LECTURE NOTE

ADVANCED TRANSPORTATION ENGINEERING (PCI6J001)

6^{TH} SEMESTER CIVIL ENGG.

INDIAN RAILWAYS
HISTORY & backgrounds

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).

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

Advantages of Railways

Political Advantages

- Railway have joined people of different castes, religions customs and traditions.
- With adequate network of railway central administration has become easy and effective
- Role of railway during emergencies in mobilising troops and war equipment has been very significant.
- Railway have helped in mass migration of people.

Social Advantages

- Feeling of isolation has been removed from the inhabitants of Indian villages.
- The social outlook of the masses has been broadened through railway journeys.
- Railway has made it easier to reach religious importance
- Provide safe and convenient mode of transport for the country

Economic advantages

- Mobility of people has increased.
- Transport food and clothes during famines.
- Transport raw material to the industries
- Provide employment to millions of people.
- Land values increased due to industrial development.
- Price stabilisation is possible.

Techno-economic advantages

Cost saving in transportation of long haul bulk traffic.

Energy efficient (1/7 fuel used as compared to road sector)

Environment friendliness

Higher Safety (fatal accidents 1/10 of road sector in India)

COMPARISON OF RAILWAY & HIGHWAY TRANSPORT

Tractive resistance	Its value for steel rail is less around 1/5 to 1/6 times of type of highway	Its value for steel rail is less around 5 to 6 times of type of railway
Load handling capacity	Can take heavy load with high speed	Can take heavy load with low speed
Right of entry	Track is rigid and well defined. So the pavement is not free to all	Flexible and free & everybody has right to igress
Operational control	Requires block system with signal & interlocking for safe & efficient movement	No such control
Gradient	To sustain heaviour loads at high speed the gradient should be minimum.	Steeper gradient compared to railway track

Contribution & maintenance cost	High	Low
Origin & destination	Fixed	As per the requirement it is fixed
Length of haul	Transport of good like raw materials are cheaper & covinient.	Convenient for small & medium distance upto 500km.
Employement potential	less	high
Time consumption	Long distance it is cheaper and time consuming.	Best suited for short distance with less time consuming
Suitability for hilly region	not	more
Type & size of load	All most all type of load	Restricted the size & type of goods
power	less	high
Accident rate & safety	few	more

Railway is basically built for three reasons:
i- Economy.
ii- Safety.
iii- Military

Traffic on railway:
1- Fright traffic = 90% (tons/ mile).
2- Passenger traffic = 10% (passenger / mile).
Classification of Transport Systems on the basis of :
1- Surface of Transport
a- Land Transport
b- Water Transport
c- Air Transport

2- Degree of Freedom
a- System of one degree of freedom.
b- System of Two degree of freedom.
c- System of three degree of freedom.

Water Transport: provide facilities for transport of heavy and bulk commodities where time may not be of movement importance.
Air Transport: obtains maximum utility where safely of time is almost importance rather than the others.
Land Transport: door to door service.

** **Railway Transport:** have the greatest utilization in the transport of large volumes of heavy and bulk commodities over long distance.

Revenues & Cost:

• Capital Expenditure:

1- Road & Equipment (R &E).

2- Additions & Betterment.

3- Depreciation & Renewals.

• Operation Expenditure:

1- Maintenance

a- Way. b- Structure. 20%

b- Equipment 25%

2- Transportation 45%

3- Administration 10%

• Operation Revenues:

Mainly revenues is from fright traffic > 95%

And the other revenues is from passengers < 5%

** Operation ratio = Operation Expenditure / Operation Revenues

The ratio should be in minimum value

Historical devlopement

1844 1st proposal for construction in india by east

First five year plan (1951-56)

- The rehavitation of railway assetsa was the main objective of railway development under the plan
- Hepled india in achiving self suffieniency
- Station & railway facilities were improved
- Chittaranjan locomotives & tata engg were worked these days

Second five year plan (1956-61)

- New lines were devloped, open & new locomotives & passengers coaches were placed
- Progress in electrification of railway
- Some source of supply made for self sufficient facility

Third five year plan (1961-66)

- Locomotive, wagons, coaches were developed
- Complete track renewal, sleeper renewals

- Provision of railway electrification
- Many bridges, staff quarters, railway constructions and other facilities was undertaken.
- There was a gap of 3 years of 3rd year plan 1966-69 as the govt wanted to review the results of proceeding capacity

Fourth five year plan (1969-74)

