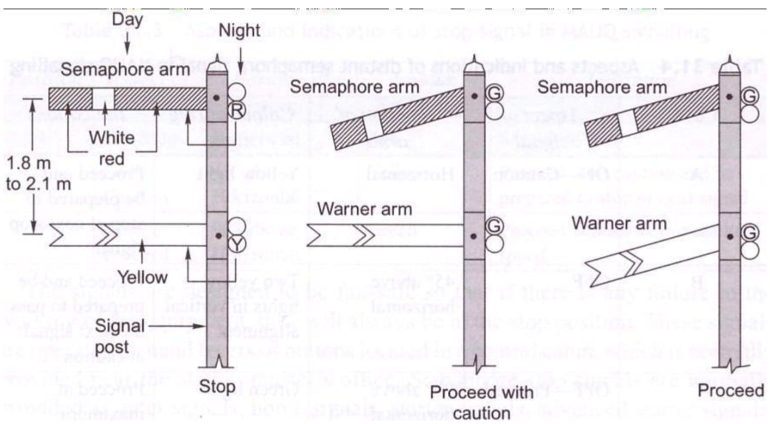
(b) On the same post below the outer signal or the home signal

In case a warner is fixed below an outer signal the various positions of the outer and warner signals and their corresponding indications are given in Fig. below.

* Under revision

Table: Position of warner arm or distant signal

Position	*Day indication for semaphore signal*	*Night indication for semaphore signal**	*Aspect*
Caution	Arm horizontal	Red light Yellow light	Proceed with caution and be prepared to stop at the next stop signal
Attention	Arm inclined 45° in the upward direction	Two yellow lights	Proceed cautiously so as to pass the next stop signal at a restricted speed
Proceed	Arm inclined 90° in the upward or 45° in the downward direction	Two green lights	Proceed at full permissible speed



* Under revision

Lecture-27

SIGNAL-II

STOP SIGNALS

The various types of stop signals with reference to their location on a station are discussed here in detail.

Outer signal on double-line section

This is the first semaphore stop signal at a station that indicates the entry of a train from a block section into the station limits. This signal is provided at an adequate distance beyond the station limits so that the line is not obstructed once the permission to approach has been given. It is provided at a distance of about 400 m from the home signal. The signal has one arm but has a warner signal nearly 2 m below on the same post.

Home signal on double-line section

After the outer signal, the next stop signal towards the station side is a home signal. It is provided right at the entrance of the station for the protection of the station limits. The signal is provided about 50 m short of the points and crossings. The arms provided on a home signal are generally as many as the number of reception lines in the station yard. The signal for the main line is provided on a 'doll', which is higher than others.

Routing signal

The various signals fixed on the same vertical post for both main and branch lines are known as routing signals. These signals indicate the route that has been earmarked for the reception of the train. Generally, the signal for the main line is kept at a higher level than that for the loop line. It is necessary for the driver of a train approaching a reception signal to know the line on which his or her train is likely to be received so that he or she can regulate th speed of the train accordingly. In case the train is being received on the loop li 3, the speed has to be restricted to about 15 km per hour, whereas if the reception s on the main line, a higher speed is permissible.

Signaling arrangement under Modified Lower Quadrant Signaling System

Since lower quadrant semaphore two aspect signaling system is capable of conveying limited information to the loco pilot, the arrangement was modified to be known as Modified Lower

* Under revision

Quadrant Signaling. In this an arrangement a warner is provided on the same doll as that of mainline home signal. see Fig. below.

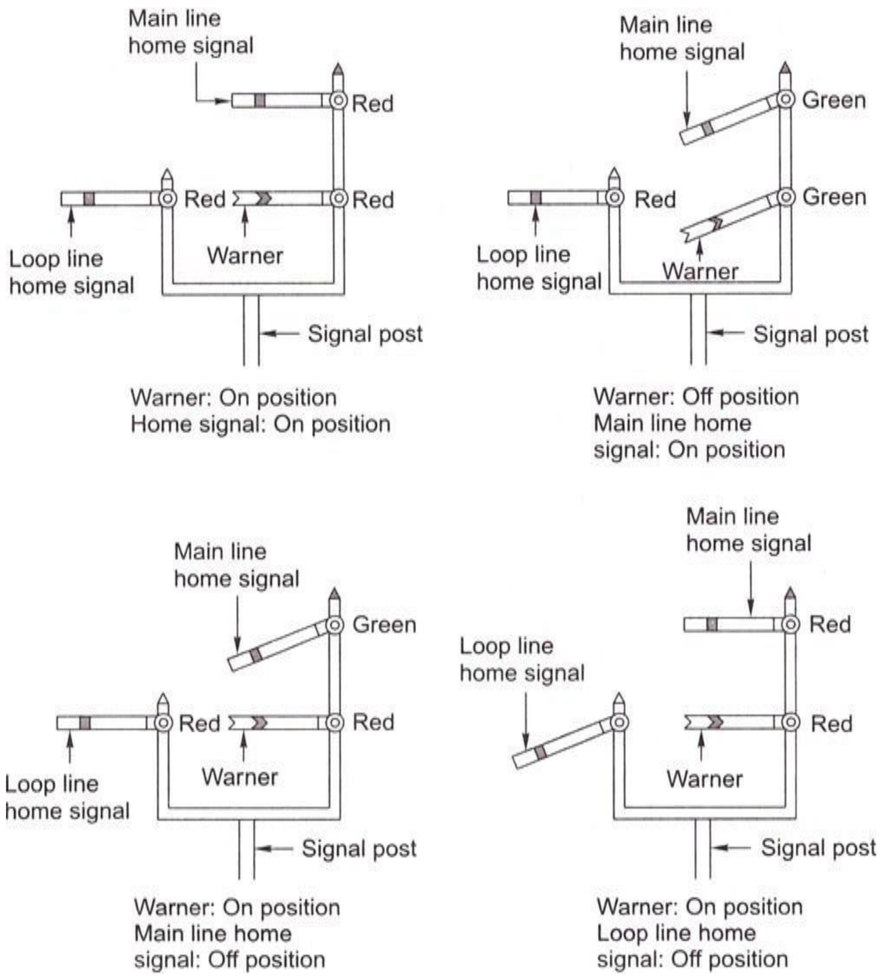


Fig. Modified lower quadrant signaling arrangement

Route indicators can also be provided by including separate home signals foi each line, with the main line home signal being placed the highest while all the other signals are placed at the same level.

In the case of coloured light signals, the home signal is provided with either a graphic lighted route indicator displaying the line number on which the train is to be received or different arms lighted by five lamps. These lamps form the arm. which is used for indicating a line, while there is no arm in the case of a main line as depicted in Fig. below.

* Under revision

Starter signal

The starter signal is a stop signal and marks the limit upto which a particular line can be occupied without infringing on other lines. A separate starter signal is provided for each line. The starter signal controls the movement of the train when it departs from the station. The train leaves the station only when the starter signal is in the 'off position. As this signal controls the departure of a train, it comes under the category of departure signals.

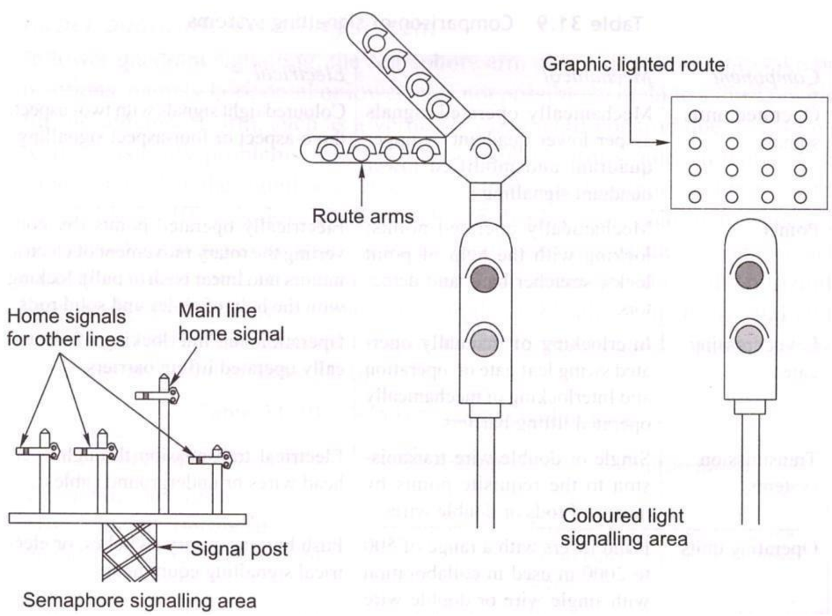


Fig. Route indicators in semaphore and colour light signalling areas

Advanced starter signal

This is the last stop signal provided for the departure of trains from a station. The signal is provided beyond the outermost points or switches and marks the end of the station limits. A block section lies between the advanced starter signal of one station and the outer signal of the next station. No train can leave the station limits until and unless the advance starter is taken off.

SIGNALLING SYSTEMS

The signalling system can be broadly classified into two main categories.

(a) Mechanical signalling system

(b) Electrical signalling system

In addition to these two main categories of signalling systems, electronic or solid-state signalling system is also in use. Each system of signalling comprises five main components.

* Under revision

(a) Operated units such as signals and points

(b) Interlocking system

(c) A transmission system such as single- or double-wire transmission or electrical transmission through cables

(d) Operating units such as levers and press buttons

(e) Monitoring units such as detectors, treadle bars, and track circuits

The comparison between mechanical and electrical signalling based on these five broad components is given in Table below.

Table : Comparison of signalling systems

Component	*Mechanical*	*Electrical*
Operated units signals	Mechanically operated signals as per lower quadrant or upper quadrant and modified lower quadrant signalling	Coloured light signals with two- aspect, three-aspect or four-aspect signalling
Points	Mechanically operated points; locking with the help of point locks, stretcher bars, and detectors	Electrically operated points (by converting the rotary movement of electric motors into linear push or pull); locking with the help of slides and solid rods
Level crossing gates	Interlocking of manually operated swing leaf gate or operation and Interlocking of mechanically operated lifting barriers	Operation and Interlocking of electrically operated lifting barriers
Transmission systems	Single or double wire transmission to the requisite points by means of rods or double wires	Electrical transmission through overhead wires or underground cables
Operating units	Hand levers with a range of 500 to 2000 m used in collaboration with single wire or double wire lever frames	Push buttons, rotary switches, or electrical signalling equipment
Interlocking units	Mechanical interlocking with plungers attached with levers and tappets moving across in a locking trough	Interlocking through electromagnetic switches known as relays or solid-state switching devices
Monitoring units	Monitoring of points with the help of mechanical detectors; monitoring of the passage of trains using a treadle, which is an electro-mechanical device	Monitoring with the help of direct current track circuits, alternating current track circuits, electronic track circuits, axle counters, etc.

* Under revision

MECHANICAL SIGNALLING SYSTEM

The mechanical signalling system mostly involves signals and points as explained in this section. In this system, both the signalling system and the interlocking are managed mechanically.

Signals

The signals used in a mechanical signalling system are semaphore signals. These signals are operated by means of either a lower quadrant or an upper quadrant signalling system.

Lower quadrant signalling system

This system of signalling was designed so that the semaphore arm of the signal could be kept either horizontal or lowered. The lower left-hand quadrant of a circle is used for displaying a semaphore indication to the driver of a train. This concept was possibly developed based on the left-hand driving rules applicable on the roads in UK and India.

Upper quadrant signalling system

In lower quadrant signalling, the semaphore arm of the signal can only take two positions, namely horizontal or lower; it is not possible to include a third position for the semaphore arm, such as a vertically downward position due to design as well as visibility problems, since as the semaphore arm would, in that case, be superimposed on the signal post. Due to this limitation, the upper quadrant system (see Table 31.10) was developed, which can display more than two aspects. In this system, it is possible to incorporate three positions of the semaphore arm, namely (a) horizontal, (b) inclined at an angle of about 45° above the horizontal level, and (c) vertical, i.e., inclined at an angle of 90° above the horizontal level, see Fig. below. The positions of the arm, the corresponding indications, and their meanings are listed in Table below.

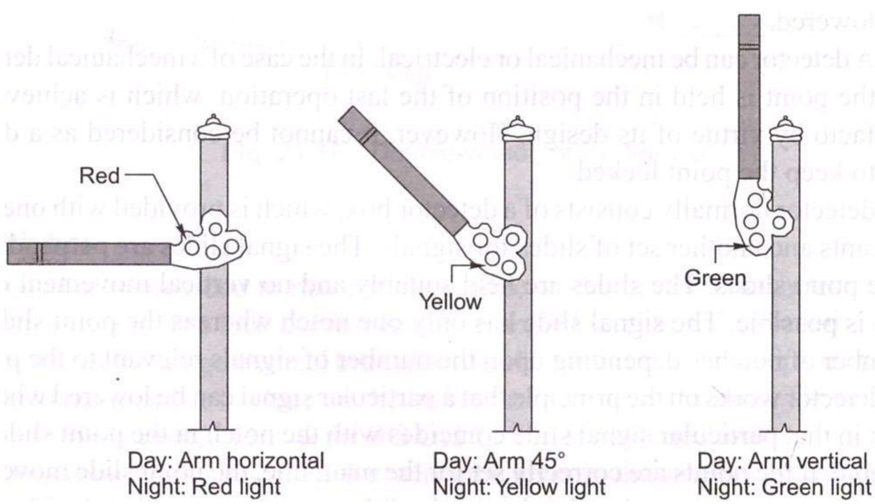


Fig. Upper Quadrant signalling

* Under revision

Lecture-28

SIGNAL-III

COLOURED LIGHT SIGNALS

These signals use coloured lights to indicate track conditions to the driver both during the day and the night. In order to ensure good visibility of these light signals, particularly during daytime, the light emission of an electric 12 V, 33 W lamp is passed through a combination of lenses in such a way that a parallel beam of focused light is emitted out. This light is protected by special lenses and hoods and can be distinctly seen even in the brightest sunlight. The lights are fixed on a vertical post in such a way that they are in line with the driver's eye level. The system of interlocking is so arranged that only one aspect is displayed at a time. Coloured light signals are normally used in automatic signalling sections, suburban sections, and sections with a high traffic density

Coloured light signals can be of the following types.

(a) Two-aspect, namely green and red

(b) Three-aspect, namely green, yellow, and red

(c) Four-aspect, namely green, double yellow, and red

In India, mostly three-aspect or four-aspect coloured light signalling is used. In the case of three-aspect signalling, green, yellow, and red lights are used. Green indicates 'proceed', yellow indicates 'proceed with caution', and red indicates 'stop'(Fig. below).

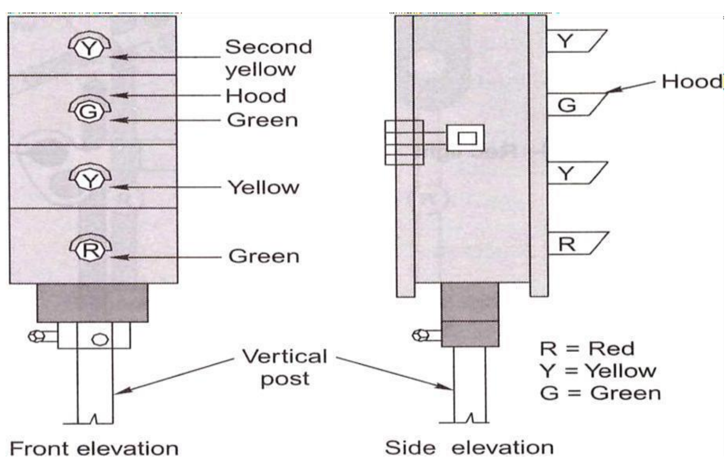


Fig. Colored light signals

* Under revision

In the case of four-aspect colored light signaling, the interpretations of the colours are given in Table below.

Table : Indications of colored light signals

Colour of signal	Interpretation
Red	Stop dead
Yellow	Pass the signal cautiously and be prepared to stop at the next signal
Two yellow lights together	Pass the signal at full speed but be prepared to pass the next displayed signal, which is likely to be yellow, at a cautious speed
Green	Pass the signal at full permissive speed

In conventional semaphore signals, the 'on' position is the normal position of the signal and the signals are lowered to the 'off' position only when a train is due. In the case of coloured light signals placed in territories with automatic signalling, the signal is a\way green or in the 'proceed' position. As soon as a train enters a section, the signal changes to 'red' or the 'stop' position, which is controlled automatically by the passage of the train itself. As the train passes through the block section, the signal turns yellow to indicate the driver to 'proceed with caution' and, finally, when the train moves onto the next block section, the signal turns green indicating to the driver to 'proceed at full permissible speed'.

Thus, it can be seen that each aspect of the signal gives two pieces of information to the driver. The first is about the signal itself and the second is about the condition of the track ahead or of the next signal. This helps the driver to manoeuvre the train safely and with confidence even at the maximum permissible speed.

Calling-on signal

This consists of a small arm fixed on a home signal post below the main semaphore arm. When the main home signal is in the horizontal (on) position and the calling-on signal is in an inclined (off) position, it indicates that the train is permitted to proceed cautiously on the line till it comes across the next stop signal. Thus, the calling-on signal is meant to 'call' the train, which is waiting beyond the home signal.

* Under revision

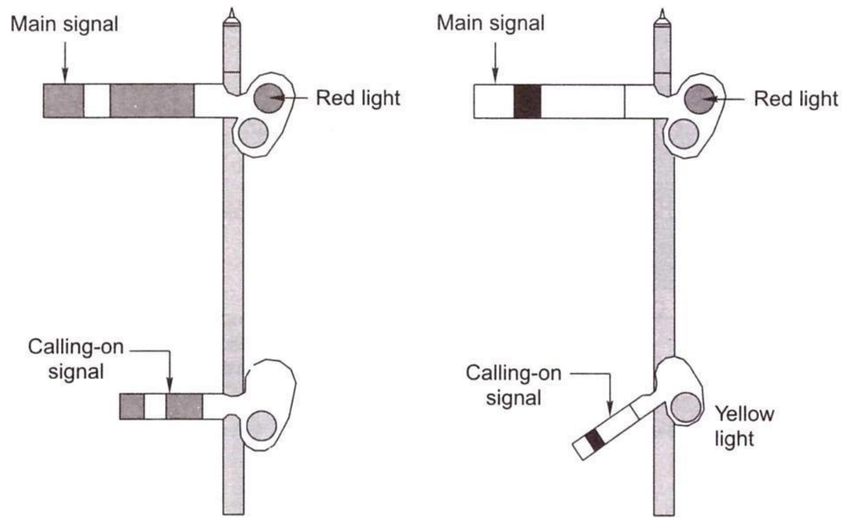


Fig. Calling-on signal

The calling-on signal is useful when the main signal fails, and in order to move a train, an authority letter has to be sent to the driver of the waiting train to instruct him/her to proceed to the station against what is indicated by the signal. In big stations and yards, the stop signals may be situated far off from the cabin and the calling-on signal expedites the quick reception of the train even when the signal is defective.

Co-acting signal

In case a signal is not visible to the driver due to the presence of some obstruction, such as an overbridge or a high structure, another signal is used to move along the main signal on the same post. This signal, known as the co-acting signal, is an exact replica of the original signal and works in unison with it.

Repeater signal

In case where a signal is not visible to the driver from an adequate distance due to sharp curvature or any other reason or where the signal is not visible to the guard of the train from his position at the rear end of a platform, a repeater signal is provided at a suitable position at the rear of the main signal. A repeater signal is provided with an R marker and can be of the following types.

(a) A square-ended semaphore arm with a yellow background and a black vertical band

(b) A colored light repeater signal

(c) A rotary or disc banner type signal

The 'off positions of these three types of repeater signals are depicted in Fig. below.

* Under revision

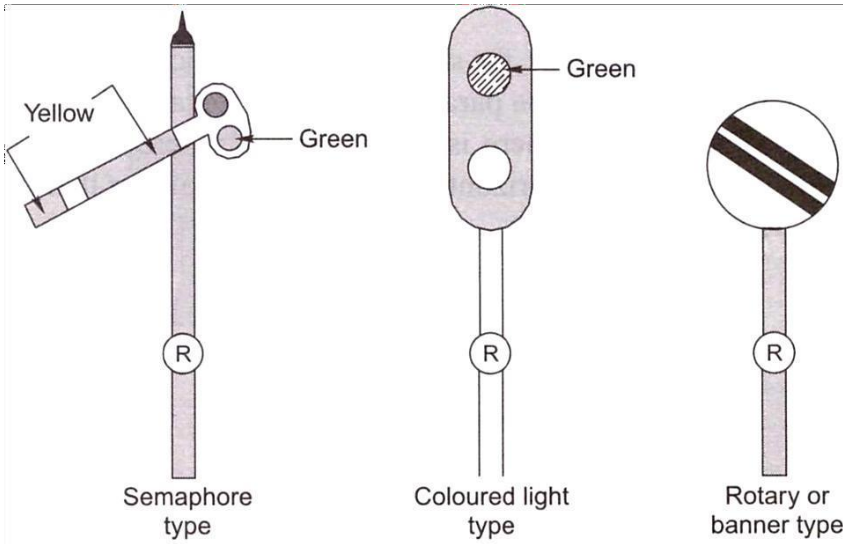


Fig. Different types of repeater signals

Shunt *signals*

These are dwarf or miniature signals and are mostly used for regulating the shunting of vehicles in station yards. Unlike fixed signals, these are small in size and are placed on an independent post or on a running signal post (Fig. below). In semaphore signaling areas, the shunt signals are of the disc type.