It Develops with twin objectives

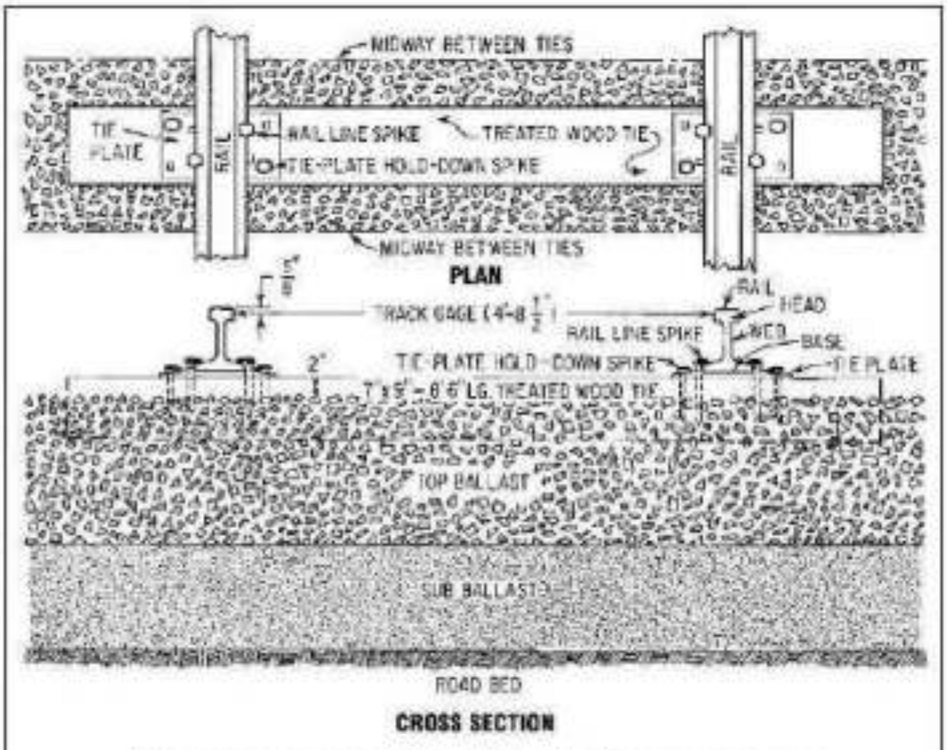
- Demonstration the railway
- Improving the operational efficiency of the system with more intensive utilisation of existing assets

Fifth five year plan (1974-78)

- Main objective is to development of rapid transport system in metropolitan cities
- Improve the financial with cost reduction techniques, resource mobilisation & optimum utilisation of assets & self sufficiency

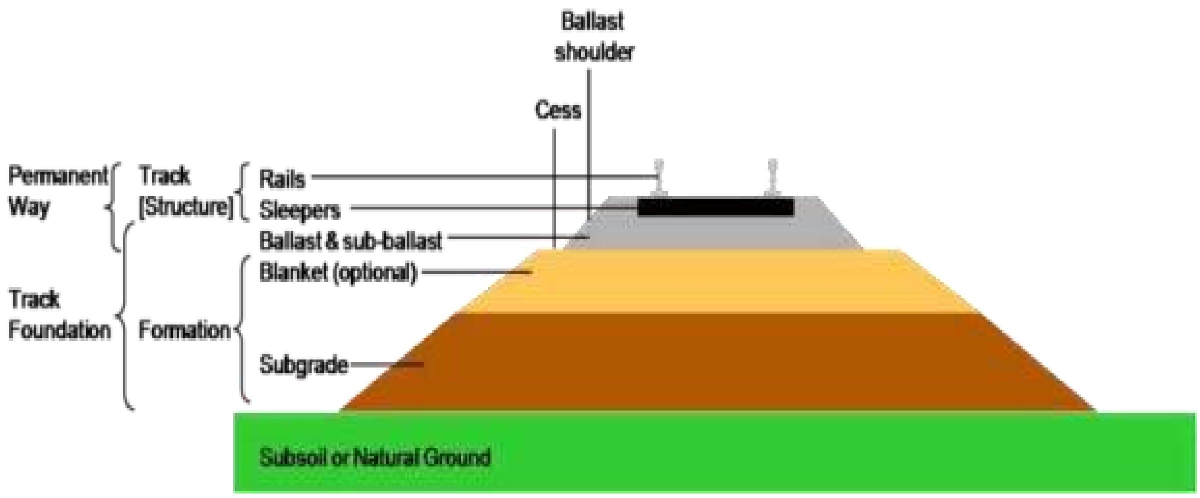
PERMANENT WAY:

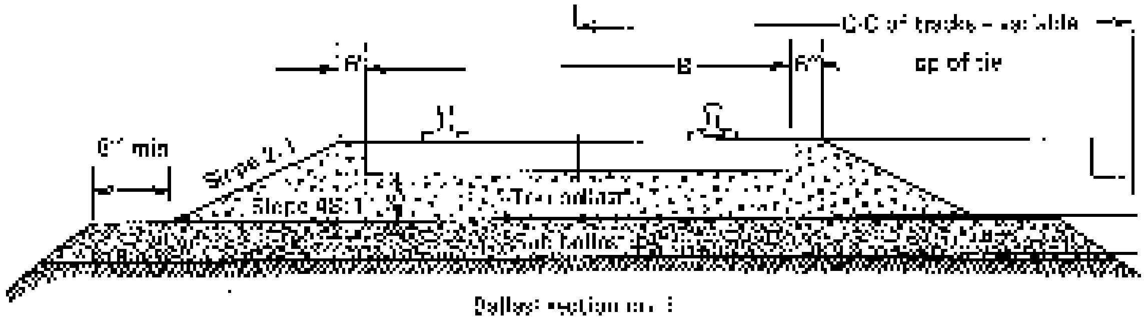
Permanent way:
The permanent way or railway track consist generally of two lines of parallel steel rails which bear and guide the flanged wheel of cars and locomotive and which are support on tie plates, ties (sleepers), resting on ballast and subgrade.



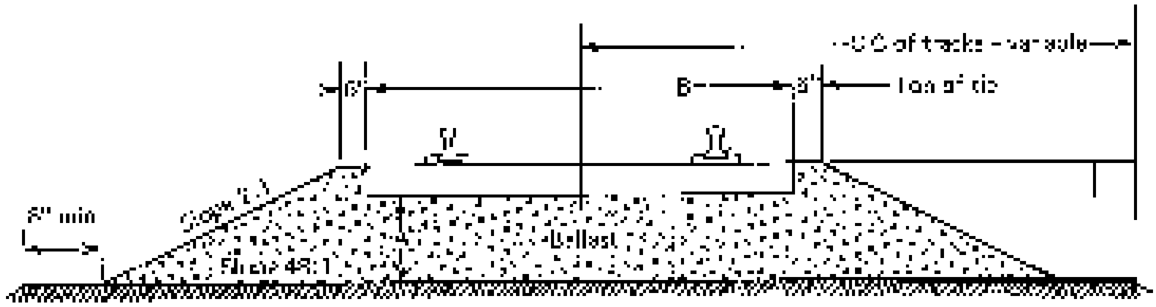
Typical cross-section of a railway track permanent way

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





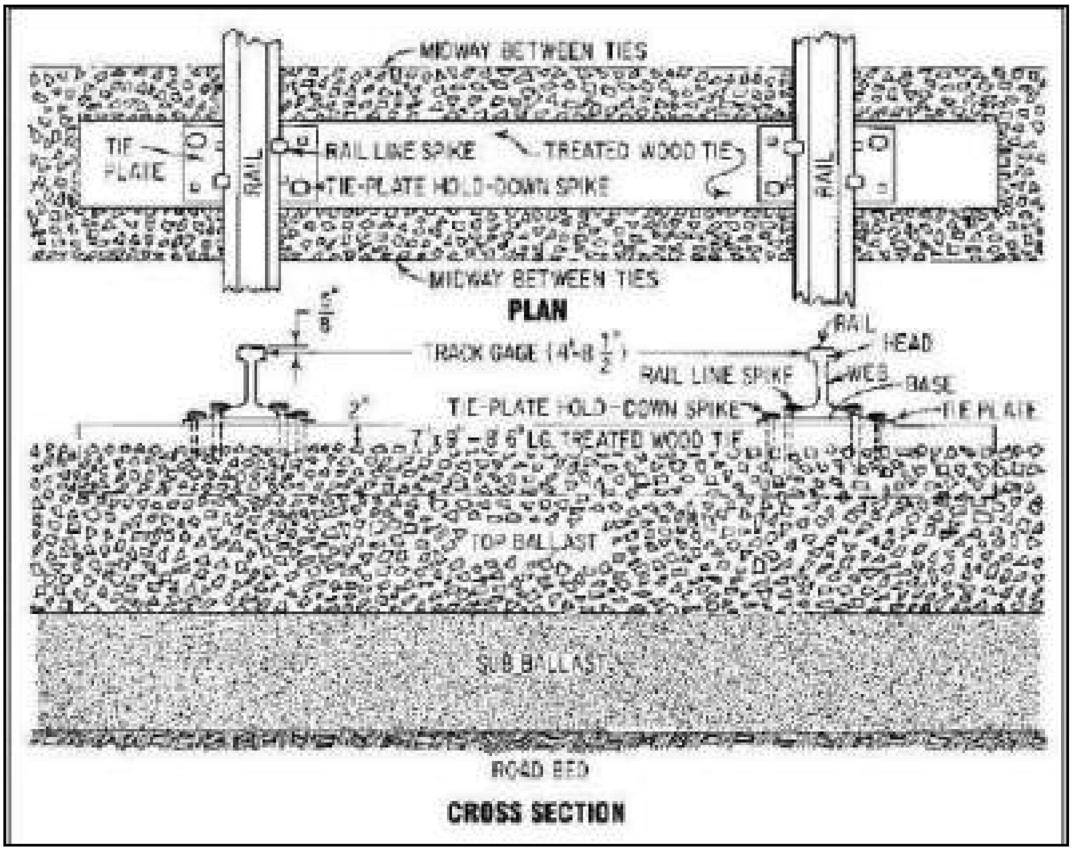
Ballast section no. 1



Ballast section no. 2

Area ballast sections, single and multiple track, tangent

Notes



REQUIREMENTS OF AN IDEAL PERMANENT WAY

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

- The Gauge should be uniform, correct and it should not get altered.
- Both the rails should be at the same level on tangent (straight) portion of the track.
- Proper amount of superelevation should be provided
- Permanent way should be sufficiently strong against lateral forces.
- The Curves in the track, should be properly designed.
- Even and uniform gradient should be provided through out the length of the track.
- Tractive resistance should be minimum.
- 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.
- It Should provide adequate elasticity in order to prevent the harshness of impacts between the rails and the moving wheel loads of a train.
- It should be free from excessive rail joints and all the joining should be properly designed and constructed.
- All the components parts such as *rails, sleepers, ballast, fixtures* and *fastenings,* etc. should satisfy the design requirements.
- 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.
- *The points and crossings,* should be properly designed and carefully constructed.
- It should be provided with fence near *level crossings* and also in urban areas.
- There should be proper drainage facilities so as to drain off the rain water quickly away from the track.
- There should be safe and strong bridges coming in the alignment of the track.

PROBLEMS OF MULTI GAUGE SYSTEM

- 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.

UNI-GAUGE POLICY OF INDIAN RAILWAYS

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

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 a better turnaround of wagons and locomotives, and their usage will improve the operating ratio of the railway system as a whole that 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 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

1- RAILS:

a- General.

1. Rails are steel girders which provide the hard and smooth surface for movement of wheels of a locomotive and railway vehicles.