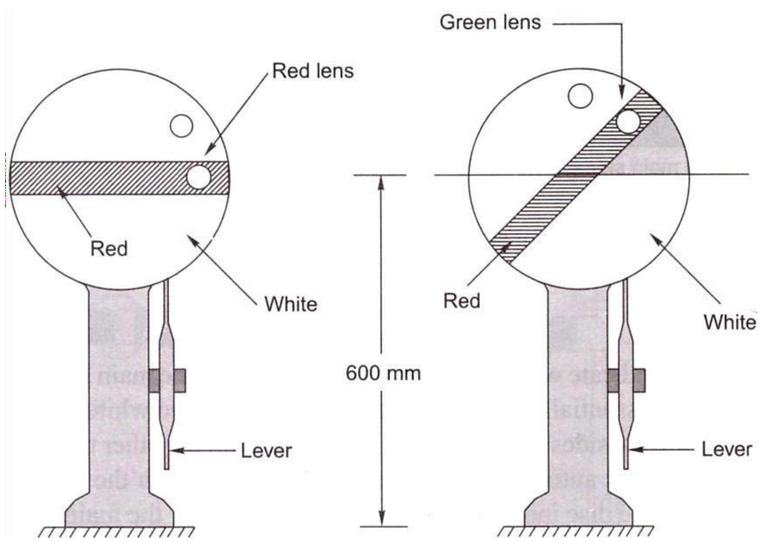


Fig. Disc type shunt signals

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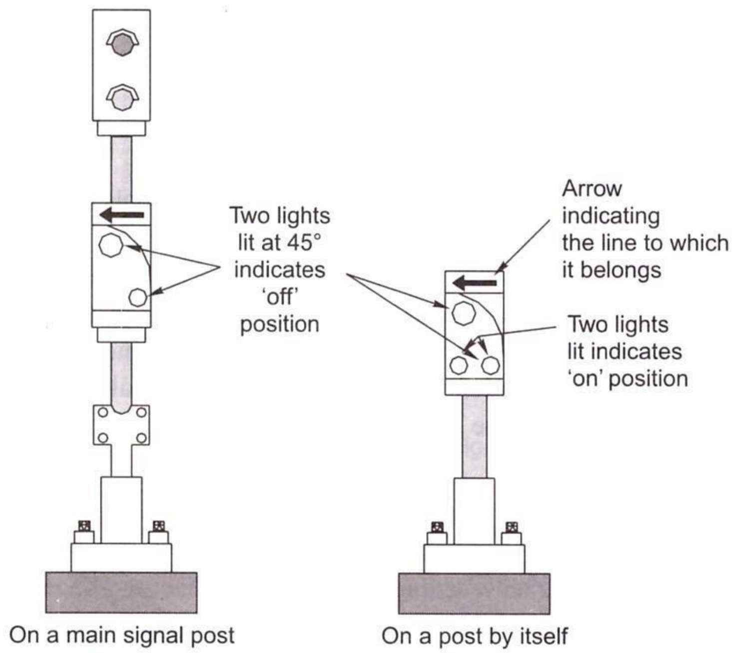

Point indicators

These are used to indicate whether points have been set for the main line or turnout side (Fig. below). It essentially consists of an open box with two white circular discs forming two opposite sides of the box and green bands on the other two remaining sides. The box rotates automatically about a vertical axis with the movement of the points. The white disc indicates that the points are set for the main line. When the points are set for the turnout side, the green bands are visible to the loco pilot (driver). At night white light indicates a main line setting and green light signifies a turnout side settings.

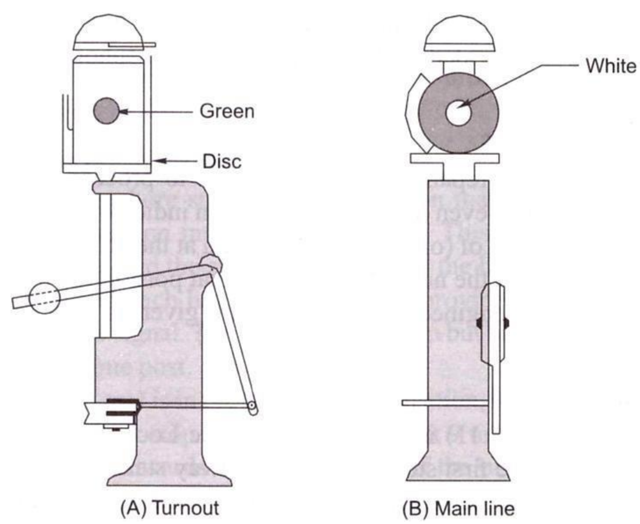

Fig. Point indicators

* Under revision

Trap indicator

A trap is a device fitted on the track, which in its open position derails the vehicle that passes over it. When the trap is closed, the vehicle passes over it as it would over a normal track. A trap indicator reveals whether the trap is in an 'open' or 'closed' position. The details of the same are given in Table below.

Table Operation of a trap indicator

Position of trap	*Day indication*	*Night indication*
Trap open	Red target	Red light
Trap closed	Green target	Green light

Dock signal This signal leads the train to the dock platform. In this case, the semaphore reception signal is provided with a stencil-cut letter 'D' on the signal for use. Figure (a) below shows the 'on' position of the dock signal.

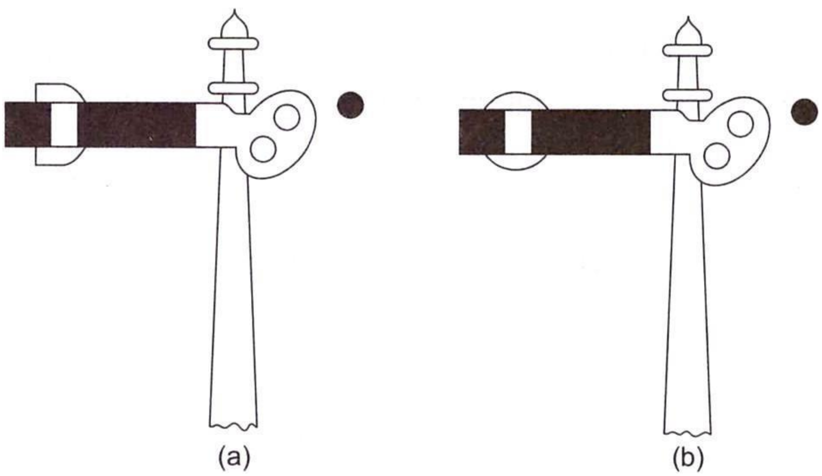

Fig. (a) Dock signal (on position) and (b) Goods signal (on position)

Goods signal This signal leads the train to the goods running line. In this case a stencil-cut letter 'O' is provided on the signal arm of a semaphore signal as shown in Fig. (b) above.

Engineering *indicators*

When the track is under repair, trains are required to proceed with caution at restricted speeds and may even have to stop. Caution indicators help the driver of a train to reduce the speed of (or even stop) the train at the affected portion of the track and then return it to the normal speed once that portion has been covered.

* Under revision

Sighting board

A sighting board (Fig. below) is an indication to the Loco pilot (driver) that he or she is approaching the first stop signal of a railway station. The function of a sighting board is to allow the driver to estimate the location of the next stop signal from the current location so that he/she starts applying brakes in case the first stop signal is in an 'on' position.

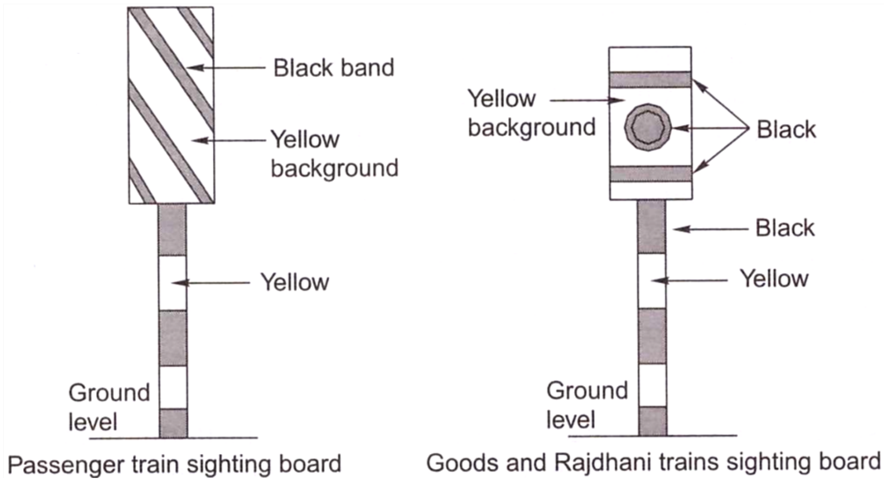

Fig. Sighting board

As the requisite braking distance of goods trains and Rajdhani trains is greater than that of the passenger trains, the sighting boards for goods trains and Rajdhani trains are located farther and their design is different from that of sighting boards meant for passenger trains. The distances of sighting boards are listed in Table below.

Table : Positions of sighting boards

Type of sighting board	*Position*
Passenger train sighting board	1000 m for speeds over 72 kmph for BG tracks and 48 kmph for MG tracks
Goods trains and Rajdhani sighting board	1400 m for speeds over 72 kmph for BG tracks and 48 kmph for MG tracks

* Under revision

Lecture-29

PRINCIPLES OF INTERLOCKING-I

Points

Points are set mechanically and are kept in locks and stretcher bars. The mechanical arrangement for operating them includes a solid rod with a diameter of 33 mm running from the lever provided in the cabin and connected to the point through cranks and compensators. Owing to transmission losses, the operating points with rods is restricted to a specified distance from the cabin.

The following devices are used to ensure that the points are held rigidly in the last operated position under a moving train and to ensure absolute integrity of the same.

(a) Point locks to hold the point in the required position and to rigidly hold the point in the position of the last operation

(b) Facing point lock with lock bars to prevent the movement of points when a train is passing over them

Point locks

A point lock is provided to ensure that each point is set correctly. It is provided between two tongue rails and near the toe of the switch assembly. The point lock consists of a plunger, which moves in a plunger casing of facing point lock. The plunger is worked by means of a plunger rod, which is connected to the signal cabin through a lock bar. Additionally, there is a set of stretcher blades and each blade is connected to one of the tongue rails. Each blade has two notches and they move inside the facing point lock plunger casing along with the tongue rails. When the points are set correctly for a particular route, the notch in the stretcher blade rests in its proper position and the plunger rod enters the notch, locking the switch in the last operated position.

Detectors

Detectors are normally provided for all the points for the following reasons.

(a) To detect any defect or failure in the connection between the points and the lever as well as any obstruction between the stock and the tongue rail.

(b) To ensure that the correct signal, which corresponds to the point set, is lowered.

* Under revision

(c) Adetector can be mechanical or electrical. In the case of a mechanical detector, the point is held in the position of the last operation, which is achieved de facto by virtue of its design. However, it cannot be considered as a device to keep the point locked.

A detector normally consists of a detector box, which is provided with one slide for points and another set of slides for signals. The signal slides are perpendicular to the point slides. The slides are held suitably and no vertical movement of the same is possible. The signal slide has only one notch whereas the point slide has a number of notches depending upon the number of signals relevant to the points. The detector works on the principle that a particular signal can be lowered when the notch in that particular signal slide coincides with the notch in the point slide. For example, if the points are correctly set for the main line, the point slide moves and its notch comes to rest opposite the notch of the main line signal slide. The main line signal slide can then be pulled and the main line signal lowered. It may be noted here that the point slide will move and its notch will rest in its correct position only if the points are properly set and there is no obstruction in between.

The linear type (or slide type) of mechanical detector is used for single-wire signalling (Fig. a below), whereas the rotary type of detector (Fig. b below) is used for the double-wire signalling. A double-wheel detector is a rotary-type detector that rotates in a vertical plane. It detects the correct setting of points and, in addition, locks the points in the last operated position in the case of wire breakage.

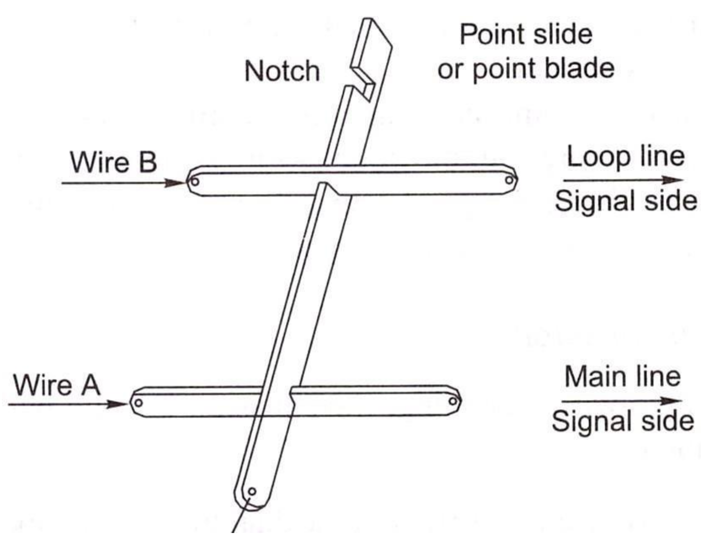

Fig. a Mechanical detector for single-wire signalling

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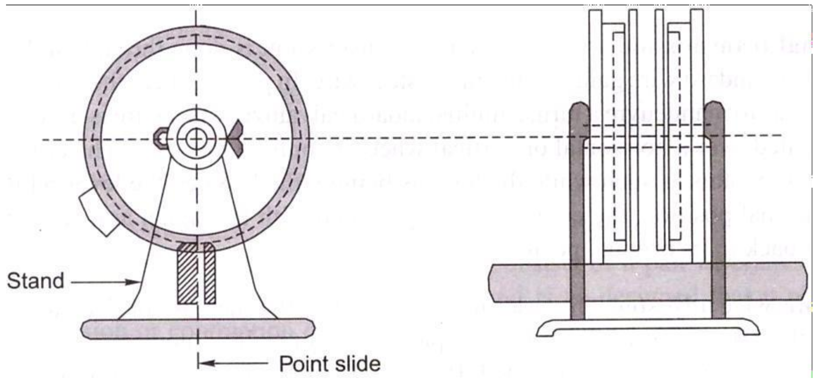

Fig. b Double-wheel rotary detector

Lock bar

A lock bar is provided to make it impossible to change the point when a train is passing over it. The lock bar is made of an angled section and its length is greater than that of the longest wheel base of a vehicle. Short revolving clips are provided to hold the lock bar in place on the inside face of one of the rails. The length of a lock bar is normally 12.8 m for BG and 12.2 m for MG sections. The system is so designed that when the lever in the cabin is pulled to operate the locking device, the lock bar rises slightlv above the rail level and then comes down. In the occurrence that a vehicle is positioned on the same location, the lock bar cannot rise above the rail level due to the flanges of the wheel and as such the point cannot be operated.

Types of Transmission Systems

A signal is operated by pulling the associated lever and this action is transmitted through a single-wire or double-wire system. Initially, the single-wire system was the most popular way of operating signals and, in fact, some stations on Indian railways still use this system.In the single-wire system, only one wire is stretched between the operating lever and the signal, whereas in the double-wire system a loop of two wires that run parallel to each other is wrapped over a drum lever and this system works on the principle of the pull and push arrangement.

- ✓ ***Single-wire transmission***
- ✓ **Lever frame**
- ✓ **Signal transmission wire**
- ✓ **Cabin wire adjuster**
- ✓ **Signal parts and fitting**
- ✓ ***Limitations of single-wire signaling***

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Rod transmission In the single-wire transmission system, the signal is lowered or set in the 'off' position by pulling the lever. The signal returns to the 'on' position due to the effect of gravity as soon as the lever is restored to its normal position and the tension in the wire is released.

Where the operation of points is concerned, the points have to be set in either the normal or the reverse position; one of these positions can be attained through pulling and the other by pushing. Solid rods of 30 mm (11/4 ") diameter are used to connect the levers to the points. The rods or pipes move on standard roller guides fixed at about 2 m (6 ft) intervals. A suitable crank is also used at every change of direction. The rods are subjected to expansion and contraction due to temperature variations and as such are provided with rod compensators at designed intervals.

Rod *temperature compensator*

A rod compensator, also known as a temperature compensator, is provided to neutralize the effect of thermal variations. It consists of a pair of cranks—one acute and one obtuse—connected by a link and is so designed that it absorbs the expansion or contraction due to temperature variations. The compensator is normally placed at the centre of the rod upto a length of 36.5m. If more than one compensator is required, these are placed at quarter points.

As can be seen in Fig. below, the points, A or B may move left or right, but the total distance between them remains the same.

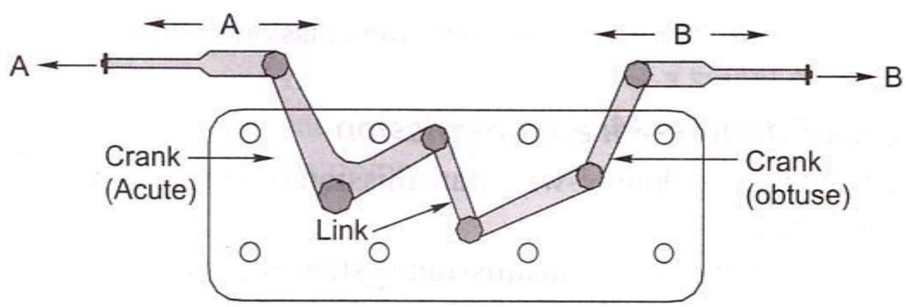

Fig. Temperature compensator

Double-wire transmission system

In this system, power is transmitted with the help of two wires from the lever to operated units, such as signals, points, locks, detectors, and so on. Each wire consists of eight to ten SWG solid galvanized steel wires attached to pulley stakes, which are driven firmly into the ground. The two wires are connected between the lever and the signal to form a continuous loop. When the

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lever is operated, it leads to the wire getting pulled and when the lever is brought back to its normal position, it results in a push to the wire. This pull and push mechanism (Fig. a below) causes the drum to rotate in one direction when the lever is pulled and in the other direction when it is restored to its normal position. The rotary motion of the drum is then converted into linear movement by the use of cams and cranks and this finally actuates the signal. Figure b below shows the complete double-wire transmission system.

It may be brought out that double-wire compensators are provided in the wire run to always keep the same tension in the wire.

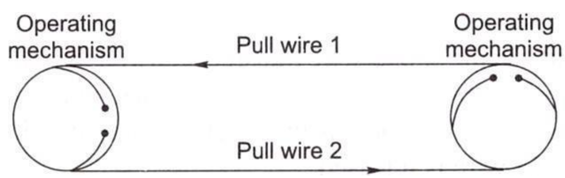

Fig: a Double wire mechanism

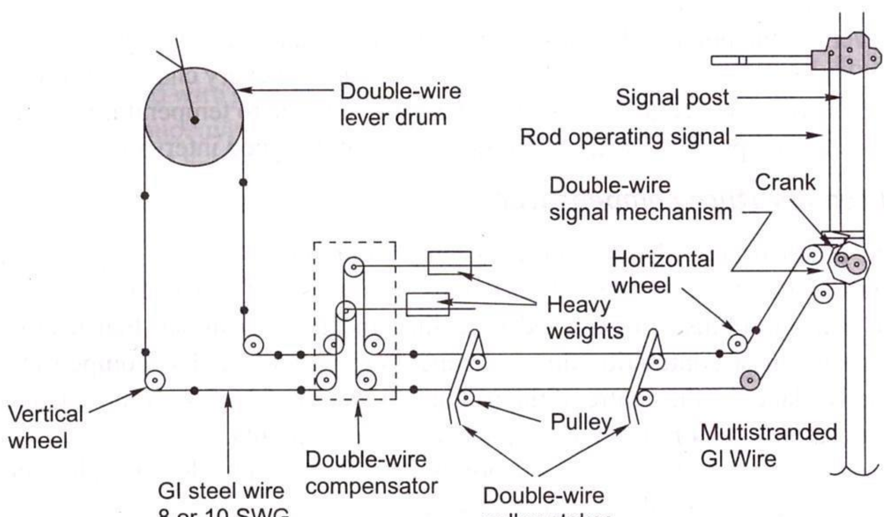

Fig: b Double wire Transmission system

Table below compares a signal-wire and a double-wire signalling system. The special features of a double-wire signalling system are as follows.

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ELECTRICAL SIGNALLING SYSTEM

The electrical signalling system is progressively replacing the mechanical signalling system on Indian Railways, especially with the coming up of railway electrification projects facilitating availability of electric power reading. The main reasons behind this are as follows.

(a) There are a number of movable parts in the mechanical signalling system, such as rods, wires, and cranks, which cause heavy wear and tear, frictional losses, and many of these parts can be sabotaged by unauthorized persons.

(b) The arms of the semaphore signals used in mechanical signalling afford poor visibility during the day. The night indications of these signals are also not satisfactory.