2. They are made of high carbon steel to withstand wear and tear.
3. Flat – footed rails are mostly used in railway track.

b- Functions.

- Rails provide hard, smooth and unchanging surface for passage of heavy moving loads with minimum friction between steel rail and steel wheel
- Rails bear the stresses developed due to heavy vertical loads, lateral and braking forces and thermal stresses
- The rail material used is such that it gives minimum wear to avoid replacement charges and failure due to wear
- Rails transmit the loads to sleepers and consequently reduce pressure on ballast and formation below

Composition of rail steel

For ordinary rails Carbon (C) - 0.55 to 0.68 percent

Manganese (Mn) - 0.65 to 0.9

percent Silicon (Si) - 0.05 to 0.3

percent Sulphur (S) – 0.05 percent or below

Phosphorus (P) – 0.06 percent or below

For rails at points and crossings

Carbon (C) - 0.5 to 0.6 percent

Manganese (Mn) - 0.95 to 1.25 percent

Silicon (Si) - 0.05 to 0.2 percent

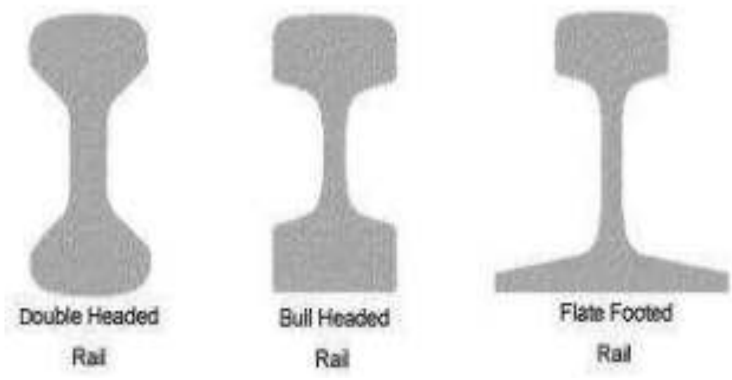
Sulphur (S) – 0.06 percent or below

Phosphorus (P) – 0.06 percent or below

REQUIREMENTS OF RAILS

- Rails should be designed for optimum nominal weight to provide for the most efficient distribution of metal in its various components
- The vertical stiffness should be high enough to transmit load to sleepers. The height of the rail should be adequate
- Rails should be capable of withstanding lateral forces. Large width of head and foot provides the rail with high lateral stiffness
- The depth of head of rail should be sufficient to allow for adequate margin of vertical wear. The wearing surface should be hard
- The web of rails should be sufficiently thick to bear the load coming to it and should provide adequate flexural rigidity in horizontal plane
- Foot should be wide enough so that the rails are stable against overturning especially on curves
- Bottom of the head and top of foot should be so as to enable the fish plates to transmit the vertical load efficiently from the head to the foot at rail joint
- The centre of gravity of rail section must lie approximately at mid height so that maximum tensile and compressive stresses are equal
- The tensile strength of the rail piece should not be less than 72kg/mm2.
- To bring down the contact stresses to minimum level, the contact area between the rail and wheel should be as large as possible

TYPES OF RAIL SECTIONS:

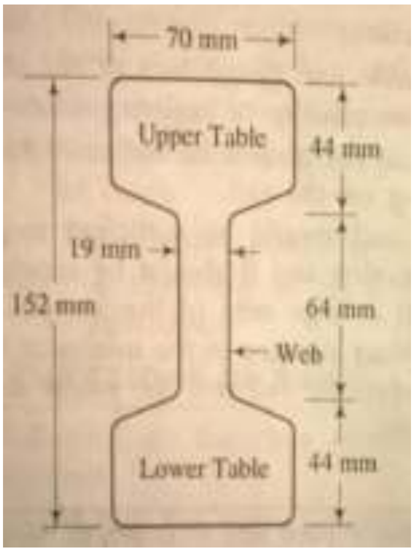


DOUBLE HEADED RAILS

First stage of development of rails. It consists of 3 main parts:

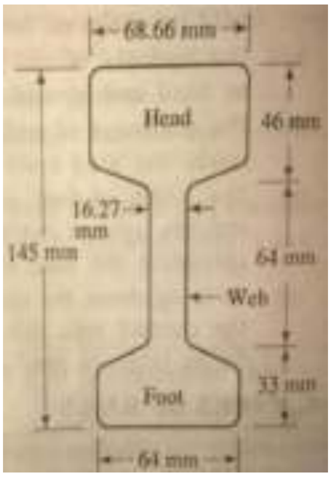
- Upper table
- Web
- Lower table

It is Similar to dumb bell section. Both upper and lower tables are identical When upper table was worn out, the rail can be reversed thus lower table can be brought into use It is Practically out of use It is Made of wrought iron The Length of the rail varying from 610 cm to 732 cm



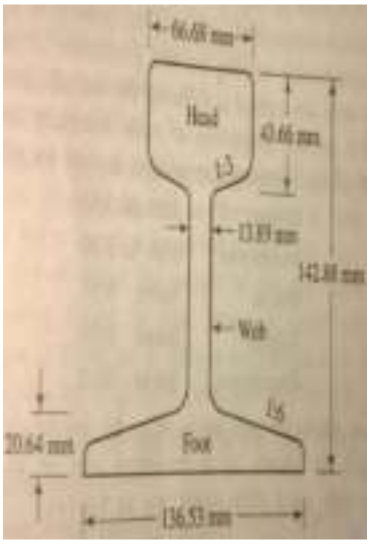
BULL HEADED RAIL

It is Made up of steel. The Head part is larger than foot. The Foot is designed only to hold the wooden keys with which rails are secured to chairs. It is Extensively used in England. The Weight of standard rail or British rail is 47 kg/m of length for main lines and 42 kg/m length on branch lines. The Length of rail usually 18.29 m



FLAT FOOTED RAIL

Foot is spread out to form a base. This rail was Invented by Charles Vignoles in 1836 and hence also known as “Vignoles Rails”. Recently 90 % of railway track is made up of flat footed rails



Advantages of flat footed rails

Chairs

No chairs are required

Foot of rail directly spiked to sleepers

Stiffness

Vertically and laterally stiffer than BHR of equal weight especially on curves

Kinks

Less liable to develop kinks and maintains regular top surface than BHR

Cost

Cheaper than BHR

Load distribution

Distributes loads over large area

Results great track stability, longer life of rails and sleepers, reduced maintenance cost, less rail failures and few interruptions to traffic

d- Selection of rails.

A rail is designated by its weight per unit length. The various important factors to be considered in deciding the weight of rails to be used are the following:

1- Speed of train.

2- The gauge of the track.

3- The axle load and nature of traffic.

4- Type of rails whether D.H. or B.H. or F.F. rails.

5- Spacing of sleepers or sleeper density.

6- Maximum permissible wear on top of rails. (5 percent of the weight of rail is allowed).

e- Length of rails.

The rails of larger length are preferred to smaller length of rails, because they give more strength and economy for a railway track. The weakest point of track is the joint between two rails. Lesser the number of joints, lesser would be the number of fish plates and this would lead to less maintenance cost, smooth running of trains and comfort to the passengers. Length of rail jointed shall not be less than 15 m long and desirable length is 36m.

— On Indian Railways the standard lengths are the following:

— Length = 12.80 m. (42 ft.) for BG (say 13 m) and

— Length = 11.89 m. (39 ft.) for MG (say 12 m)

DEFECTS IN RAILS

Wear On Rails

- Wear is one of the prominent defects of rails. Due to heavy loads concentrated stresses exceeds the elastic limit resulting in metal flow; on the gap or joints the ends are battered and at the curves the occurrence of skidding, slipping and striking of wheel flanges with rails results in wear and tear on rails.