(c) The operational time of the mechanical signalling system is much greater than that of the electrical signalling system.

In the electrical signalling system, electrical energy is used for displaying signal aspects. The transmission of power is done electrically and the units are operated by electrical push buttons while the system is monitored by electrical systems. The interlocking in this system is also done electrically.

In the case of electronic or solid state signalling system, the signals are operated by the electrical method, but the interlocking is done electronically.

System of electronic interlocking For electronically managed interlocking system a computer and mouse is used for controlling the signalling system; however, a panel is also used with a switch to change the mode of control from a panel to a visual display unit (VDU).

As control of the signalling system is carried out by a VDU and a mouse, the portion of the signal and interlocking plan shall be selected for taking off the concerned signal by clicking on to the signal profile on the VDU. The system shall work within, following the same principles as in case of electrically interlocked system but analyse the requirements electronically and energize the relays in the form of the final command to operate points and make the concerned signal off.

Operated Units

The operated units consist of signals and points. The electrical signalling system consists of either coloured light signals or signals with semaphore arms operated by electric motors.

A point is operated by converting the rotary movement of the electrical point machines fastened on the sleepers near the point into a linear push or pull force. There are low-voltage point machines operated with a 24 V dc supply and high-voltage point machines operated using a 110

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V dc supply. The operation of a point machine involves first unlocking the lock, bringing the point from normal to reverse or reverse to normal as the case may be, and then locking the point once again. The operating time of these point machines varies between three and five seconds.

Transmission Medium

The medium of transmission for operating electrical equipment is either an overhead alignment or an underground copper cable. The overhead alignment is used when the number of conductors is limited. In areas provided with 25 kV ac traction, it is not possible to use overhead alignments due to the induced electromotive force (EMF) generated as a result of electrostatic and electromagnetic induction. In big yards, cables are used as a medium of transmission for the operation of point machines. The cables are either hung on hooks and run by the side of the track or laid underground. In areas provided with ac traction, underground screened cables are used.

Operating System

Normally push buttons and rotary switches are used for operating signalling equipment that work on electricity. The complete yard layout is represented on the face of a console. Signals, tracks, points, and the gates of level crossings are depicted in their geographical positions on this console and the positions of these switches are then marked at the foot of signals and on various tracks.

Complete interlocking is achieved through electromagnetic switches known as *relays*. The two methods of interlocking available are panel interlocking or route relay interlocking.

Pressing of two buttons on the operating console checks clearance of route; if found clear, sets the route by operating points automatically by the system and then locks the route, takes the concerned signal off. This is known as route relay interlocking, often called on smaller stations as 'panel interlocking' as a misnomer.

Monitoring System

A monitoring system mainly consists of point detectors, track circuits, and axle counters, all of which are discussed here in detail.

Electrical point detector

The electrical point detector detects and ensures that points are properly set. It also works on a 'slide system' as used in the mechanical system. These slides are so adjusted that a gap of 3 mm is left between the switch rail and the stock rail so that the two do not come in contact and, therefore, it is not possible to turn the signal off at any time.

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Track circuit

The track circuit is an electric circuit formed along with the running rails and connected to the signal and cabin. Its function is to indicate the presence of a train (or vehicle) on the track. In order to set up a track circuit, the ends of the rails forming the circuit are isolated by insulating the rail joints.

The various types of track circuits used on the Railways are as follows.

(a) Direct current track circuit

(b) Alternating current track circuit

(c) Electronic track circuit, which are audio-frequency track circuits

Axle counters

As already mentioned, two consecutive rails need to be insulated from each other for setting up a track circuit. A pair of rail inductors are installed at either end of the track for counting the axles. As soon as a train enters the track section from one end, the number of axles entering the section are counted automatically. Similarly, when the train leaves the track section at the other end, the axles are counted once again at the other end.

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Lecture-30

PRINCIPLES OF INTERLOCKING-II

INTERLOCKING

Interlocking is a device or a system meant to ensure the safety of trains. With the increase in the number of points and the signals and introduction of high speeds, it has become necessary to eliminate human error, which would otherwise lead to massive losses of life and property. The points and signals are set in such a way that the cabin man cannot lower the signal for the reception of a train unless the corresponding points have been set and locked. The signal is thus interlocked with the points in a way that no conflicting movement is possible and the safety of trains is ensured. Interlocking may therefore, be defined as a technique, achieved through mechanical or electrical means by which it is ensured that before a signal is taken 'off, the route which the signal controls is properly set, locked and held till such time the entire route is traversed by the train and at the same time all the signals and points, the operation of which would lead to conflicting movements, are locked against the feasibility of such conflicting movements.

The signal and interlocking system is so designed that the failure of any equipment results in the turning 'on' of the signal, thus ensuring train safety.

Essentials of Interlocking

Lever frames and other types of equipment provided for the operation and control of signals, points, etc., must be so interlocked and arranged as to comply with the following essential regulations:

(a) It should not be possible to turn a signal off unless all points for the line on which the train is to be received are correctly set, all the facing points are locked, and all interlocked level crossings are closed and inaccessible to road traffic.

(b) The line should be fully isolated before the signal is turned off, i.e., no loose wagons should be able to enter this line.

(c) After the signal has been taken off, it should not be possible to make adjustments in the points or locks on the route, including those in the isolated line. Also, no interlocked gates should, be released until the signal is replaced to the 'on' position

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(d) It should not be possible to turn any two signals off at the same time, which can lead to conflicting movements of the trains.

(e) Wherever feasible, the points should be so interlocked as to avoid any conflicting movement.

Standards of Interlocking

The speed of a train depends on a number of factors such as the haulage capacity of the locomotive, the fitness of the track, the fitness of the rolling stock, the load of the train, the ruling gradient and standard to which the signalling system is provided.

Signaling arrangements

The signalling equipment, manner of locking points, and operation of signals and points differ in the different standards of interlocking. The types of signalling equipment to be provided at different interlocked stations and other requirements to be met for each of the four categories do differ.

Locking of points

The method of locking of points is the key locking in Standard-I. It is an indirect method of interlocking between signals and points. In Standard-II, a plunger type facing point lock is used. The plunger lock can be operated from the cabin or from the site itself. In standard-Ill and IV, the points are to be centrally operated and the locking between points and signals is required to be direct.

Isolation of lines

In Standard-I, isolation is optional. In Standards II, III, and IV, the main line musl be isolated from all the adjoining lines.

Details of signalling as well as of interlocking for different interlocked stations, viz., Standard I, Standard II, Standard III, and Standard IV are briefly summarized in Table below.

Methods of Interlocking

There are basically two methods of interlocking as explained below.

Key interlocking

Key interlocking is the simplest method of interlocking and still exists on branch lines of small stations on Indian Railways. The method involves the manipulation of keys in one form or the other. This type of interlocking is normally provided with standard interlocking with a speed limit below 50 km per hour. The simplest arrangement of key interlocking is accomplished in the following manner.

(a) Take the example of a station with a main line and a loop line, the point can be set either for the main line or branch line.

(b) The point has two keys, the first is key A, which can be taken out when the point is set and locked for the main line. Similarly, key B can be taken out when the point is set and locked for the loop line. At any given time either key A or key B can be taken out, depending upon whether the route is set for the main line or the loop line.

(c) The lever frame operating the signals is provided with two levers. The lever concerning the main line signal can be operated only by key A and similarly the loop line signal lever can be operated only by key B.

(d) If the train is to be received on the main line, the points are set and locked for the main line and key A is released. This key is used for interlocking the main line signal lever, thus lowering the signal for the main line. Since key A cannot be used for interlocking and lowering the loop line signal, only the appropriate signal can be taken off. This type of interlocking is called indirect locking.

Mechanical system of interlocking

Almost 70 per cent of railway stations in the country work with the mechanical system of signalling. The interlocking arrangements for mechanical signalling system have to be mechanically oriented. There are two systems of mechanically designed signals: (i) single-wire system and the (ii) double-wire system.

A mechanically structured signal has (i) spectacle with an arm; (ii) signal post, which may be tubular or lattice. Longer posts are chosen to be lattice; and (iii) a counterweight to help pull the wire back to allow the signal to go back to its on/normal position.

Such mechanical structures of signals are: (i) two-aspect semaphore signal and (ii) multiple-aspect semaphore signal.

Mechanical interlocking or interlocking on lever frames is an improved form of interlocking comtmred to key locking.

Electrical system of interlocking

As the signal displays fixed light illuminated by incandescent lamp or a light emitting diode (LED) signal, the operation of such system may be through mechanically operated levers or by push buttons provided on the yard layout depicted on the top of panel box to be termed as the control cum indication panel. Under the electrical signalling system the colour light signals are used in any case operated by lever, points (i) operated by wrought iron solid 33 mm rod; (ii) operated by electric point machines, or operated by Control cum Indication Panel operating points by an electric point machine with signals being coloured light. The system of operation of electrically operated signals by levers is hybrid and is invariable an interim measure to suit 25 kV ac traction, to be subsequently converted to oepration by control-cum-indication panel.

Typical Cases of Interlocking

The following typical cases of interlocking are usually encountered.

Normal locking In this case, pulling one lever locks the other lever in its normal position. Such locking shall be required in situation like the signal lever locking a point lever, when the signal requires the point to be moved for train movement.

Back locking or release locking In this case, when the lever is in its normal position, it also blocks the other lever in its normal position, but when this lever is pulled it releases the other lever, which can then be pulled. Furthermore, once the second lever is also pulled, the first lever gets locked in the 'pulled' position and cannot be returned to its normal position unless the second lever is restored to its normal position.

Both-way locking In this case, once a lever is pulled, it locks the other lever in its current position that is, in the normal or pulled position. Such type of locking is normally required in situations when the lock on point is to lock the point in either position. Here, if the point is to be locked in normal condition, the point lever shall get locked as it is by pulling back the lever.

Special or conditional locking In this case, the pulling of one lever locks the other lever only when certain conditions are fulfilled, say the third lever being in a normal or pulled position as the case may be. Such a locking is normally required when a signal leads to more than one route.

CHAPTER-31

BRIDGE ENGINERRING

DEFINATION

The following definitions of certain important terms used in Bridge Engineering are given below:

1. **Bridge: -** A structure is facilitating a communication route for carrying road traffic or other moving loads over a depression or obstruction such as river, stream, channel, road or railway. The communication route may be a railway track, a tramway, a roadway, footpath, a cycle track or a combination of them.
2. **High Level Bridge or Non-submersible Bridge: -** The Bridge which does not allow the high flood waters to pass over them. All the flood water is allowed to pass through its vents. In other words it carries the roadway above the highest flood level of the channel.
3. **Submersible Bridge: -** A submersible bridge is a structure which allows fold water to pass over bridge submerging the communication route. Its formation level should be so fixed as not to cause interruption to traffic during floods for more than three days at a time nor for more than six times in a year.
4. **Causeway: -** It is a pucca submersible bridge which allows floods to pass over it. It is provided on less important routes in order to reduce the construction cost of cross drainage structures. It may have vents for low water flow.
5. **Foot Bridge: -** The foot bridge is a bridge exclusively used for carrying pedestrians. Cycles and animals.
6. **Culvert: -** When a small stream crosses a road with linear waterway less than about 6 meters. The cross drainage structure so provided is called culvert.
7. **Desk Bridge: -** These are the bridge whose floorings are supported at top of the superstructures.
8. Through Bridge. These are the bridges whose floorings are supported or suspended at the bottom of the superstructures.
9. **Semi-Through Bridges: -** These are the bridges whose floorings are supported at some intermediate level of the superstructure.
10. **Simple Bridges: -** They include all beam, girder or truss bridges whose flooring is supported at some intermediate level of superstructure.
11. **Cantilever Bridges: -** Bridges which are more or less fixed at one end and free at other. It can be used for spans varying from 8 meters to 20 meters.
12. **Continues Bridges: -** Bridges which continue over two or more spans. They are used for large spans and where unyielding foundations are available.

13. **Arch Bridge: -** These are the bridges which [produce inclined pressures on supports under vertical loads. These bridges can be economically used up to spans about 20 meters. The arches may be in the barrel from or in the form of ribs.
14. **Rigid Frame Bridges: -** In these bridges the horizontal deck slab is made monolithic with the vertical abutments walls. These bridges can be used up to span about 20 meters. Generally this type of bridge is not found economical for spans less than 10 meters.
15. **Square Bridge: -** These are the bridges at right angles to axis of the river.
16. **Square Bridge: -** These are the bridges not at right angles to axis of the river.
17. **Suspension Bridges: -** These are the bridges which are suspended on cables anchored at ends.
18. **Under-Bridges: -** It is a bridge constructed to enable a road to pass under another work or obstruction.
19. **Over-Bridges: -** it is a bridge constructed to enable one from of land communication over the other.
20. **Class AA Bridges: -** These are bridges designed for I.R.C. class AA loading and checked for class A loading. Hey are provided within certain municipal limits, in certain existing or contemplated industrial area, in other specified areas, and along certain specified highways.
21. **Class A Bridges: -** These are permanent bridges designed for I.R.C. class A loading.
22. **Class B Bridges: -** These are permanent bridges designed for I.R.C. class B loading.
23. **Viaduct: -** It is a long continues structure which carries a road or railways like Bridge over a dry valley composed of series of span over trestle bents instead of solid piers.
24. **Apron: -** It is a layer of concrete, masonry stone etc. placed like flooring at the entrance or out of a culvert to prevent scour.
25. **Piers: -** They are the intermediate supports of a bridge superstructure and may be solid of open type.
26. **Abutments: -** They are the end supports of the superstructure.
27. **Curtain Wall: -** It is a thin wall used as a protection against scouring action a stream.
28. **Effective Span: -** The centre to centre distance between any two adjacent supports is called as the effective span of a bridge.
29. **Clear Span: -** The clear distance between any two adjacent supports of a bridge is called clear Span.
30. **Economic Span: -** the span, for which the total cost of bridge structure is minimum is known as economic span.
31. **Afflux: -** due to construction of the Bridge there is a contraction in waterway. This results in rise of water level above its normal level while passing under the Bridge. This rise is known as afflux.
32. **Free Board: -** Free Board at any point is the difference between the highest flood level after allowing for afflux, if any, and the information level of road embankment on the approaches or top level of guide bunds at the points.
33. **Headroom: -** Headroom is the vertical distance between the highest points of a vehicle or vessel and the lowest points of any points of any protruding member of a Bridge.
34. **Length of the Bridge: -** The length of a Bridge structure will be taken as the overall length measure along the centre line of the Bridge from the end to end of the Bridge deck.

35. **Liner Waterway: -** The liner waterway of a Bridge shall be the length available in the bridge between extreme edges of water surface at the highest flood level, measures at right angles to the abutment faces.
36. **Low Water Level (L.W.L.): -** The low water level is the of water surface obtained generally in the dry season.
37. **Ordinary Flood Level (O.F.L.):-** It is average level of a high flood which is expected to occur normally every year.
38. **Highest Flood Level (H.F.L.):-** It is the level of highest flood every recorded or the calculated level for the highest possible flood.
39. **Effective Liner Waterway: -** Effective linear waterway is the total width of waterway of a bridge minus the effective width of obstruction. For calculating the effective linear waterways, the width of mean obstruction due to each pier shall be taken as mean submerged width of the pier at its foundation up to maximum scour level. The obstruction at ends due to abutments or pitched slopes should be ignored.

COMPONENTS OF A BRIDGE

The bridge structure is divided mainly into two components:

1) Substructure

- The function of substructure is similar to that of foundations, columns and walls etc. of a building. Thus the substructure supports the superstructure and distributes the load into the soil below through foundation.
- The substructure consists of foundation piers and abutment piers, foundation for the piers, abutments, wing walls, and approaches.
- The above all supports the superstructure of the bridge.

2) Superstructure

- The superstructure of a bridge is analogues to a single story building roof and substructure to that of walls, columns and foundations supporting it.
- Superstructure consists of structural members carrying a communication route
- It consists of handrails, parapets, roadways, girders, arches, wall trusses over which the road is support.
- It is that part of the bridge over which the traffic moves safely

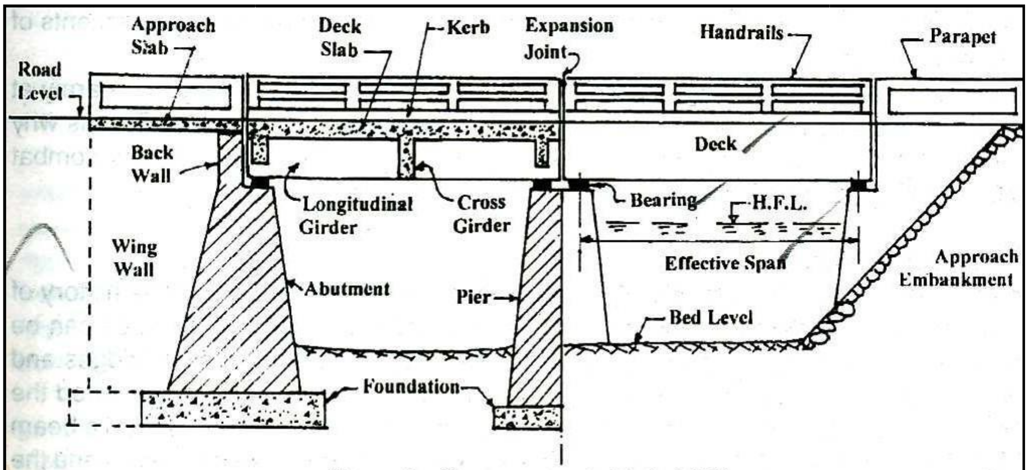


Figure 1 Components of a Typical Bridge.

Classification of a Bridge: -

The bridges may be classified depending upon the following factors:-

(a) Their functions or purpose as railway, highway Foot Bridge, aqueduct etc.

(b) Their material of construction used as timber masonry, R.C.C. Steel, prestresses concrete etc.

(c) Nature or life span such as temporary permanent bridge etc.

(d) Their relative position of floor such as deep bridge, through bridges etc.

(e) Type of super-structure such as arched girder, truss, suspension bridge etc.

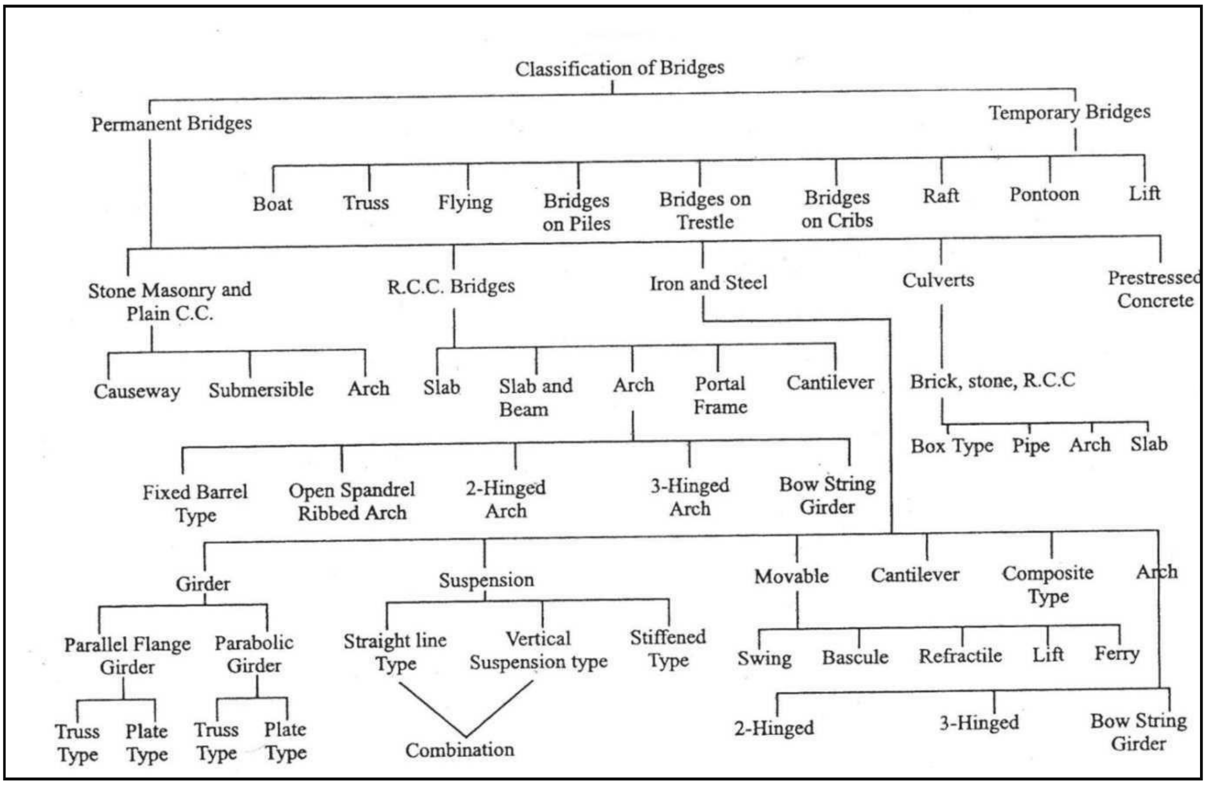
(f) Loadings: - Road Bridges and culverts have been classified by I.R.C. into class AA, Class A, Class B bridges according to the loadings they are designed to carry.

(g) Span Length:- Under this category the bridges can be classified as

- Culverts (Span Less than 8m) i.e. BOX Type, Hume Pipe Type,
- Minor Bridge (Span length = 8 to 30m) i.e. BOX type, Girder Type
- Major Bridge (Span Length =above than 30m)

(h) Degree of Redundancy: - Under this the bridges can be classified as indeterminate bridges

(i) Types of Connection:- Under this category the steel bridges can be classified as pinned connected , riveted or welded bridges.



Classification of Bridge

REQUIRMENTS OF AN IDEAL BRIDGE:-

An ideal bridge meets the following requirements to fulfil the three criteria of efficiency, effectiveness and equity

- It serves the intended function with utmost safety and convenience
- It is aesthetically sound
- It si economical

The site characteristic of an Ideal Bridge has been discussed below:

1. The stream at the bridge side should be well defined and as narrow as possible.
2. There should be a straight reach of stream at bridge site
3. The site should have firm, permanent, straight and high banks.
4. Te flow of water in the stream at the bridge site should be in steady regime condition. It should be free from whirls and cross-current
5. There should be no confluence of large tributaries in the vicinity of bridge site
6. It should be reliable to have straight approach roads and square alignment, i.e. right-angled crossing
7. There should be minimum obstruction of a natural waterway so as to have minimum afflux
8. In order to achieve economy there should be easy availability of labour, construction material and transport facility in the vicinity of bridge site.
9. In order to have minimum foundation cost, the bridge site should be such that no excessive work is to be carried inside the water
10. At bridge site it should be possible to provide secure and economical approaches.

11. In case of curved alignment the bridge should not be on the curve, but preferably on the tangent since otherwise there is a greater like hood of accident as well as an added centrifugal force which increases the load effect on the structure and will require modification of design.
12. There should be no adverse environmental input
13. The bridge site should be such that adequate vertical height and waterway is available
14. Underneath the bridge for navigational use.

In actual practice the determination of best possible site for any proposed bridge is truly an economic problem. The various factors which should be carefully examined before setting finally upon the layout of a bridge as follows:

i. Grade on alignment,
ii. Geographical Conditions,
iii. Government requirements,
iv. Commercial influences ,
v. Adjacent property consideration,
vi. General features of the bridge structure,
vii. Future trends for enlargement,
viii. Time Consideration,
ix. Foundation Considerations,
x. Construction facilities available,
xi. Erection Consideration,
xii. Aesthetics,
xiii. Maintenance and repairs,
xiv. Environment Impact

CHAPTER-32

Bridge Alignment:-

Depending upon the angle which the bridge makes with tee axis of the river, the aliment an me of two types:

a) Square Alignments: - In this the bridge is at right angle to the axis of the river.

b) Skew Alignments: - In this the bridge is at some angle to the axis of the river which is not a right angle.

Note: - As far as possible, it is always desirable to provide the square alignment. the skew alignments suffers from the following disadvantages:-

(i) A great skill is required for the construction of skew Bridges. Maintenance of such type of Bridges is also difficult.

(ii) The water-pressure on piers in case of skew alignment is also excessive because of non-uniform flow of water underneath the bridge superstructure.

(iii) The foundation of skew bridge is more susceptible to scour action.

Flood Discharge: -

One of the essential data for the bridge design is fair assessment of the maximum flow which could be expected to occur at the bridges site during the design period of the bridge. The conventional practice in India for determination of flood discharge is to use a few convenient formulae or past records.

Note: - This faulty determination of flood discharge which led to failure of many hydraulic structures.

As per I.R.C. recommendation the maximum discharge which a bridge on a natural stream should be designed to pass determined by the following methods:-

(a) From the rainfall and other characteristics of the catchment.

(i) By use of an empirical formula applied to that region, or

(ii) By a rational method, provided it is possible to evaluate for the region concerned the various factors employed in the method.

(b) From the hydraulic characteristics of the stream such as cross-sectional area, and slope of the stream allowing for velocity of flow.

(c) From the records available, if any, of discharges observed on the stream at the site of the bridge, or at any other site vicinity.

Empirical Methods for Estimation of Flood Discharge:-

In these methods are of basin or catchment is considered mainly. All other factors which influence peak flow are merged in a constant.

A general equation may be followed in the form:-

$$\boxed{\mathbf{Q = C \cdot M^{n}}}$$

Here, Q= Peak Flow or rate of maximum discharge

C= a constant for the catchment

M= area of catchment, and '***n***' is an index

The constant for catchment is arrived at, after taking the following factors into account:

(A) Basin Characteristics

a) Area
b) Shape
c) Slope

(B) Strom Characteristics

a) Intensity
b) Duration
c) Distribution

Limitations

These methods do not take frequency of flood into consideration.

These methods cannot be applied universally

Fixing of constant is very difficult and exact theory cannot be put forth for its selection.

1) **Dicken's Formula**

$$\boxed{\mathbf{Q = C. M^{3/4}}}$$

Here, Q= Discharge in cum/sec

C= a constant

M= area of catchment in sq .km.

2) Tyve's formula

$$\boxed{Q = C.\ M^{2/3}}$$

Here, Q= Discharge in cum/sec

C= 6.74 for area within 24 km from coast or,

C= 8.45 for areas within 24-161 km from coast or,

C= 10.1 for limited hilly areas

In worst case C goes up to 40.5

M= area of catchment in sq .km.

3) Inglis Formula

This formula used only Mahastra state and here three different cases are taken into consideration.

(a) For small areas only (It is also applicable for fan-shaped catchment)

$$\boxed{Q = 123.2\sqrt{M}}$$

(b) For areas between 160 to 1000 square km.

$$\boxed{Q = 123.2\sqrt{M} - 2.62(M - 259)}$$

(c) For all type of catchment

$$\boxed{Q = 123.2\ M\ /\ \sqrt{(M + 10.36)}}$$

In all equations, M= area of catchment in sq .km.

4) Nawab Jang Bahadur's Formula :-

$$\boxed{Q = C\ (M / 2.59)\ (a - b.\log A)}$$

Here, a, b, and C are constant.

a= 0.993 and b= 1/14

C = 59.5 for North India or,

= 48.1 for South India

5) Creager's Formula :-

$$\boxed{q = C.M\ n}$$

Here, q=the peak flow per sq. km of a basin

M= area of catchment in sq. km. and '***n***' is some index

By multiplying both sides of the above equation are of the basin M, we get

$$\boxed{Q = C.\ M^{n+1}}$$

Where Q is peak value

Equation given by Creager , Justin and Hinds is

$$Q=46.\ CM^{(0.849M-0.048)}$$

6) Khosla's Formula :-

It is a rational formula, It si based on the equation **P= R + L**

Or **R= P - L**

Here, R is round off, P is rainfall and L is losses.

L=4.82 Tm, where L is in mm and Tm is in centigrade {in C.G.S. System}

R= P - 4.82Tm

7) Besson's Formula :-

This formula is very rational and can be used in any case:

$$\mathbf{Q_m = (P_m \times Q_r) / (P_r)}$$

Here, Q_m = Peak flow expected

Q_r = Some observed peak flow

P_r = Observed rainfall

P_m= expected rainfall

Rational Methods for Estimation of Flood Discharge:-

This method is applicable for determination of flood discharge for small culverts only. In order to arrive at a rational approach, a relationship has been established between rainfall and runoff under various circumstances. The size of flood depends upon the following factors.

(i) Climate or Rainfall Factors. This includes

(a) Intensity (b) Distribution and (c) Duration of Rainfall

(ii) Catchment Area Factors. This includes:

(a) Catchment Area (b) its slope (c) its shape (d) porosity of soil

(e) Vegetable cover (f) initial state of wetness

WATERWAY

The area through which the water flows under a bridge superstructure is known as the waterway of the bridge. The linear measurement of this area along the bridge is known as the linear waterway. This linear waterway is equal to the sum of all the clear spas. This may be called as artificial linear waterway.

Due to the construction of a bridge the natural waterway gets contracted thereby increasing the velocity of flow under a bridge. This increased velocity results into heading up of water on the upstream of the river or stream, known as Afflux.

Economic Span: **-** the economic span of a bridge is the one which reduces the overall cost of a bridge to be minimum. The overall cost of a bridge depends upon the following factors

a. Cost of material and its nature.
b. Availability of skilled labour
c. Span Length.
d. Nature of stream to be bridged.
e. Climatic and other conditions.

Notes:-

It is not in the hand of engineers to bring down the cost of living index or price of the materials like cement, steel, timber, etc. but they can help in bringing down the cost of bridges by evolving economical designs.

Considering only variable items, the cost of superstructure increases and that of sub-structure decreases with an increase in the span length. Thus most economic span length is that which stultifies the following :-

i.e. The cost of Super Structure= The cost of the Sub-Structure

AFFLUX

When a bridge is constructed, the structure such as abutments and piers cause the reduction of natural waterway area. The contraction of stream is desirable because it leads to tangible saving in the cost specially for alluvial stream whose natural surface width is too large than required for stability. Therefore, to carry the maximum flood discharge, the velocity under a bridge increases. This increased velocity gives rise to sudden heading up of water on the upstream side of the stream. The phenomenon o0f heading up of water on the upstream side of the stream is known as "**AFFLUX"**

Greater the afflux greater will be the velocity under the downstream side of the bridge and greater will be the depth of scour and consequently greater will be depth of foundations required.

Afflux is calculated by one of the following formula

(A) Marriman's Formula

$$\boxed{h_a = (V^2 / 2g) \{(A/Ca)^2 - (A/A_1)\}}$$

Here, h_a = Afflux in meters

V= Velocity of approach in meters per second

A= Natural Waterway area at the site

a=Contracted area in square meters

A_1= The enlarged area upstream of the bridge square meters

C= Coefficient of Discharge = 0.75+0.35 (a/A)- 0.1(a/A)^2 approximately

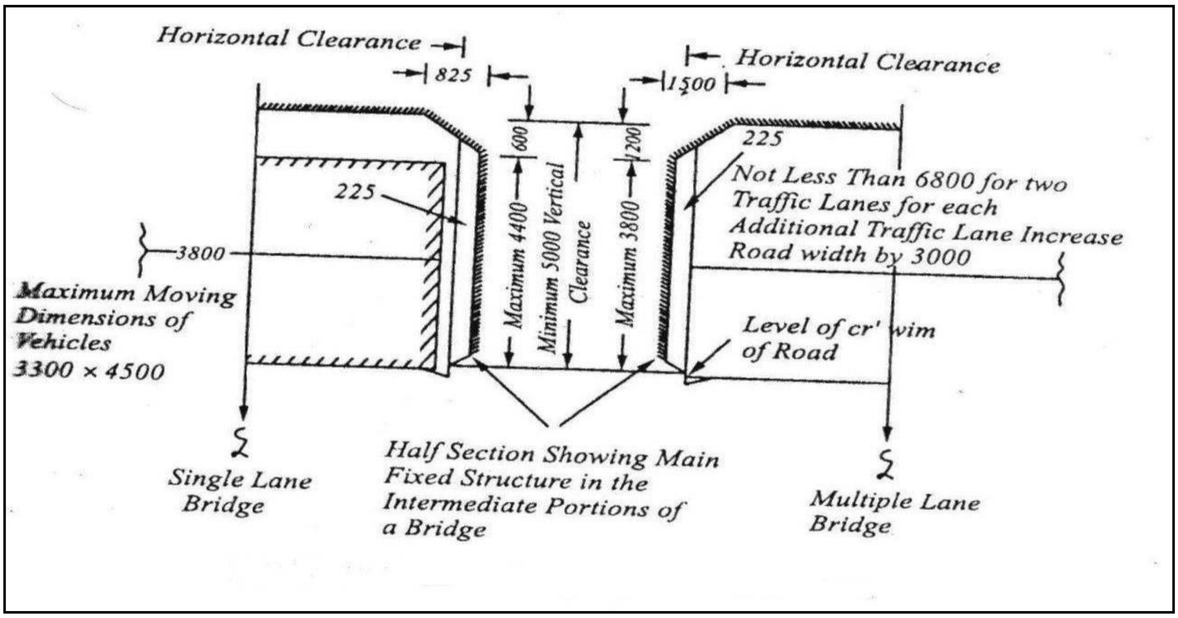
(A) Molesworth's Formula

$$h_a = \left(\frac{V^2}{17.9} + 0.015 \right) \{ (A/a)^2 - 1 \}$$

Here, V, A and a have the same meaning as in the Marriman's Formula

CLEARANCE

To avoid any possibility of traffic striking any structural part clearance diagram are specified. The horizontal clearance should be the clear width and vertical clearance of the clear height, available for the passage of vehicular traffic as shown in the clearance diagram in the figure below.



Clearance Diagram for Road Bridges

Note : - *For a bridge constructed on a horizontal curve with superelevated road surfaces, the horizontal clearance should be increased on the side of inner kerb by an amount equal to 5m multiplied by the superelevation. The minimum vertical clearance should be measured from the super elevated level of roadway.*

FREE BOARD

Free board is the vertical distance between the designed high flood level, allowing for the afflux, if any, and level of the crown of the bridge at its lowest point.

It is essential to provide the free board in all types of bridges for the following reasons:-

- Free Board is required to allow floating debris, fallen tree trunks and approaches waves top pass under the bridge.
- Free board is also required to allow for the afflux during the maximum flood discharge due to contraction of waterway.
- Free board is required to allow the vessels to cross the bridges in case of navigable rivers. The value of free-broad depends upon the types of the bridge.

Collection of Bridge Design Data: -

For a complete and proper appreciation of the bridge project the engineer in charge of the investigation should carry out studies regarding its financial, economic, social and physical feasibility. The detailed information to be collected may cover loading to be used for design based on the present and anticipated future traffic, hydraulic data based on stream characteristics, geological data, subsoil data, climatic data, alternative sites, aesthetics, cost etc.
The following drawings containing information as indicated should be prepared

1. INDEX MAP
2. CONTURE SURVEY PLAN
3. SITE PLAN
4. CROSS-SECTION
5. LONGITUDINAL SECTION
6. CATCHEMENT AREA MAP
7. SOIL PROFILE

Design data for major bridge:-

A- General data:-

(i) Name of the road and its classification.
(ii) Name of the stream.
(iii) Location of nearest G.T.S. bench mark and its reduced level.
(iv) Chainage at centre line of the stream.
(v) Existing arrangement for crossing the stream.
a) During Monsoon b) During dry season
(vi) Liability of the site to earthquake disturbance

B- Catchment Area and Run Off Data:-

(i) Catchment Area

(a) Hilly Area b) In plains

(ii) Maximum recorded intensity and frequency of rainfall in catchment.

(iii) Rainfall in cementer per year in a reason

(iv) Length of catchment in kilometres.

(v) Width of catchment in kilometres.

(vi) Longitudinal slope of catchment.

(vii) Cross slope of catchment.

(viii) The nature of catchment and its shape.

C- Data Regarding Nature of Stream

Sub-Surface Investigation:-

Sub-Surface investigation is essential for to know the properties of the bridge site soil. The field and laboratory investigations required to obtain the necessary soil data for the design are called soil exploration.

The principal requirements of a complete investigation can be summarized as follows:-

1. Nature of the soil deposits up to sufficient depth.
2. Depth, thickness and composition of each soil stratum.
3. The location of ground water.
4. Depth to rock and composition of rock.
5. The engineering properties of soil and rock strata that affect the design of the structure.

In exploration programme the extent of distribution of different soils both in the horizontal and vertical directions can be determined by the following methods:

1. By use of open pits.
2. By making bore holes and taking out samples.
3. By Soundings.
4. By use of geophysical methods.

Equipments for laboratory Work:-

The disturbed soil sample as taken from bed level to scour level at every one meter interval or at depths wherever strata changes ate tested to determine the following properties:-

1. Liquid Limit, Plastic ,Limit and Plasticity Index
2. Organic Content
3. Harmful Salts
4. Sieve Analysis
5. Silt Factor

The undisturbed soil samples as taken below the scour level to a level where the pressure is about 5% of the pressure at the base are tested to determine

1. Particle size analysis.
2. Values of cohesion and angle of internal friction by shear test.
3. Compression index and pre-consolidation pressure by consolidation test.
4. Density specific gravity and moisture content.

Advantage of Sub-Surface Investigation:-

There are manifold advantages of carefully planned investigation programme. These can be summarized as below:-

1. A suitable and economical solution can be worked out.
2. The construction schedule can be properly planned.
3. The extent and nature of difficulties likely to be met with can be determined.
4. The rate and amount of settlements can be determined.
5. The variation in the water –table, of the presence of artesian pressures can be found out.

CHAPTER 33

Depth of Scour:-

DEPTH OF SCOUR (D) is the depth of the eroded bed of the river, measured from the water level for the discharge considered. Well-laid foundation is mostly provided in road and railway bridges in India over large and medium-sized rivers. The age-old Lacey–Inglis method issued for estimation of the design scour depth around bridge elements such as pier, abutment, guide bank, spur and groyene. Codal provisions are seen to produce too large a scour depth around bridge elements resulting in bridge sub-structures that lead to increased construction costs. Limitations that exist in the codes of practice are illustrated in this paper using examples. The methods recently developed for estimation of the scour are described. New railway and road bridges are required to be built in large numbers in the near future across several rivers to strengthen such infrastructure in the country. It is strongly felt that provisions in the existing codes of practice for determination of design scour depth require immediate review. The present paper provides a critical note on the practices followed in India for estimating the design scour depth.

Indian practices on estimation of design scour depth

1. Lacey–Inglis method
2. Comments on Lacey's method

- The probable maximum depth of scour for design of foundations and training and protection works shall be estimated considering local conditions.
- Wherever possible and especially for flashy rivers and those with beds of gravel or boulders, sounding for purpose of determining the depth of scour shall be taken in the vicinity of the site proposed for the bridge. Such soundings are best taken during or immediately after a flood before the scour holes have had time to silt up appreciably. In calculating design depth of scour, allowance shall be made in the observed depth for increased scour resulting from:

(i) The design discharge being greater than the flood discharge observed.

(ii) The increase in velocity due to the constriction of waterway caused by construction of the bridge.

(iii) The increase in scour in the proximity of piers and abutments.

- 4.6.3 In the case of natural channels flowing in alluvial beds where the width of waterway provided is not less than Lacey's regime width, the normal depth or Scour (D) below the foundation design discharge (Qf) level may be estimated from Lacey's formula as indicated below

$$\mathbf{D = 0.473\ (Q^{f} / f)^{1/3}}$$

Where D is depth in metres Qf is in cumecs and 'f' is Lacey's silt factor for representative sample of bed material obtained from scour zone.

- Where due to constriction of waterway, the width is less than Lacey's regime width for Qf or where it is narrow and deep as in the case of incised rivers and has sandy bed, the normal depth of scour may be estimated by the following formula:

$$\mathbf{D = 1.338\ (Q_f{}^{2} / f)^{1/2}}$$

Where 'Q_f' is the discharge intensity in cubic metre per second per metre width and f is silt factor The silt factor 'f' shall be determined for representative samples of bed material collected from scour zone using the formula : f = 1.76 $\sqrt{m}$ where m is weighted mean diameter of the bed material particles in mm. Values of 'f' for different types of bed material commonly met with are given below :

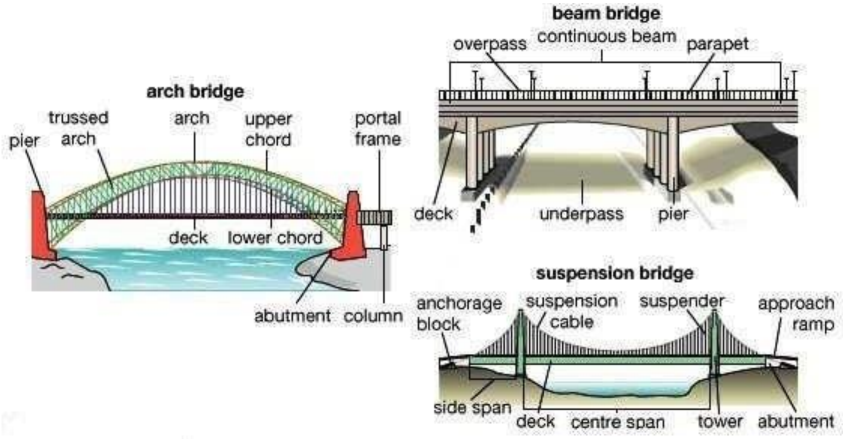
Type of bed	Material Weighted mean dia of particle(mm)	Value of 'f'
(i)Coarse silt	0.04	0.35
(ii) Fine sand	0.08 0.15	0.50 0.68
(iii) Medium sand	0.3 0.5	0.96 1.24
(iv) Coarse sand	0.7 1.0 2.0	1.47 1.76 2.49

The depth calculated (vide clause 4.6.3 and 4.6.4 above) shall be increased as indicated below, to obtain maximum depth of scour for design of foundations, protection works and training works:-

Nature of the river	**Depth of scour**
In a straight reach	1.25D
At the moderate bend conditions e.g. along apron of guide bund	1.5D
At a severe bend	1.75D
At a right angle bend or at nose of piers	2.0D
In severe swirls e.g. against mole head of a guide bund.	2.5 to 2.75D

In case of clayey beds, wherever possible, maximum depth of scour shall be assessed from actual observations.