Classification of wear

- On the basis of location

I. On sharp curves
II. On gradients
III. On approach to stations
IV. In coastal area etc.

- **On the basis position of wear**

I. On the top of rail
II. At the end of rail
III. on the sides of the head

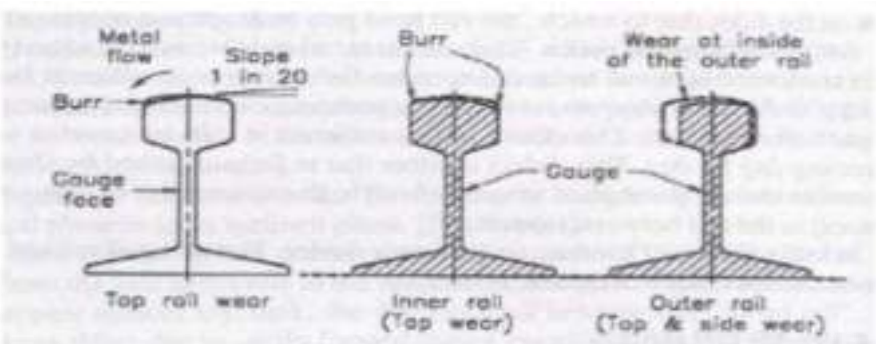


Fig. 6.5. Wear on Rails.

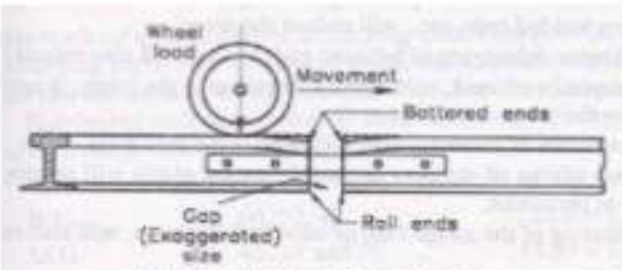


Fig. 6.6. Wear at the Ends of the Rails.

The metal from top of rail flows and forms projections. These are known as “BURRS”

Causes:

- The rails are worn out on top due to abrasion of rolling wheels over them
- The heavy wheel loads are concentrated on very small areas – results into flow of metal from top
- Due t to Impact of heavy wheel load
- Due to the Grinding action of sand particles between rails and wheels

Wear of rails on top or head of rail

Causes:

- The corrosion of metal of rails especially near sea
- The metal on top of rail burns during starting when the wheels slip or when brakes are applied to the moving trains

Wear of rails at end of rails

- Takes place at end of rail
- Much greater than wear at top of rails
- At expansion gap the wheels of the vehicle have to take a jump and during this jump, they impart a blow to the end of rail – causes wear of rail at end
- Wear due to high static pressure combined with impact blows
- End of rail gets battered – causes rough riding in the track, loosens the ballast under joints and disturbs sleeper

Wear of rails at end of rails

Causes:

- Due to Loose fish plates & fish bolts
- Due to Heavy loads & large joint openings
- Due to Difference in rail levels at joints
- Due to Small wheels

- Due to Bad condition of vehicle springs
- Due to Poor maintenance of track

Wear of rails on the sides of rail head

The wear on inner side of head of inner rail is due to slipping action of wheel on curves

Allowable limits of wear

In India, prescribed limit for wear is 5 % of rail weight. Allowable wear of 25 % of the section of head is also exceptionally adopted

Methods adopted to reduce wear of rails

wear of rails can be reduced by

- Use of special alloy steel
- Good maintenance of track
- Reduction of expansion gap
- Exchange of inner and outer rails on curves
- Introducing check rails
- Use of lubricating oil
- Head hardened rails

RAIL FEATURES/FAILURES

- Corrugation
- Rail End Battens
- Broken Base
- Flaking
- Piped Rail
- Shelling
- Split Heads
- Split Web
- Square or Angular Break
- Horizontal Fissures
- Transverse Fissures

- Flowing Metal in Heads
- Horizontal Cracks

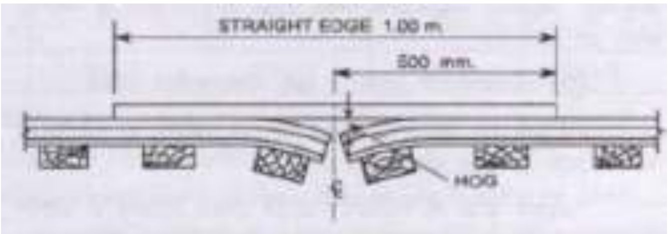
CORRUGATED OR ROARING RAILS

In certain places, head of rails are found to be corrugated rather than smooth and straight, when the vehicles pass over such rails, a roaring sound is created which is intense enough to be unpleasant.

Hogged Rails

Due to battering action of wheels over the end of the rails, the rails get bent down and get deflected at the ends. These rails are called hogged rails. Measures taken to rectify the hogged rails are:

1. Cropping
2. Replacing
3. Welding
4. Dehogging



HOGGING OF RAIL - METHOD OF MEASUREMENT

Kinks In Rails

When the ends of adjoining rails move slightly out of position, “shoulders” or “kinks” are formed.

Measures taken to rectify kinks in rails:

1. By correcting alignment at joints and at curved locations.
2. Proper packing of joints.
3. Proper maintenance of the track periodically in repect of cross levels, gauge, alignment, welding of worn out portions etc.

Buckling of Rails

Buckling means the track has gone out of its original position or alignment due to prevention of expansion of rails in hot weather on account of temperature variations.

Damaged Rails

These are the rails which should be removed on account of their becoming unsafe for a railway track.

Crushed Heads

Split Heads

Flowing Metal in Heads

Horizontal & transverse Fissures

REQUIREMENTS OF AN IDEAL RAIL JOINT

An ideal rail joint provides the same strength and stiffness as 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.

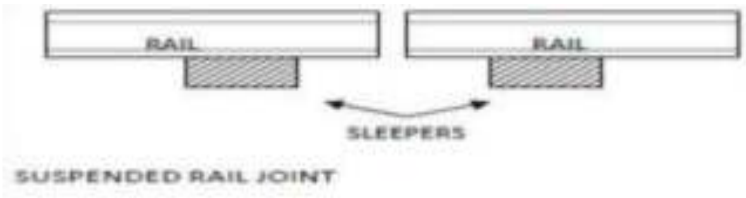
Elasticity:It should provide adequate elasticity as well as resistance to longitudinal forces so as to ensure a trouble-free track.

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

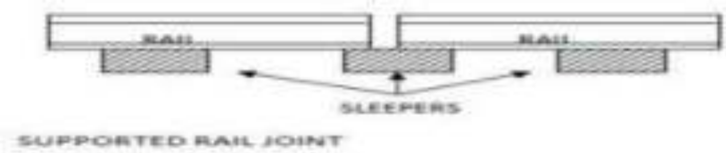
Rail joint

Rail joints are the steel sections connecting the adjacent ends of rails, in distinction from a chair, which is merely a seat. Following are the types of rail joints:

(1) **Supported rail joints**: When the rail ends rest on a single sleeper it is termed as supported joint. The duplex joint sleeper with other sleepers is an example of the supported joint.



(2) Suspended rail joint: When rail ends are projected beyond sleepers it is termed as suspended joint. This type of joint is generally used with timber and steel through sleepers.

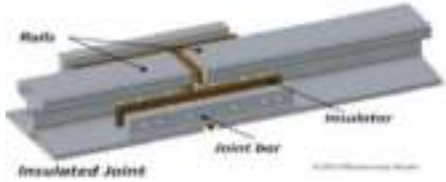


(3) Bridge joints: When the rail ends are projected beyond sleepers as in the case of suspended joint and they are connected by a flat or corrugated plate called as bridge plate it is termed as a bridge joint.

(4) **Compromise joint**: Where two different rail sections are required to be joined together it is done by means of fishplates which fit both rails and this joint is termed as compromise joint.

(5) **Welded joint**: To increase length of rails and to reduce the number of fish plate joints, the rails are welded together by suitable type of welding and hence it is known as welded rail joints.

Insulated joint

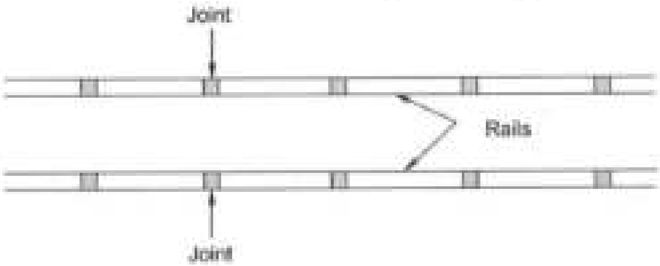


Expansion joint

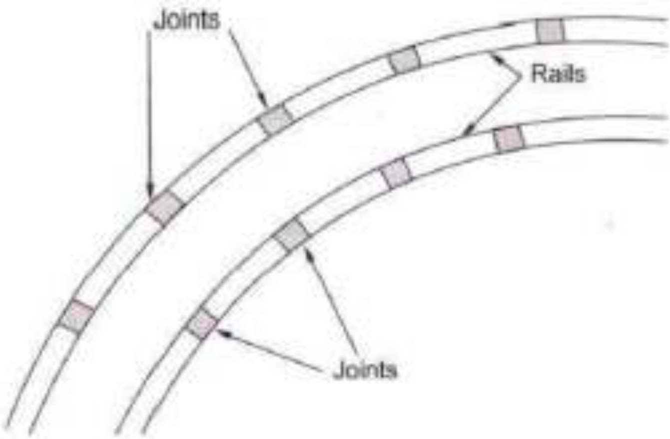
Classification Based on the Position of the Joint

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).



GAUGE IN RAILWAY TRACK:

Gauge in Railway Track:

The gauge of a railway track is defined as

Track gauge is the clear distance between the inside heads of rail 5/8 in below the top of rail.

The distance between the inner faces of a pair of wheels is called **Wheel gauge**.