Types of Bridge

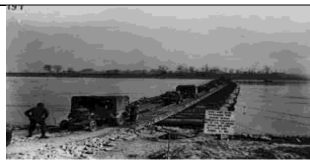


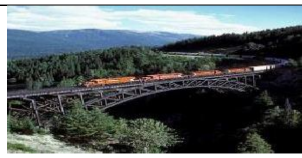
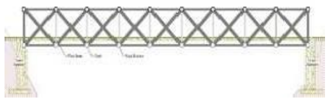
Types of Bridge

Arch bridge	
Arch bridge (concrete)	
Through arch bridge	
Beam bridge	
Log bridge (beam bridge)	
Cavity wall Viaduct	
Bowstring arch	
Box girder bridge	

Cable-stayed bridge	
Cantilever bridge	
Cantilever spar cable-stayed bridge	
Clapper bridge	
Covered bridge	
Girder bridge	
Continuous span girder bridge	
Moon bridge	

Movable bridge	

Pigtail bridge	
Plate girder bridge	
Pontoon bridge	
Roving bridge	
Segmental bridge	
Self-anchored suspension bridge	
Side-spar cable-stayed bridge	
Simple suspension bridge (Inca rope bridge))	
Step-stone bridge	
Stressed ribbon bridge	
Suspension bridge	

Transporter bridge	
Trestle	
Truss arch bridge	
Truss bridge	
Vierendeel bridge	
Brown truss	
Covered bridge	
Lattice truss bridge (Town lattice truss	
Tubular bridge	

Bridge Foundation:-

Definition:- A foundation is the part of the structure which is in direct contact with the ground. It transfers the load of the structure to the soil below. Before deciding upon its size, we must ensure that:

(i) The bearing pressure at the base does not exceed the allowable soil pressure.

(ii) The settlement of foundation is within reasonable limits

(iii) Differential settlement is to limited as not to cause any damage to the structure.

Broadly, foundation may be classified under two categories i.e.

1. Shallow foundation
2. Deep Foundation

Shallow Foundation:-According to Trezaghi, a foundation is said to be shallow if its depth is equal or less than its width.

Deep Foundation:- According to Trezaghi, a foundation is said to be deep , the depth is greater than its width and it cannot be prepared by open excavation.

Types of Bridge Foundation:-

The selection of foundation type suitable for a particular site depends on the following considerations:-

1) Nature of Subsoil

2) Nature and extent of difficulties, e.g. presence of boulder, buried tree trunks, etc. Likely to be met with, and

3) Availability of expertise and equipment.

Depending upon their nature and depth, bridge foundation can be categories as follows:

i. **Open Foundation,**
ii. **Raft Foundation,**
iii. **Pile Foundation,**
iv. **Well foundation,**

(i)Open Foundation in Bridges:-

1. An open foundation or spread foundation is a type of foundation and can be laid using open excavation by allowing natural slopes on all sides.
2. This type of foundation is practicable for a depth of about 5m and is normally convenient above the water table.
3. The base of the pier or abutment is enlarged or spread to provide individual support.
4. Since spread foundations are constructed in open excavation, therefore, they are termed as open foundation.
5. This type of foundation is provided for bridges of moderate height built on sufficiently form day ground.
6. The piers in such cases are usually made with slight batter and provided with footings widened at bottom. Where the ground is not stiff the bearing surface is further extended by a wide layer of concreter at bottom (see the figure).

(ii) Raft Foundation:-

1. A raft foundation or mat is a combined footing that covers the entire area beneath a bridge and supports all the piers and abutments.
2. When the allowable soil pressure is low, or bridge loads are heavy, the use of spread footing would cover more one-half of the area, and it may prove more economical to use raft foundation
3. They are also used where the soil mass contains compressible lenses so that the differential settlement would be difficult to control.
4. The raft tends to bridge over the erratic deposits and eliminates the differential settlement.

5. Raft foundation is also used to reduce the settlement above highly compressible soils by making the weight of bridge and raft may undergo large settlement without causing harmful differential settlement. For this reason, almost double settlement of that permitted for footings is acceptable for rafts.
6. Usually when hard soil is not available within 1.5 to 2.5 m a raft foundation is adopted.
7. The raft is composed of reinforced concrete beams a relatively thin slab underneath, figure

(iii) Pile foundation in Bridges:

1. The pile foundation is constructions for the foundation of abridge pier or abutment supported on piers.
2. A pile is an element of construction composed of timber, concrete or steel or combination of them.
3. Pile foundation may be defined as a column support type of foundation which may be cast-in-situ or precast.
4. The piles may be place separately or they may be placed in form of a cluster throughout the length of the pier or abutment.
5. This type of construction is adopted when the loose soil extends to great depth.
6. The load of the bridge is transmitted by the piles to hard stratum below or it is resisted by the friction developed on the sides of piles.

Classification of piles:-

Piles are broadly classified into two categories:-.

i- Classification based on the function

ii- Classification based on the materials and composition

Classification based on the function

- Bearing Pile.
- Friction Pile.
- Screw Pile.
- Compaction Pile.
- Uplift Pile.
- Batter Pile.
- Sheet Pile.

Classification based on the function

- Cement concrete piles.
- Timber Piles.
- Steel Piles.
- Sand Piles.
- Composite Piles.

(iv)Well Foundation in bridges

a) Well foundations are commonly used for transferring heavy loads to deep strata in river or sea bed for bridges, transmission towers and harbour structures. The situation where well foundations are resorted are as below as) Wherever consideration of scour or bearing capacity require foundation to be taken to depth of more than 5 M below ground level open foundation becomes uneconomical. Heavy excavation and dewatering problem coupled with effort involve in retaining the soil makes the open foundation costlier in comparison to other type of foundation.

b) Soil becomes loose due to excavation around the open foundation and hence susceptible to scouring. This is avoided in well foundation which is sunk by dredging inside of the well.

c) From bearing pressure considerations, a well foundation can always be left hollow thereby considerably reducing bearing pressure transmitted to the foundation material. This is very important in soils of poor bearing capacity, particularly in clayey soils. In other type of foundation, the soil displaced is occupied by solid masonry/concrete which are heavier than the soil displaced and hence this does not give any relief in respect of adjusting bearing capacity. However in case of well foundation this is easily achieved because of cellular space left inside the well.

Caisson:-

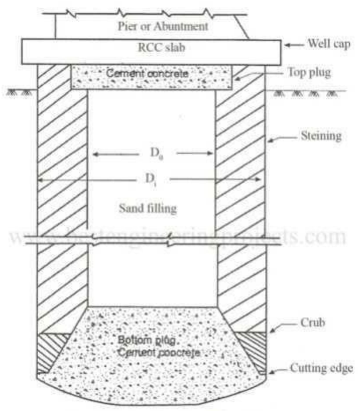


Fig 1 Parts of a Well Foundation

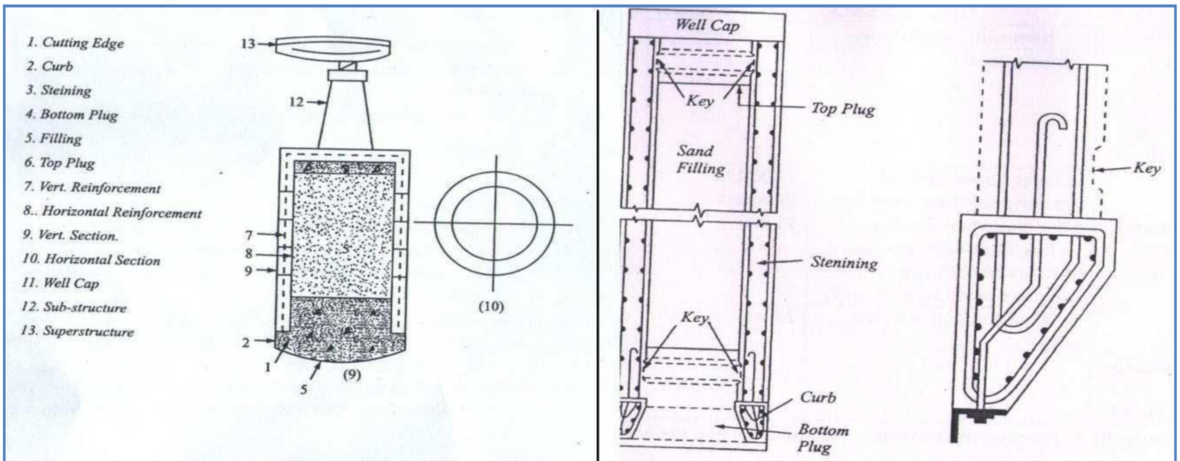


Figure :- DETAILS OF WELL FOUNDATION

Caisson: - The caisson is a structure used for the purpose of placing as foundation in correct position under water. The term caisson is derived from the French word ‘caisse’ meaning a box. It is a member with hollow portion, which after installing in palace by any means is filled with concrete or other material. Caissons are prepared in sandy soils the caissons can be divided in the following three groups

a. Box Caissons
b. Open Caissons or Wells
c. Pneumatic Caissons

Well components and their functions:

- ***Cutting edge:*** - It provides a comparatively sharp edge to cut the soil below during sinking operation. It is usually consists of a mild steel equal angle of side 150mm.
- ***Curb: -*** It has a two-fold purpose. During sinking it acts as an extension of cutting edge and also provided support to the well steining and bottom plug while after sinking it transfers the load to the soil below. It is made up of reinforced concrete using controlled concrete of grade M200.
- ***Steining:***- It is the main body of the well. It is serves dual purpose. It acts as a cofferdam during sinking and structural member to transfer the load to the soil below afterwards. The steining may consist of brick masonry or reinforced concrete. The thickness of steining should not be less than 4.5 cm not less than that given by equation.

$$t= K \{(H/100) + (D/10)\}$$

Here, t= minimum concrete steining thickness.

H= well depth below bed

D= External diameter of Well

K= a constant which is 1.0 for sandy strata.

- Bottom Plug: - Its main function is to transfers load from the steining to the soil below.
- Sand Plug: - Its utility is doubtful. It is supposed to afford some relief to the steining by transforming directly a portion of load from well cap to bottom plug.
- Top Plug: - The opinion is divided about the top plug. It, at least, serves as a shuttering for laying well cap.
- Reinforcement: – It provides requisite strength to the structure during sinking and

service.

- Well Cap: - It is needed to transfer the loads and moments from the pier to the well or wells below. The shape of well cap is similar to that of the well with a cantilevering of about 15cm. Whenever 2 or 3 wells of small diameter are needed to support the sub-structure , the well cap designed as a slab resting over the well or wells with partial fixity at the edges of the wells.
- Depth of Well Foundation:- As per I.R.C. Bridge Code (Part-III), the depth of well foundation is to be decided on the following consideration
    1. The minimum depth of foundation below the H.F.L. should be 1.33D, Where D is the anticipated max. Depth of scour below H.F.L. Depth should provided proper grip according to some rational formula.
    2. The max bearing pressure on the subsoil under the foundation resulting form any combination of the loads and forces except wind and seismic forces should not exceed the safe bearing capacity of the subsoil, after taking into account the effect of scour.

       With wind and seismic forces in addition, the max. Bearing pressure should not exceed the safe bearing capacity of the subsoil by more than 25%.
    3. While calculating max. Baring pressure on the foundation bearing layer resulting from the worst combination of direct forces and overturning moments, the effect of a passive resistance of the earth on sides of the foundation structure may be taken into account below the max, depth of the scour only.
    4. The effect of skin friction may be allowed on the portions below the max, depth of scour. Accordingly for deciding the depth of well foundation, we require correct estimation of the following.
        1. Max. Sour depth.
        2. Safe bearing capacity.
        3. Skin friction.
        4. Lateral earth support below max. Scour level.

It is always desirable to fix the level of a well foundation on a sandy strata with adequate bearing capacity. Whenever a thin stratum of clay occurring between two layers of sand is met with, in that case well must be pierced through the clayey strata. If at all foundation has to be laid on clayey layer it should be ensured that the clay is stiff.

Design loads and Forces. The forces acting o n a bridge structure, to be considered fo the design of a well foundation, are as follows:

Vertical

(i) Dead load,

(ii) Live load,

(iii) Buoyancy.

Horizontal

(i) Wind force.

(ii) Force due to water currents.

(iii) Longitudinal forces caused by the tractive effort of vehicle or by braking effect of vehicles.

(iv) Longitudinal force on account of resistance of the bearing against movement due to variations of temperature.

(v) Seismic force.

(vi) Earth pressure.

(vii) Centrifugal force.

The I.R.C. Bridge code II stipulates the magnitude of above loads and forces. The magnitude, direction and point of application of all the above forces can be resolved into two horizontal forces, P and Q and a single vertical force W under the worst possible combinations.

Chapter 34

Piers:-

Piers provide vertical supports for spans at intermediate points and perform two main functions: transferring superstructure vertical loads to the foundations and resisting horizontal forces acting on the bridge. Although piers are traditionally designed to resist vertical loads, it is becoming more and more common to design piers to resist high lateral loads caused by seismic events. Even in some low seismic areas, designers are paying more attention to the ductility aspect of the design. Piers are predominantly constructed using reinforced concrete. Steel, to a lesser degree, is also used for piers. Steel tubes filled with concrete (composite) columns have gained more attention recently.

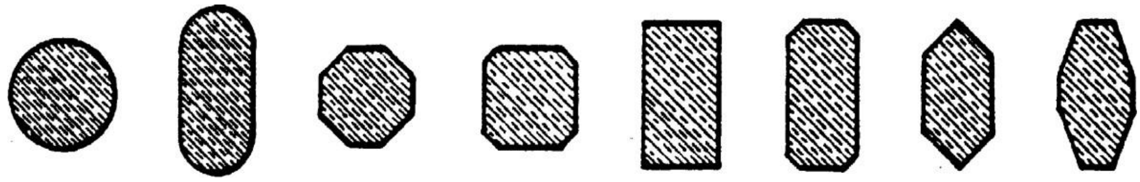


FIGURE: 1 : Typical cross-section shapes of piers for overcrossings or viaducts on land.

Pier is usually used as a general term for any type of substructure located between horizontal spans and foundations. However, from time to time, it is also used particularly for a solid wall in order to distinguish it from columns or bents. From a structural point of view, a column is a member that resists the lateral force mainly by flexure action whereas a pier is a member that resists the lateral force mainly by a shear mechanism. A pier that consists of multiple columns is often called a bent.

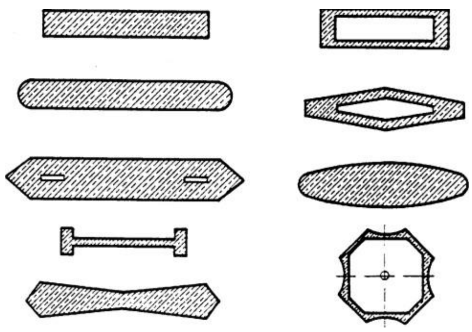


FIGURE:-2 Typical cross-section shapes of piers for river and waterway crossings.

There are several ways of defining pier types. One is by its structural connectivity to the superstructure: monolithic or cantilevered. Another is by its sectional shape: solid or hollow; round, octagonal, hexagonal, or rectangular. It can also be distinguished by its framing configuration: single or multiple columns bent; hammerhead or pier wall. Selection of the type of piers for a bridge should be based on functional, structural, and geometric requirements. Aesthetics is also a very important factor of selection since modern highway bridges are part of a city's landscape. Figure-1 shows a collection of typical cross section shapes for overcrossings and viaducts on land and Figure-2 shows some typical cross section shapes for piers of river and waterway crossings. Often, pier types are mandated by government agencies or owners.

Many state departments of transportation in the United States have their own standard column shapes.

Broadly piers are classified under following two categories:-

I. Solid Piers.

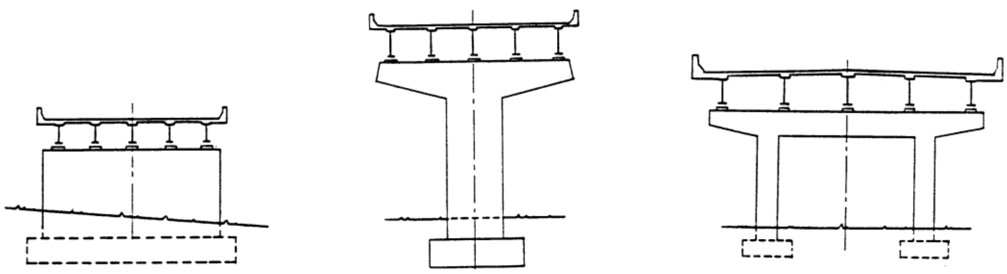
II. Open Piers.

Solid wall piers, as shown in Figures 3-a and 4, are often used at water crossings since they can be constructed to proportions that are both slender and streamlined. These features lend themselves well for providing minimal resistance to flood flows.

Hammerhead piers, as shown in Figure 3-b, are often found in urban areas where space limitation is a concern. They are used to support steel girder or precast prestressed concrete superstructures. They are aesthetically appealing. They generally occupy less space, thereby providing more room for the traffic underneath. Standards for the use of hammerhead piers are often maintained by individual transportation departments. A column bent pier consists of a cap beam and supporting columns forming a frame.

Column bent piers, as shown in Figure 3-c and Figure 27.5, can either be used to support a steel girder superstructure or be used as an integral pier where the cast-in-place construction technique is used. The columns can be either circular or rectangular in cross section. They are by far the most popular forms of piers in the modern highway system.

A pile extension pier consists of a drilled shaft as the foundation and the circular column extended from the shaft to form the substructure. An obvious advantage of this type of pier is that it occupies minimal amount of space. Widening an existing bridge in some instances may require pile extensions because limited space precludes the use of other types of foundations.



(a) Solid wall pier (b) Hammerhead pier (c) Rigid frame pier

FIGURE-3

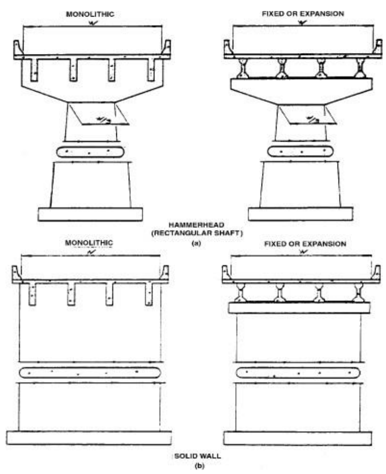
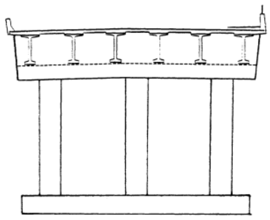
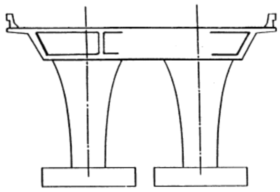


FIGURE-4



(a) Bent for precast girders



(b) Bent for cast-in-place girders

Abutments:-

They are the end supports of the superstructure, retaining earth on their back. They are built either with masonry, stone or brick work or ordinary mass concrete or reinforced concrete. The top surface of the abutment is made flat when the superstructure is of trusses or girders or semi-circular arch. In case of segmental or elliptical arch type of superstructure, the abutment top is made skew. Weep holes are provided at different levels through the body of the abutment to drain of the retained earth.

The salient features of bridge abutments are listed below.

(a) Height. The height of the abutments is kept equal to that of the piers.

(b) Abutment batter. The water face of the abutment is usually kept vertical or could be given a batter of 1 in 12 to 1 in 24 as of piers. The face retaining earth is given a batter of 1 in 6 or may be stepped down.

(c) Abutment Width. The top width of the abutment should provide enough space for the bridge seat and for the construction of a dwarf wall to retain earth up to the approach level.

(d) Length of Abutment. The length of abutment is kept at least equal to the width of the bridge.

(e) Abutment cap. The design is similar to that of pier cap.

Abutments can be spill-through or closed. The spill through abutment generally has a substantial berm to help restrain embankment settlement at the approach of the structure.

Approach embankment settlement can also be accommodated by approach slabs to eliminate bumps at the bridge ends, closed abutments partially or completely retain the approach embankments from spilling under the span, and Bridges of several spans require expansion at the abutments. Therefore they are no usually required to resist the longitudinal forces that develop.

Broadly, abutments are classified under the following categories.

1. Abutments with wing walls
2. Abutments without wing walls

Abutments with wing walls

(a) Straight Wing walls

(b) Splayed Wing walls

(c) Return Wing Walls

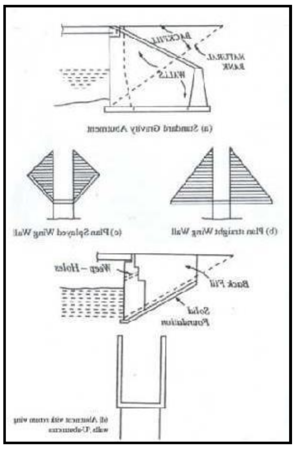
Abutments without wing walls

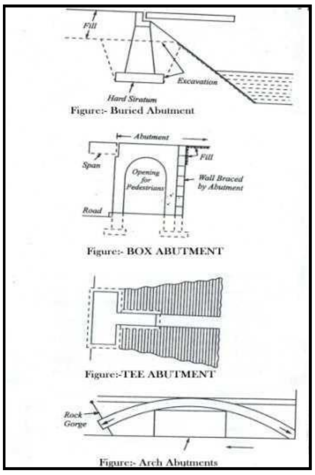
(a) Buried Abutments

(b) Box Abutments

(c) Tee Abutments

(d) Arch Abutments





FIGURES: - ABUTMENTS

Buried Abutments: - This type of abutments is generally built prior to the placing of the fill. Since it is filled on both sides the earth pressure is low. Superstructure erection can be begin before placement of fill .

Box Abutments: - This employs a short span of bridge built integral with columns to act as a frame and resist earth pressure of the approaches. It is most often used overpass work where the short span may be employed for pedestrian passage (see figure).

Tee Abutments: - This type looks like T in plan and has now become absolute (see figure)

Arch Abutments: - This type of abutment is used where arches are employed because of their economy in certain conditions. The high inclined skewback thrusts are difficult to handle unless the abutment can be seated in rock. Therefore, they are often used for span over gorges. (see figure)

WING WALLS:

In a bridge, the wing walls are adjacent to the abutments and act as retaining_walls. They are generally constructed of the same material as those of abutments. The wing walls can either be attached to the abutment or be independent of it. Wing walls are provided at both ends of the abutments to retain the earth filling of the approaches. Their design period depends upon the nature of the embankment and does not depend upon the type or parts of the bridge.[1]

The soil and fill supporting the roadway and approach embankment are retained by the wing walls, which can be at a right angle to the abutment or splayed at different angles. The wing walls are generally constructed at the same time and of the same materials as the abutments.

Classification of wing walls

Wing walls can be classified according to their position in plan with respect to banks and abutments. The classification is as follows:

1. Straight Wing walls: They are used for small bridges, on drains with low banks and for railway bridges in cities (weep holes are provided).

2. Splayed Wing walls: These are used for bridges across rivers. They provide smooth entry and exit to the water. The splay is usually 45°. Their top width is 0.5 m, face batter 1 in 12 and back batter 1 in 6, weep holes are provided.

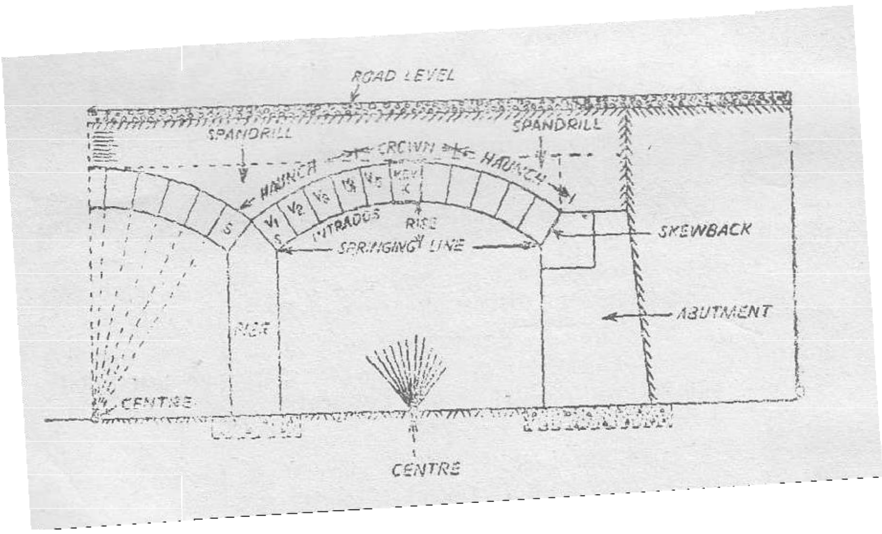
3. Return Wing walls: They are used where banks are high and hard or firm. Their top width is 1.5 m and face is vertical and back battered 1 in 4. Scour can be a problem for wing walls and abutments both, as the water in the stream erodes the supporting soil.[

CHAPTER-35

PERMANENT BRIDGES

Masonry Bridges:-

Bridge unit the spandrel, which supports the bridge roadway. The spandrel is made from gravel or crushed stone backing held in by lateral (side) walls made of concrete masonry or stonework or in the form of an open main load-bearing structures are made of natural stone, brick, or concrete blocks. Such a bridge is always arched, with massive supports. The main load-bearing element of a masonry bridge is the arch, over which is structure of small arches resting on crosswalk. The advantages of a masonry bridge are its architectural attractiveness and its durability. Masonry bridges are known that have been in use for more than 1,000 years. The basic short comings that limit the use of masonry bridges are their complexity and labor intensiveness of construction.. Their simplicity, economy and ease with which pleasing appearance can be obtained make them suitable for this purpose.



Classification of steel bridges

Steel bridges are classified according to

- the type of traffic carried
- the type of main structural system
- the position of the carriage way relative to the main structural system

These are briefly discussed in this section.

Classification based on type of traffic carried

Bridges are classified as

- Highway or road bridges
- Railway or rail bridges
- Road - cum - rail bridges

Classification based on the main structural system

Many different types of structural systems are used in bridges depending upon the span, carriageway width and types of traffic. Classification, according to makeup of main load carrying system, is as follows:

(i) Girder bridges - Flexure or bending between vertical supports is the main structural action in this type. Girder bridges may be either solid web girders or truss girders or box girders. Plate girder bridges are adopted for simply supported spans less than 50 m and box girders for continuous spans up to 250 m. Cross sections of a typical plate girder and box girder bridges are shown in Fig.7.2 (a) and Fig. 7.2(b) respectively. Truss bridges [See Fig.7. 2(c)] are suitable for the span range of 30 m to 375 m. Cantilever bridges have been built with success with main spans of 300 m to 550 m. . They may be further, sub-divided into simple spans, continuous spans and suspended-and-cantilevered spans, as illustrated in Fig.7. 3.

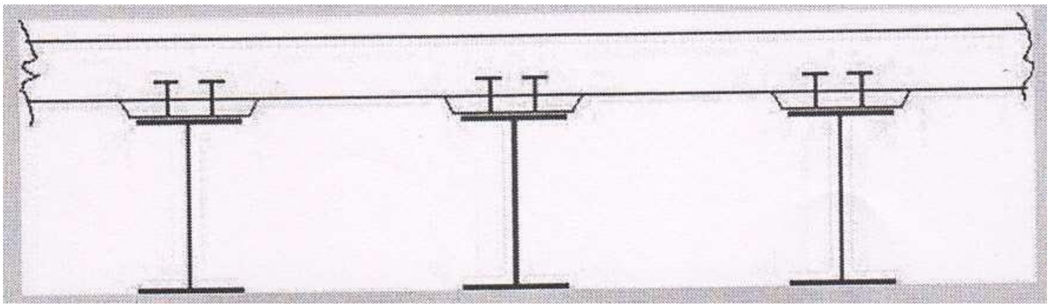


Fig.7.2 (a) Plate girder bridge section

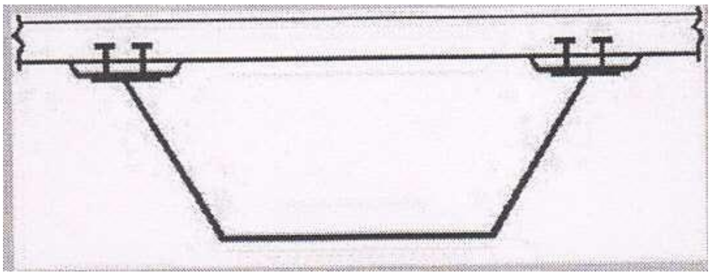


Fig.7.2 (b) Box girder bridge section

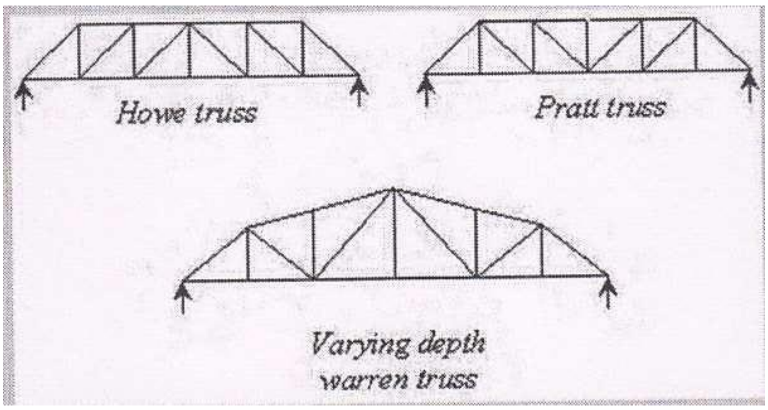


Fig.7.2 (c) Some of the trusses used in steel bridges

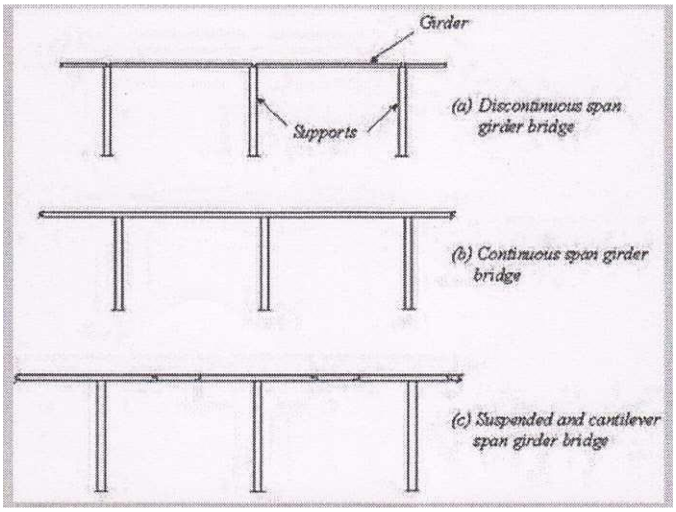


Fig.7.3 Typical girder bridges

(ii) Rigid frame bridges - In this type, the longitudinal girders are made structurally continuous with the vertical or inclined supporting member by means of moment carrying joints [Fig.7.4]. Flexure with some axial force is the main forces in the members in this type. Rigid frame bridges are suitable in the span range of 25 m to 200 m.

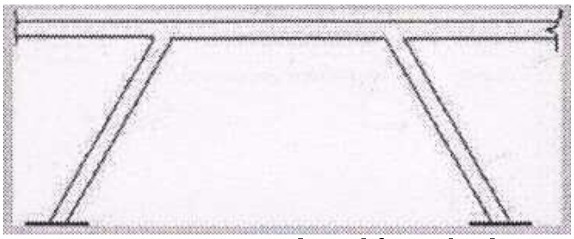
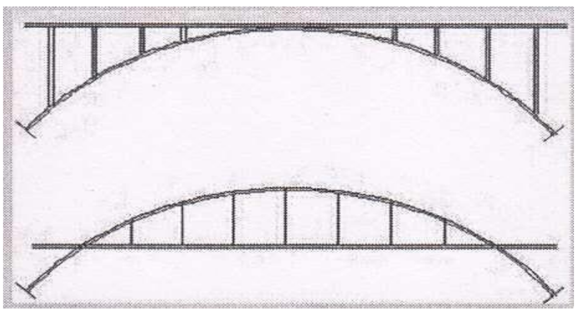


Fig.7.4 Typical rigid frame bridge

(iii) Arch bridges

The loads are transferred to the foundations by arches acting as the main structural element. Axial compression in arch rib is the main force, combined with some bending. Arch bridges are competitive in span range of 200 m to 500 m.



(iv) Cable stayed bridges - Cables in the vertical or near vertical planes support the main longitudinal girders. These cables are hung from one or more tall towers, and are usually anchored at the bottom to the girders. Cable stayed bridges are economical when the span is about 150 m to 700 m. Layout of cable stayed bridges are shown in Fig. 7.6.

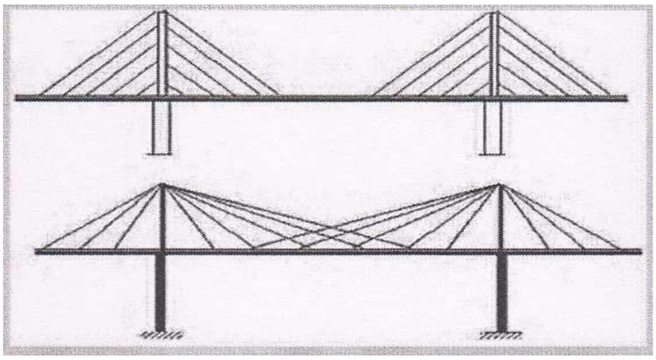


Fig.7.6 Layout of cable stayed bridges

(v) Suspension bridges - The bridge deck is suspended from cables stretched over the gap to be bridged, anchored to the ground at two ends and passing over tall towers erected at or near the two edges of the gap. Currently, the suspension bridge is best solution for long span bridges. Fig. shows a typical suspension bridge. Fig. 7.8 shows normal span range of different bridge types.

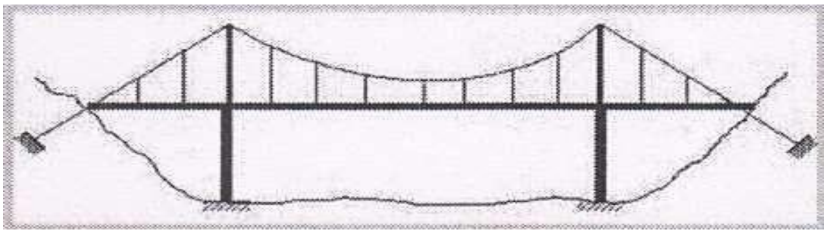


Fig.7.7 Suspension bridge

Classification based on the position of carriageway

The bridges may be of the "deck type", "through type" or "semi-through type". These are described below with respect to truss bridges:

(i) Deck type bridge -The carriageway rests on the top of the main load carrying members. In the deck type plate girder bridge, the roadway or railway is placed on the top flanges. In the deck type truss girder bridge, the roadway or railway is placed at the top chord level as shown in Fig. 7.9(a).

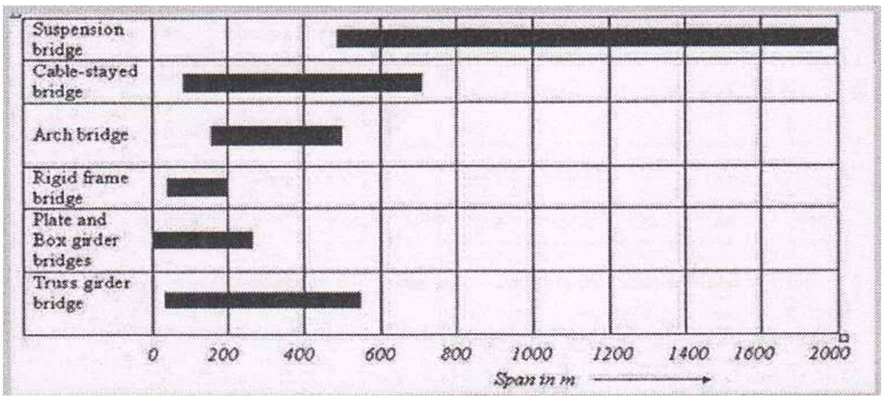
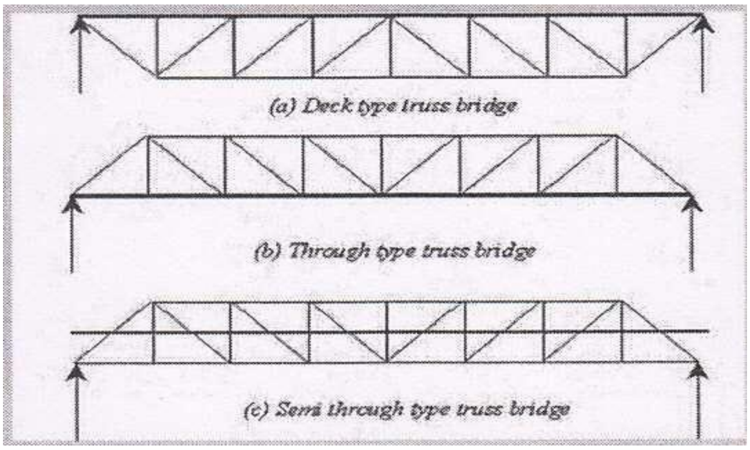


Fig.7.8 Normal span ranges of bridge system



TYPES OF CONCRETE BRIDGES

Arch Bridges

Arch bridges derive their strength from the fact that vertical loads on the arch generate compressive forces in the arch ring, which is constructed of materials well able to withstand these forces. The compressive forces in the arch ring result in inclined thrusts at the abutments, and it is essential that arch abutments are well founded or buttressed to resist the vertical and horizontal components of these thrusts. If the supports spread apart the arch falls down. Traditionally, arch bridges were constructed of stone, brick or mass concrete since these materials are very strong in compression and the arch could be configured so that tensile stresses did not develop. Modern concrete arch bridges utilize prestressing or reinforcing to resist the tensile stresses which can develop in slender arch rings.

Reinforced Slab Bridges

For short spans, a solid reinforced concrete slab, generally cast in-situ rather than precast, is the simplest design. It is also cost-effective, since the flat, level soffit means that false work and formwork are also simple. Reinforcement, too, is uncomplicated. With larger spans, the reinforced slab has to be thicker to carry the extra stresses under load. This extra weight of the slab itself then becomes a problem, which can be solved in one of two ways. The first is to use prestressing techniques and the second is to reduce the deadweight of the slab by including 'voids', often expanded polystyrene cylinders. Up to about 25m span, such voided slabs are more economical than prestressed slabs.

Beam and Slab Bridge

Beam and slab bridges are probably the most common form of concrete bridge in the UK today, thanks to the success of standard precast prestressed concrete beams developed originally by the Prestressed Concrete Development Group (Cement & Concrete Association) supplemented later by alternative designs by others, culminating in the Y-beam introduced by the Prestressed Concrete Association in the late 1980s.

They have the virtue of simplicity, economy, wide availability of the standard sections, and speed of erection.The precast beams are placed on the supporting piers or abutments, usually on rubber bearings which are maintenance free. An in-situ reinforced concrete deck slab is then cast on permanent shuttering which spans between the beams.

The precast beams can be joined together at the supports to form continuous beams which are structurally more efficient. However, this is not normally done because the costs involved are not justified by the increased efficiency.

Simply supported concrete beams and slab bridges are now giving way to integral bridges which offer the advantages of less cost and lower maintenance due to the elimination of expansion joints and bearings.

Techniques of construction vary according to the actual design and situation of the bridge, there being three main types:

1. Incrementally launched
2. Span-by-span
3. Balanced cantilever

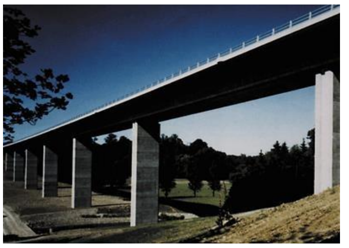
Incrementally launched

As the name suggests, the incrementally launched technique creates the bridge section by section, pushing the structure outwards from the abutment towards the pier. The practical limit on span for the technique is around 75m.

Span-by-span

The span-by-span method is used for multi-span viaducts, where the individual span can be up to 60m.

These bridges are usually constructed in-situ with the false work moved forward span by span, but can be built of precast sections, put together as single spans and dropped into place, span by span.



Balanced cantilever

In the early 1950's, the German engineer Ulrich Finsterwalder developed a way of erecting prestressed concrete cantilevers segment by segment with each additional unit being prestressed to those already in position. This avoids the need for false work and the system has since been developed.

Whether created in-situ or using precast segments, the balanced cantilever is one of the most dramatic ways of building a bridge. Work starts with the construction of the abutments and piers. Then, from each pier, the bridge is constructed in both directions simultaneously. In this way, each pier remains stable - hence 'balanced' - until finally the individual structural elements meet and is connected together. In every case, the segments are progressively tied back to the piers by means of prestressing tendons or bars threaded through each unit.

Integral Bridges

One of the difficulties in designing any structure is deciding where to put the joints. These are necessary to allow movement as the structure expands under the heat of the summer sun and contracts during the cold of winter. Expansion joints in bridges are notoriously prone to leakage. Water laden with road salts can then reach the tops of the piers and the abutments, and this can result in corrosion of all reinforcement. The expansive effects of rust can split concrete apart. In addition, expansion joints and bearings are an additional cost so more and more bridges are being built without either. Such structures, called 'integral bridges', can be constructed with all types of concrete deck. They are constructed with their decks connected directly to the supporting piers and abutments and with no provision in the form of bearings or expansion joints for thermal movement. Thermal movement of the deck is accommodated by flexure of the supporting piers and horizontal movements of the abutments, with elastic compression of the surrounding soil.

Already used for lengths up to 60m, the integral bridge is becoming increasingly popular as engineers and designers find other ways of dealing with thermal movement.

Cable-Stayed Bridges

For really large spans, one solution is the cable-stayed bridge. These types of bridges first developed in west Germany. They consists of cables provided above the deck and are connected to the towers. The deck is either supported by a number cables meeting in a bunch at the tower or by joining at different levels on the tower. The multiple cables would facilitate smaller distance between points of supports for the deck girders. This results in reduction of structure depth. The cables can arrange in one plane or two planes. The two plane system requires additional widths to accommodate the towers and deck anchorages. Singly plane system requires less width of deck. Where all elements are concrete, the design consists of supporting towers carrying cables which support the bridge from both sides of the tower. Most cable-stayed bridges are built using a form of cantilever construction which can be either in-situ or precast.

The cable stayed bridges are similar to suspension bridges except that there are no suspenders in the cable stayed bridges and the cables are directly stretched from the towers to connect with decking. No special anchorage is required for the cables as incase of suspension bridges because the anchorage at one end is done in the girder and at the other on top of tower. The cable-stayed bridges have been found economical for up to span 300m. However due to cantilever effect their deflection is rather high and hence they are not preferred for very long span in railways.

Suspension Bridges

Concrete plays an important part in the construction of a suspension bridge suspension bridgs are ideal solution for bridging gaps in hilly areas because of their construction technology and capacity of spanning large gaps. There will be massive foundations, usually embedded in the ground, that support the weight and cable anchorages .The cable takes shape of catenary between two points of suspension. The flooring of bridge supported by the cable by virtue of tension developed in its cross section. The vertical members are known as **suspenders** are provided to transfer load from bridge floor to suspension cable. There will also be the abutments, again probably in mass concrete, providing the vital strength and ability to resist the enormous forces, and in addition, the slender superstructures carrying the upper ends of the supporting cables are also generally made from reinforced concrete.

Typical deck, through and semi-through type truss bridges

(ii) Through Type Bridge - The carriageway rests at the bottom level of the main load carrying members. In the through type plate girder bridge, the roadway or railway is placed at the level of bottom flanges. In the through type truss girder bridge, the roadway or railway is placed at the bottom chord level. The bracing of the top flange or lateral support of the top chord under compression is also required.

(iii) Semi through Type Bridge - The deck lies in between the top and the bottom of the main load carrying members. The bracing of the top flange or top chord under compression is not done and part of the load carrying system project above the floor level The lateral restraint in the system is obtained usually by the U-frame action of the verticals and cross beam acting together.

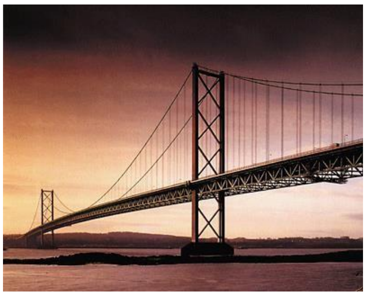
Concrete bridges-

They can be divided into the following main classes

(1)Unstiffened suspension Bridges.

(2) Stiffened suspension Bridges.

Un-stiffened suspension Bridges:-Incase of Un-stiffened suspension Bridges the moving load is transferred direct to the cables by each suspender. These are used for light construction such as foot bridges forest train structures, etc where the moving load is negligible and deflection requirements are not controlling. Also the places where span is very long and the ratio dead to moving load intensity is so great to render stiffening unnecessary.



Stiffened suspension Bridges:-In stiffened type suspension Bridges moving loads are transformed to the cables through medium of trusses called **stiffening girders** .The stiffening girder assists the cable to become more rigid and prevent change in shape and gradient of roadway platform. It is therefore adopted for heavy traffic .

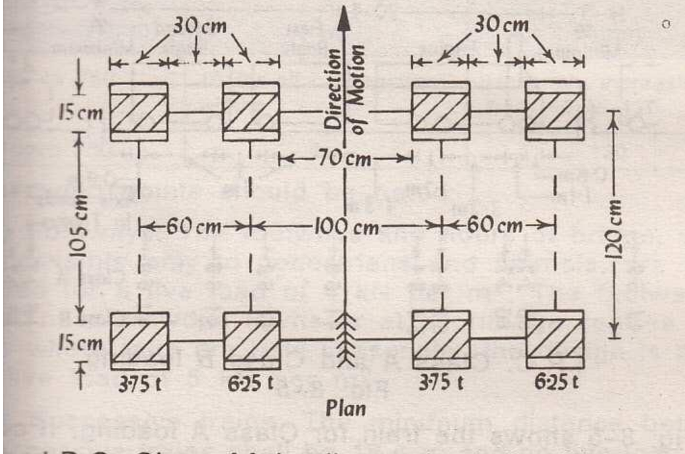
IRC Bridge loading:-

The public roads in India are managed and controlled by the Government and hence bridges to be constructed for roads to be designed as per standards set up by standard authorities. For highway bridges standard specifications are contained in the Indian Road Congress (I.R.C) Bridge code. In India, highway bridges are designed in accordance with IRC bridge code. IRC: 6 - 1966 – Section II gives the specifications for the various loads and stresses to be considered in bridge design. There are three types of standard loadings for which the bridges are designed namely,

(a) IRC class AA loading,
(b) IRC class A loading
(c) IRC class B loading.

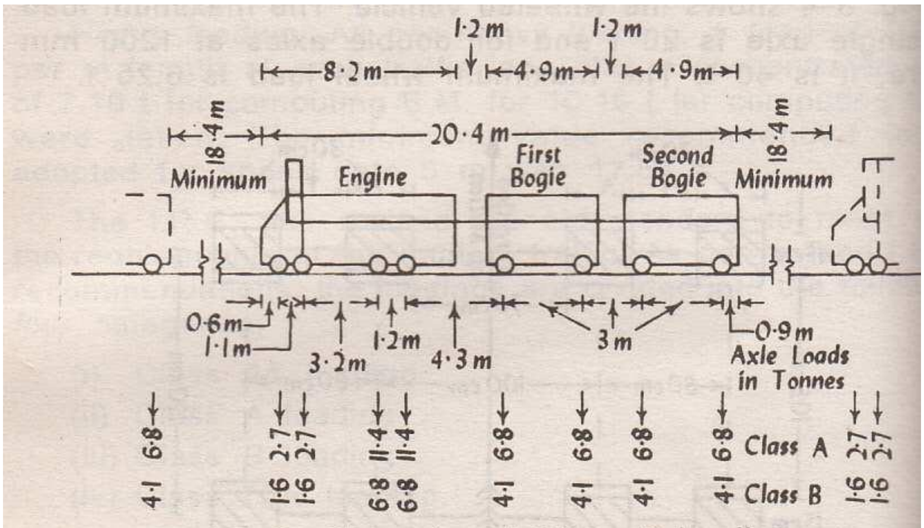
IRC class AA loading:-

IRC class AA loading consists of either a tracked vehicle of 70 tonnes or a wheeled vehicle of 40 tonnes with dimensions as shown in Fig. The units in the figure are mm for length and tonnes for load. Normally, bridges on national highways and state highways are designed for these loadings. Bridges designed for class AA should be checked for IRC class A loading also, since under certain conditions, larger stresses may be obtained under class A loading. Sometimes class 70 R loading given in the Appendix - I of IRC: 6 - 1966 - Section II can be used for IRC class AA loading. Class 70 Rloading is not discussed further here.



I.R.C. Class AA loading—wheeled vehicle

IRC class A loading:-Class A loading is based on heaviest type commercial vehicle consists of a wheel load train composed of a driving vehicle and two trailers of specified axle spacings. This loading is normally adopted on all roads on which permanent bridges are constructed.



I.R.C. Class *A* and Class *B* loading

. **IRC class B loading**:-Class B loading is adopted for temporary structures and for bridges in specified areas. For class A and class B loadings, reader is

referred to IRC: 6 - 1966 – Section II.

CHAPTER-36

CULVERTS AND CAUSE WAYS

Culvert- A culvert is defined as a small bridge constructed over a stream which remains dry most part of the year. It is across drainage work having total length not exceeding 6m between faces of abutment.

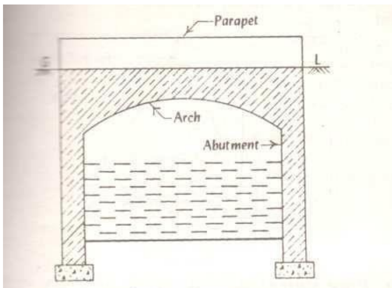
Types of Culverts;-

The following are six different type culvert.

1. Arch culvert
2. Box culvert
3. Pipe Culvert
4. Slab Culvert

Arch culvert:-

An arch culvert consists of abutments wing walls, arch, parapets and the foundation. The construction materials commonly used are brick work or concrete. Floor and curtain wall may or may not be provided depending upon the nature of foundation soil and velocity of flow. A typical arch culvert is shown in figure.



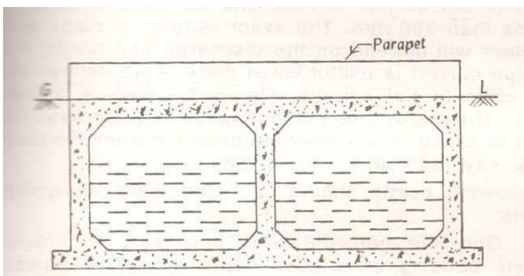
Arch culvert
FIG. 6–1

Box culvert:-

In case of box culvert the rectangular boxes are formed of masonry, R.C.C or steel. The R.C.C box culverts are very common and they consist of the following two component

(i) The barrel or box section of sufficient length to accommodate the roadway and the Krebs.

(ii) The wing walls splayed at 45 for retaining the embankment and also guiding the flow of water into and out of the barrel.



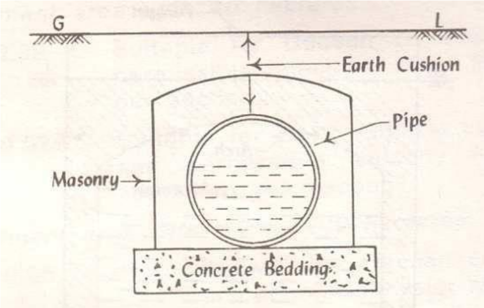
An R.C.C. box culvert
FIG. 6–2

Fig. 6-2 shows an R.C.C box culvert with two openings. Following points should be noted.

(i)Foundation: The box culverts prove to be safe where good foundations are easily available.
(ii)Height: The clear vent height i.e. the vertical distance between top and bottom of the culvert rarely exceeds 3 meters.
(iii) Sap: The box culverts are provided singly or in multiple units with individual span exceed about 6 m or so, it requires thick section which will make the construction uneconomical.
(iv) Top: Depending upon the site conditions, the top level of box may be at the road level or it can even be at a depth below road level with filling of suitable material.

Pipe Culvert:

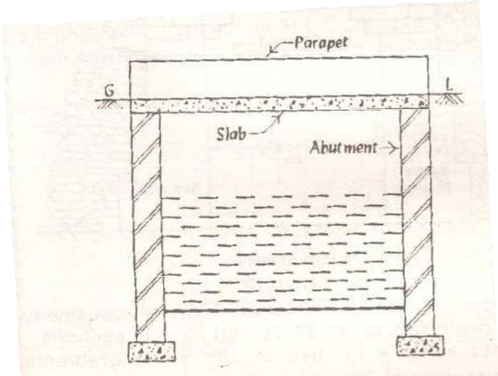
They are provided when discharge of stream is small or when sufficient headway is not available. Usually one or more pipes of diameter not less than 60cm are placed side by side. Their exact number and diameter depend upon the discharge and height of bank. For easy approach of water splayed type wing walls are provided in fig. 6.3 shows a Hume pipes culvert of single pipe. The pipes can be built of masonry. Stone ware, cement concrete, cast iron or steel. Concrete bedding should also be given below the pipes and earth cushion of sufficient thickness on the top to protect the pipes and their joints. For Economic reason road culverts should have non-pressure heavy duty pipes of type ISI class NP3 conforming to IS:458-1961. As far possible the gradient of the pipe should not be less than 1000.



Pipe culvert
FIG. 6–3

Slab Culvert:

A slab culvert consists of stone slabs or R.C.C slab, suitably support on masonry walls on either side. As shown in fig 6-4. The slab culverts of simply type are suitable up to a maximum span of 2.50 m or so. However the R.C.C culverts of deck slab type can economically be adopted up to spans of about 8 m. However, the thickness of slab and dead weight may sometimes prove to be the limiting factors for deciding the economical span of this type of culverts.



Slab culvert
FIG. 6-4

The construction of slab culverts is relatively simple as the frame work can easily be arranged, reinforcement can be suitably placed and concreting can be done easily. This type of culvert can be used for highway as well as Railway Bridge. Depending upon the span of culvert and site conditions the abutment and wing walls of suitable dimensions may be provided. The parapet or hand rail of at least 750 mm height should be provided on the slab to define the width of culvert.

CAUSEWAYS :

A road causeway is a pucca dip which allows floods to pass over it. It may or may not have opening or vents for low water to flow. If it has vents for low water to flow then it is known as high level causeway or submersible bridge ; otherwise a low level causeway.

TYPES OF CAUSEWAY:

A) **Low level causeway**:

It is also known as Irish Bridge. The beds of small rivers or streams, which remain dry for most part of the year, are generally passable without a bridge. This involves heavy earth works in cutting for bridge approaches .Banks of such types of streams are cut down at an easy slope. For streams of rivers in plains having sandy beds, it is often sufficient to lay bundles of grass over and across the sandy track. The bundles may be of 20 to 25cm in diameter whose ends are secured by longitudinal fascines pegged down by stakes.

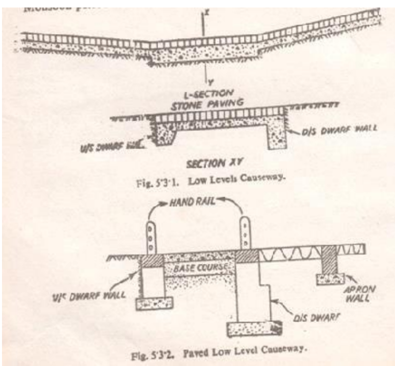


Fig. 5·3·1. Low Levels Causeway.
Fig. 5·3·2. Paved Low Level Causeway.

For crossings important from traffic point of view it is essential to lay a metal or pucca paving of stone or brick set in lime mortar on a substantial bed of concrete. To prevent against possible scour and undermining a cut off or dwarf wall usually 60cm deep on the upstream side and 120 to 150cm on downstream side is provided. Fig. 5.3.1 below shows the details of a typical Irish bridge.

The low level causeway could be provided with openings formed by concrete Hume pipes if there is a continuous flow stream during the monsoon periods.

B) **High level Causeway**:

A high level causeway is submersible road bridge designed to be overtopped in floods. Its formation level is fixed in such a way as not to cause interruption to traffic during floods for more than three days at a time not for more than six times in a year. A sufficient numbers of openings are provided to allow the normal flood discharge to pass through them with the required clearance. They are provided with abutments and piers, floors and slabs or arches to form the required number of openings. The slope of the approaches is kept as 1 in 20.When the velocity is high and stream bed is soft the aprons could be of concrete or harder masonry upto a certain distance. Similarly, the road can be formed of a cement concrete slab or stone blocks set in cement mortar. A typical type of high level causeway is shown in Fig.5.3.3.If railing are provided in the bridge, they should be of collapsible type.Temporary causeways used for an emergency military operations are formed either by using timber stringers and planking over cribs used as piers or by constructing a culvert using pipes.

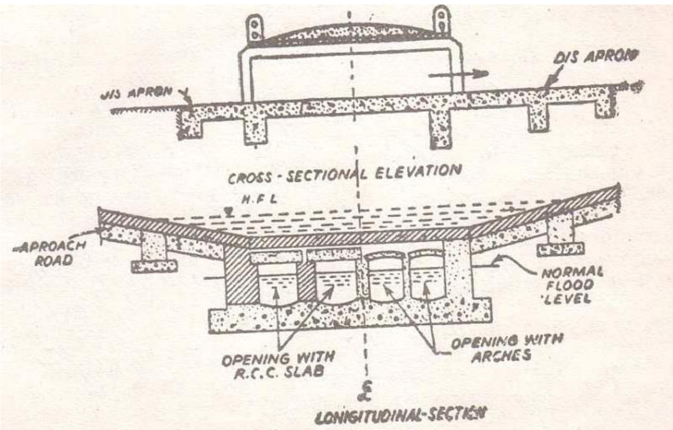


Fig. 5·3·3. High Level Causeway.

DOCKS & HARBOURS

CHAPTER-37

INTRODUCTION

Definition of Harbours:

Harbour can be defined as a protected area of the sea in which vessels/ships could be launched, built or taken for repairs; or could take refuge in time of storm; or provide facilities for loading of cargo and passengers.

Necessity of Harbours:

Followings are the necessity of harbours.

(i) To provide shelter to the ships during their cruise.

(ii) To launch a ship.

(iii) To facilitate the loading and unloading of cargo as well as passangers from the ship.

(iv) To provide shelter to the ships during storm.

(v) To provide space for repair of ships.

Types of Harbour:

Harbours could be classified as **natural** or **functional**. The **natural classification** can be as below:

(1) **Natural harbour** is protected from storms and waves by the natural land contours, rocky outcrops, or islands. The entrance to such a harbour is so formed that it permits navigation but, ensures calmness in the harbour. Examples of natural harbours are Kandla, Mumbai, New York, San Francisco, London, and Rio de Janeiro.

(2) **Semi- natural** harbour is protected on sides by headlands and requires man-made protection only to the entrance. Vishakhapatnam is example of semi-natural harbours.

(3) **Artificial harbour or man-made harbour**, is protected from storms and waves by construction of breakwaters, or is created by dredging. Hamburg, Le Havre and Madras are some of the examples. Similarly, lagoon harbours of Paradip and Mangalore, created by protective breakwaters at the entrance are other examples.

The **functional classification** is as given below.

(1) **Commercial harbour** is in which facilities are provided for loading and unloading of cargo. Docks and berths are provided for the purpose of handling cargo. Either as a part of the bigger harbour complex, or independently as a unit, single commodity harbour or terminal is provided, such as oil terminal, coal port, ore port, and so on. A fishery harbour is also provided for fishing crafts and trawlers. These are all specialised unit-purpose types of commercial harbours. Madras, Kandla, and Okha are examples of commercial harbours.

(2) **Military harbour**, or naval base, is one which is meant for the purpose of accommodating naval crafts and serving as a supply depot. Hampton Roads and Pearl Harbour are the examples. Mumbai harbour is essentially a commercial complex with an oil terminal and general cargo berths, but it has a naval base also; so is the case with Cochin.

(3) **Harbour of refuge** is that which is use as a haven for ships in a storm, or it may be a part of a commercial harbour. The requirements of such a harbour are a good anchorage and an easy and safe access from the sea. Sand bay on the east coast of U.S.A is a well known harbour of refuge. Dover in England and outer harbours of Madras and Vishakhapatnam are examples of combined harbours of refuge and commercial harbours.

Components of a Harbour:

Main function of a harbour is to provide safe and suitable accommodation for vessels seeking refuge, supplies, refuelling, repairs or the transfer of cargo and passengers. In a harbour there are a variety of elements such as entrance, approach channel, breakwater, wharves jetties, locks and dry docks, depending on the necessity of these. Such elements can be of different types.

(1) *Harbour Entrances:* The entrance to a harbour is usually more exposed to waves as compared to the harbour itself. Due to this, depth and width required at the entrance are more than those required in the channel. The width of entrance depends upon the density of the traffic and number of entrances, besides the navigational requirements and the degree of protection the channel has and what is desired within the harbour. The entrance should be wide enough for navigation requirements and so as to avoid dangerous tidal currents. It should not, however, be too wide to increase wave height within harbour.

(2) *Approach channel:* Ideally, the depth of water naturally available in the entire harbour area should be sufficient for navigation of design vessel at all the times. When such ideal condition do not prevail, a channel within sufficient depth and width must be dredged too provide for a passage of ships between the harbour entrance and the docks. The alignment and the dimensions of channel are determined after considering factors involved in channel design. The terminology approach channel is used for the dredged fairway through which ships proceed from the open sea to the harbour basin. The portion of channel which lies beyond the harbour entrance in the open sea is called an outer channel. The portion lying between the harbour entrance and harbour basin is called an inner channel. The inner channel is protected from storms and waves by natural configurations or by breakwaters.

(3) *Turning Basin*: It is the area required for manoeuvring the ship when it goes to or leaves the berth, so that a ship can leave head-on. The size of the turning basin primarily depends on the design vessel. It should preferably be designed to have a ship turn under continuous headway without help of tug. This means that the turning basin should be large enough to permit a free turning.

(4) *Sheltered Basin:* It is the area protected by shore and breakwaters. In this basin are located other elements of harbour including area for anchorage of vessels.

(5) Breakwaters: The main function of a breakwater, or a system of breakwaters, is to protect the enclosed area of water from storm waves. Thus, a breakwater helps in achieving calmness in the harbour and thereby contributes to the safety of the vessel within and its easy working. The monolithic structure usually provided at the tip of the breakwater is called the pier-head.

(6) *Wharves and Quays:* These are usually constructed parallel to shore or breakwater within the harbour and are meant to permit berthing of vessel alongside for cargo working. They have backfill of earth or other material and have wide platform at top.

(7) *Jetties and Piers:* These are solid or open type of structures with a wide platform on top to permit cargo working of vessels berthed alongside. They are built out from the shore to reduce silting and dredging, permitting free flow of tidal currents.

(8) *Lock* and *Locked Basin:* Locked basin is an enclosed basin wherein a number of vessels can be berthed and has an entrance which is controlled by lock gate(s). The water within locked basin can be independent of outside water level changes.

(9) *Dry Docks and Slipways*: These are essentially provided for maintenance, repairs and construction of ships. A dock for the construction of ships is termed as a building dock. They can be kept dry for easy working. Dry dock has a gate in the entrance which is closed after taking the vessel in and the water is pumped out to render it dry.

(10) *Ancillaries:* These include moorings, anchors, buoys, lights, transit sheds and warehouses, fire protection towers, and other service units as required at different locations in the harbour and port complex.

Layout of harbour

There are no specified rules governing the layout of a harbour. Varied layouts have worked successfully to the credit of their designers. Conception, creativity, and experience are very important in the laying out of a harbour. Seaham harbour on the rocky exposed north-east coast of U.K., lying in the lee of steep cliffs without any relief; Vishakhapatnam harbour, on the east coast of India, with an ingenious system to protect the navigation channel from fouling by sand littoral drift; Madras with its strong breakwaters as a protection against stormy seas, although having passed through vicissitudes, are a few examples of bold conception and ingenuity in design.

There are two main considerations, in the harbour layout; of littoral drift and protection from the storm waves. The third point is the size and shape of the harbour, and the layout of wharves and jetties, and spending beaches, so as to reduce the effect of sub-marine waves and eliminate ranging in the harbour as far as possible.

Where breakwaters are laid out to protect harbours, one of the two measures is, sometimes, possible against littoral drift. In one case, particularly for shallow draught harbours, openings are kept from near the shore in the breakwater to permit comparative easy flow of littoral drift across to the other side. This means that the main breakwater is connected to the shore by a sort of bridge. The other measure is to provide a sand trap, in the lee of the breakwater, as in the case of Vishakhapatnam. Here, between the shore and the breakwater, an opening was left for the littoral sand to flow in the trap provided in the sheltered area before the navigation channel. sometimes, no specific remedy to handle littoral drift is adopted and the material being accumulated is simply mechanically removed, as in case of Madras .There are, on the other hand, ports of Veraval, porbandar and Okha, on the west coast of India, where the problem of littoral drift is of minor significance.

It must be realised that, littoral drift or otherwise, in any harbour where there is shipping, there is bound to be siltation. There is no escape from it. In some situations or in some deep water harbours the ill effect of siltation may not be felt immediately.

A moderate current in the approach channel is desirable. Considerable material is carried in suspension by tidal rivers or streams. The river Hoogly, at the time of flood, is stated to carry sediment by in the ratio of 1 to 575. Practically the same will be the case at rising spring tide at Bhavnagar. If, therefore, there is ebb current, the maintenance dredging of the fairway will be reduced.

Harbours which are inland, such as Calcutta, Kandla or Bhavnagar, are safe from the sea waves. There are some others, such as Okha and Mumbai, which are afforded protection naturally by the existence, of rocks or islands on their weather side. Otherwise, artificial protection, in the form of breakwaters, is necessary to be constructed, to provide a sheltered water area of adequate size for vessels to work. It is best to arrive at the breakwater alignment by model tests.

Very careful consideration is needed for selecting the harbour approach and its width. It is advisable to protect the entrance by a longer breakwater on the weather side. The width of the entrance may not be less than the length of the biggest vessel using the harbour. If there are likely to be waves of high amplitude at the harbour entrance, the possibility of the entering vessel touching the bottom must be considered. It is known that the surface of the trough of a wave is about one-third the wave height below the still-water level. If, therefore, there is a 6 m wave, it would lower the depth some 2 m in the trough. It follows that a vessel drawing 9 m runs the risk of striking the bottom in a depth of water of 11 m.

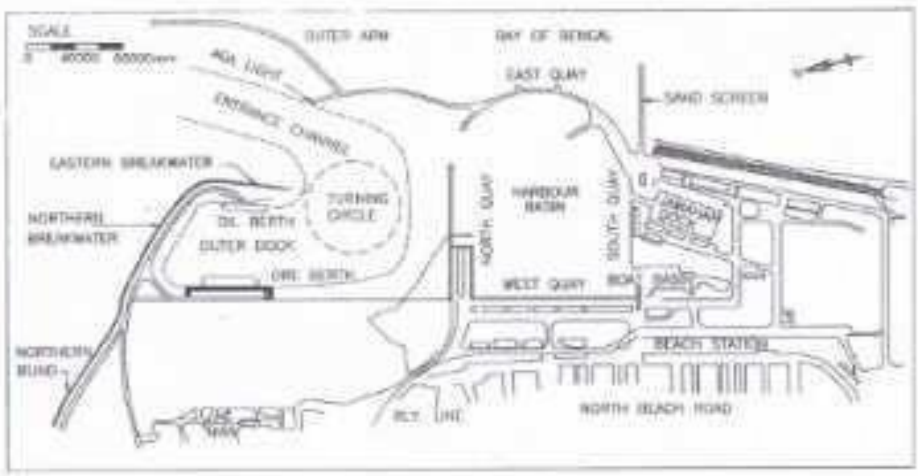


Fig. 13.1 Layout of Madras Harbour with outer Dock

Fig. 13-1 is of madras harbour with outer dock. This is an example of how adverse nature has been sought to be tackled, and what experience teaches in retrospect. It shows the original entrance from the east had to be closed and a new entrance from the north, with sheltering arm, had to be provided. It also shows the advance of the shore line to the south of the harbour.

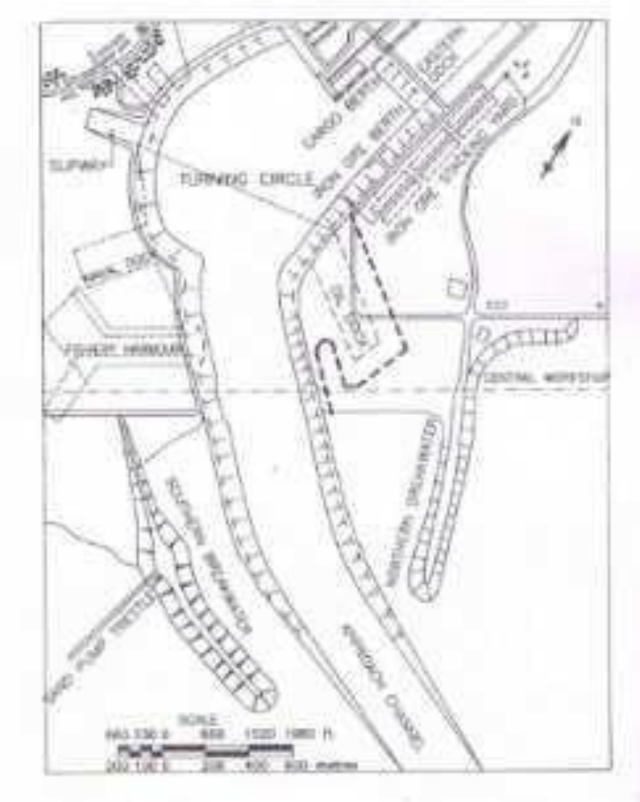


Fig. 13.2 Layout of Paradip Harbour

Fig. 13-2 is of Paradip harbour. This is also is a man-made harbour. It is a lagoon type harbour. It has carved out from an inhospitable shore and two short lengths of breakwaters are provided to shelter the approach from the sea. Technically, a lagoon-type harbour is easier to create; breakwaters are lighter, quays can be constructed in dry, and lagoon can excavated in dry before opening it up to the sea. But it requires land area and its growth potential is somewhat restricted.

Criteria for selection of site for a good harbour

In selection of a site for harbour, apart from engineering considerations, commercial, defence and strategic aspects should also be examined. In addition, due consideration of Coastal Regulation Zone (CRZ) as notified by the government of India under the Environment Protection Act (EPA) 1986 should be given. The guiding criteria in the selection of a site for good harbour are:

(1) Sea approach and marine conditions
(2) Sea-bed, sub-soil and foundation conditions
(3) Transport and communication links
(4) Seaborne traffic potential
(5) Industrial infrastructure and industrial development or potential in the hinterland
(6) Agricultural base of the hinterland and also its mining resources
(7) Electrical energy and fresh water supplies
(8) Availability of cheap land and proximity of constructional materials

The site should have maximum natural protection from winds and waves. Sufficiently large pool of water, with adequate depth, should be available to accommodate the expected shipping needs as well as to permit future expansions. The marine conditions should be favourable for structures as well as navigation. This would require low tidal range and small tidal currents, not too severe wind and waves, less littoral drift and no fog nuisance. The sea-bed should be such that it will hold ship anchors and that which would not involve excessive capital and maintenance dredging cost. Siltation should not be excessive nor scour pose a problem.

Other conditions of sub-soil for foundation purposes should be favourable. The site to be selected should preferably be on established trade route. The link with other parts of the country through rail, road, air and telephone should be relatively easy. The hinterland should be productive enough to support the trade. Also, the sea-traffic in the region should be showing signs of possible development. Availability of industrial infrastructure, electrical energy and fresh water supplies, cheap land, materials of construction and labour are also significant factors.

These are all desirable features, but not necessarily indispensable. As the world commerce and trade have expanded, more favourable harbour sites have been utilised and less advantageous ones are being developed. The modern engineering technology enables to overcome what formerly were considered to be formidable barriers: artificial protection (breakwater) could be afforded to hitherto unsafe places; even rocky sea-bed could be deepened; overland transport and communication in inaccessible places could be provided; difficult foundation condition could be mastered; and so on.

CHAPTER – 38

Breakwaters

Definition: *A breakwater is, a structure meant to reflect and dissipate the force of wind-generated waves and thereby to prevent their incidence on a water area it is intended to protect*.

Functions of Breakwaters: There are sites on the coast, or inland places, which are naturally protected from the fury of the sea. But, if a harbour is to be built on an open coast, as at Madras, it needs to be protected artificially by breakwaters. The main function of breakwater is to break the momentum of waterby means of wave breakers. Sometimes the inner side of a breakwater is constructed as quay for cargo handling and is known as a mole.

Types of breakwaters: Breakwaters are two types: (i) vertical wall type (ii) rubble mound type. Where the depth of water is very great, or the bearing capacity of the sea bed needs to be improved, a composite type with a vertical wall on a rubble mound base is used. There are many examples of composite types and the considerations will predominate depending upon whether the rubble mound or the vertical wall part dominates.

(i) Vertical Wall Breakwaters:

It was stated, in the XVIIIth International Navigation congress held at Lisbon in July 1953 that vertical wall breakwaters should be constructed, when:

a. The vertical wall breakwater should not be constructed in a depth of water less than twice the greatest storm wave as may approach the site of the proposed structure.
b. Sea bed is resistant to erosion.
c. Foundations are not subject to uneven settlement.

Even if the sea bed is not resistant to erosion, concrete block apron for protection can be provided. Also, load bearing characteristics of sea bed could be improved in various ways. If the top strata contain material like silt, soft clay, or fine sand, it is best to remove this strata, by trenching with a dredger. If the sea bed has inadequate bearing capacity, it could be improved by preparing a rubble base so as to distribute the load on a wider base. In moderate depths, a double row of sheet piles could be driven, to confine the soil, to improve its bearing capacity.

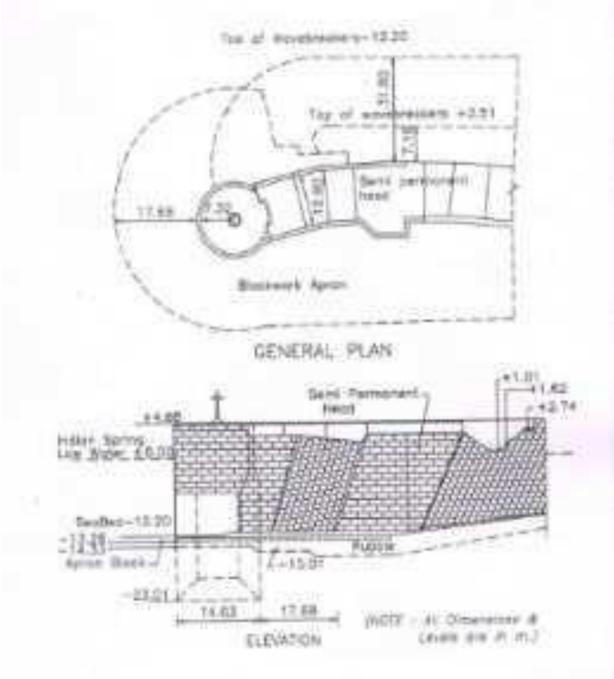


Fig.14.1 Vertical Breakwater wall at Madras

(ii) Rubble Mound Breakwater:

A rubble mound breakwater is comparatively safe. The looseness of the elements permits them to settle without damage and the broad base helps in distributing the load on a wider area and thus reducing unit load on the base. But, also quite some time, usually two years, must be allowed to pass, after laying the rubble mound, before a concrete cap is cast.

Fig. 14.2. A Rubble mound breakwater

Fig. 14. 2 is a typical rubble mound breakwater. In case of a rubble mound breakwater, the waves expend their energy on the structure. The disturbing influence of waves is most keenly felt between high water and low water levels. It is in this region that the structure is most severely tested.

A rubble mound breakwater consists of a central portion, called the core, and protective layers, called the armour. The core can consist of small pieces of stones and quarry run. But the armour layer is very important. In between the core and the armour layer, graded stones should be provided, both for the better dissipation of energy and also to protect the finer core material from being sucked out on the return wave.

(iii) Floating Breakwater:

Floating breakwater, which are a type of floating structure and differ essentially, in this respect, from gravity breakwaters which are permanently fixed to sea bottom, should be in more use. A schematic diagram, indicating the basic idea, is given as in Fig. 14.3.

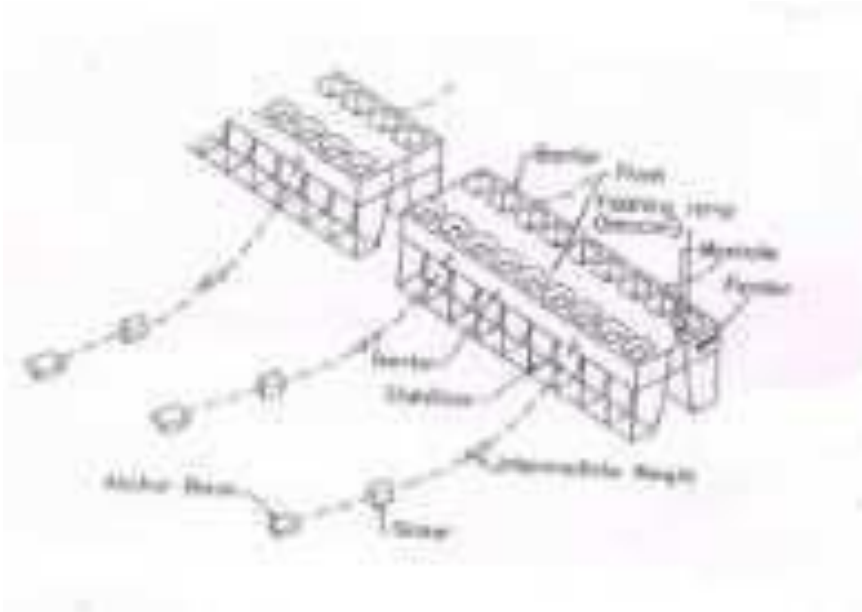


Fig. 14.3. Schematic diagram of floating breakwater

CHAPTER-39

Docks

Definition:

Docks are enclosed areas for berthing ships, to keep them afloat at a uniform level, to facilitate loading and unloading cargo. These docks are also known as wet ducks.

Functions of Docks

A. Wet docks

(i) Docks are necessary because discharging of the cargo of ships requires a number of days during which period, if the ship is subjected to vertical movement by the tide, great inconvenience will be caused and special arrangements will have to be made for the lifting of the cargo. Thus, the uniform level of water as maintained in the docks by providing locks and gates is very convenient for handling the cargo.

(ii) Harbours are prone to be affected by tides, which may cause changes in water level. If at low tides, the level of water is insufficient to ground the ships, in such cases ships could be berthed in ducks.

(iii) Ducks prevent rubbing of the ships' sides against quay walls.

(iv) Effect of storms in the outer sea and harbour do not obstruct the dock enclosure.

(v) Fig. 15.1(a) and (b) show the location of docks with lock, gates, breakwaters etc. on river and sea side's respectively.

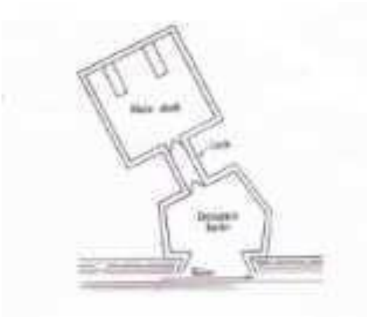


Fig. 15.1(a) Wet dock location on river side

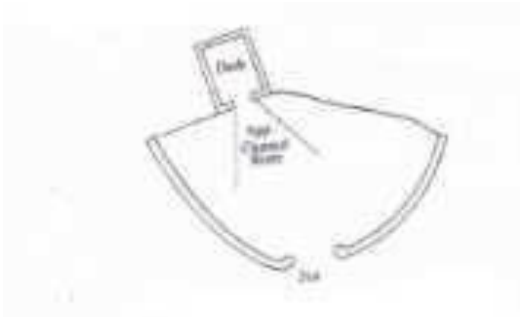


Fig. 15.1(b) Wet dock location and basin formation

B. Repair Docks

(i) Repair docks are necessary for the execution of repairs, cleaning and painting of ships' bottoms.

(ii)Hence, these docks and docking arrangements should be such as to expose the ship's exterior fully and keep it out of water during the progress of repairs or renovation.

(iii)These docks are important in case of major sea ports. The bottoms of ships require scraping and cleaning at intervals so that he ships can maintain the speed.

There are generally four classes of such docks, viz.:

- Graving or dry dock
- Floating dock
- Marine railway

- Lift docks.

Dry Dock:

As the name suggests, the arrangement in a dry dock is to take in a ship, close the gate, and pump out the water. Sometimes, it is possible to take advantage of tidal variation so as to reduce the need of pumping. We shall consider these cases.

Fig.15.2 A pictorial view of Alfredo Da Silva dock

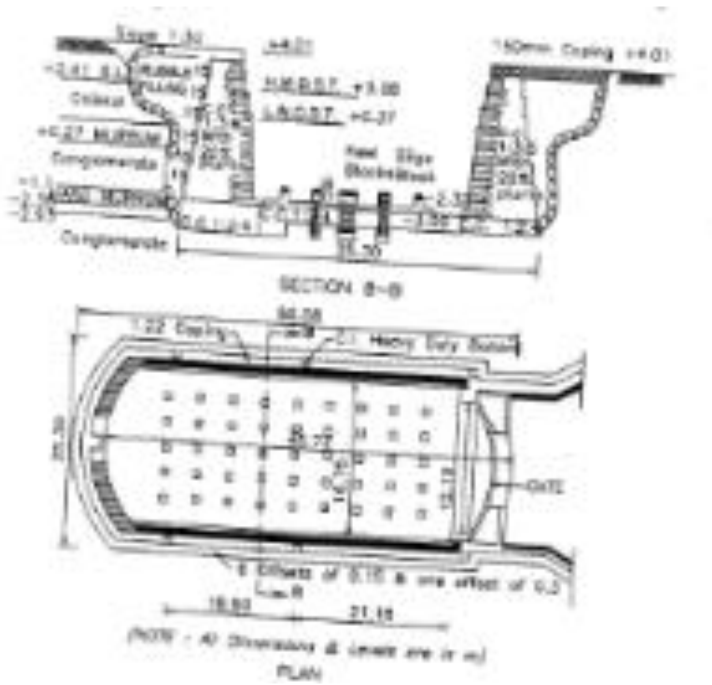


Fig. 15.3. Porbandar Dry Dock

Fig.15.2 shows pictorial view of the dry dock at Alfredo Da Silva. Fig. 15.3 shows the plan and section of the Porbandar dry dock (1961). Both in the plan and section, a number of blocks -named keel blocks and bilge blocks - will be seen. These are meant for the vessel to sit on, and their top timbers are generally adapted to the shape of the vessel.

The sequence of operation of the dry dock is as follows:

(i) At low tide, after the ‘’blocks” are arranged to receive the vessel, water from sea side is allowed to flood the dock. This is done by permitting the entry of water from outside through the sluice valves.

(ii) The gate is then opened and the water level in the dock will rise with the rise in tide. It will be seen that, with proper sluices, the dock could have been flooded just before the high water also. When the water level has raised enough so as to clear the ship, with adequate margin over the cill that is over the gate bottom, the ship to be dry-docked is manoeuvred in.

(iii) The ship is then properly aligned so that with the withdrawal of water either with the receding tides, or by pumping, the ship exactly sits on the pre-arranged blocks. Then, the gate is closed and water is pumped out.