The different gauges types are:

1- Standard gauge = 1435 mm or 1451mm.

2- Broad (wide) gauge = 1676 mm ,1600mm, or 1524mm.

3- Meter gauge = 1000 mm or 1069mm.
4- Narrow gauge = 762mm or 610 mm

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

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.

SLEEPERS

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.

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

(g) The initial as well as maintenance cost should be minimum.

(h) The weight of the sleeper should be moderate so that it is convenient to handle.

(i) The designs of the sleeper and the fastenings should be such that it is possible to fix and remove the rails easily.

(j) The sleeper should have sufficient bearing area so that the ballast under it is not crushed.
(k) The sleeper should be such that it is possible to maintain and adjust the gauge properly

(l) 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.

(j) The sleeper should be capable of resisting vibrations and shocks caused by the passage of fast moving trains,

(k) The sleeper should have anti-sabotage and anti-theft features.

FUNCTIONS.

1- To hold the rails to proper gauge.
2- To hold the rails in proper level or transverse tilt.
3- To interpose an elastic medium between the ballast and rails.
4- To distribute the load from rails to the ballast underlying it or to the girders in case of bridges.
5- To support the rails at a proper level in straight tracks and at proper superelevation

on curves.
6- Sleepers also add to the general stability of the permanent track on the whole.
c- Classification of sleepers:
Sleepers can be classified according to the material uses in their construction, in the following:
1- Wooden sleepers.
2- Metal sleepers.
a- Cast-iron sleepers.
b- Steel sleepers.
3- Concrete sleepers.
a- Reinforced concrete sleepers.
b- Prestressed concrete sleepers.

1- Timber or wooden sleepers:
Wooden sleepers are regarded to be best as they fulfill almost all the require-ments of an ideal sleeper. The life of timber sleepers depends on their ability to resist wearing, decay, attack by vermin i.e., white ants, and quality of the tim-ber used. Following are the advantages and disadvantages of using wooden sleepers.

• **Advantages:-**
1- Fittings for wooden sleepers are few and simple in design.
2- These sleepers are able to resist the shocks and vibrations due to heavy moving loads and give less noisy track.
3- Wooden sleepers are easy to lay, relay, pack, lift and maintain.
4- These wooden sleepers are suitable for all types of ballast.
5- They are best for track-circuited operations as wooden sleepers are over all economical.

• **Disadvantages:-**
1- The sleepers are subjected to wear, decay, attack by white ants, cracking and splitting, rail cutting, etc.
2- It is difficult to maintain the gauge in case of wooden sleepers.
3- Track is easily disturbed i.e., alignment maintenance is difficult.
4- Wooden sleepers have got minimum life (12 to 15 years) as compared to other types of sleepers.
5- Maintenance cost of wooden sleepers is highest as compared to other sleep-ers.

2- Metal sleepers:-
Metal sleepers are either of steel or cast-iron. Cast-iron is in greater use than steel for sleepers because it is less prone to corrosion.

• **Advantages:-**
1- Metal sleepers are uniform in strength and durability.
2- In metal sleepers, the performance of fitting is better and lesser creep oc-curs.
3- Metal sleepers are economical, as life is longer and maintenance is easier.
4- Gauge can be easily adjusted and maintained in case of metal sleepers.

• **Disadvantages:-**
1- More ballast are required than other type of sleepers.

2- Fittings are greater in number.
3- Metal, C.I. or steel are liable to rust.
4- Metal being good conductor of electricity interferes with track circuiting.

5- Metal sleepers are unsuitable for bridges, level crossing and in case of points and crossings.
6- Metal sleepers are only suitable for stone ballast.

3- Concrete sleeper:-
These sleepers are mainly of two types
a- Reinforced concrete sleepers.
b- Pre-stressed concrete sleepers.
Experiments have been proved that concrete is an ideal material for the sleepers for the following reasons:
They are made of a strong homogeneous material, impervious to effect of moisture, and is unaffected by the chemical attack of atmospheric gases or sub-soil salts.

- **Advantages :-**

1- These sleepers free from natural decay and attack by insects.
2- They have maximum life compared with the other sleepers. And life under normal conditions is (40 to 60 years).
3- This is not affected by moisture, chemical action of ballast, and sub-soil salts.
4- There is no difficulty in the circuiting.
5- The high weight of sleepers helps in minimizing joint maintenance by providing longer welded lengths, greater stability of the track and better re-sistance against temperature rise.
6- The sleepers have higher elastic modulus and can resist the stresses intro-duced by fast and heavy traffic.

- **Disadvantages:-**

1- The weight of concrete sleeper is as high as 2.5 to 3 times of wooden sleep-er.
2- These sleepers require pads and plugs for spikes.
3- They damage the bottom edge during the packing.

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.

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.

Function of Ballast.

1- Distribute loads uniformly over the subgrade.

2- To hold track structure to line and grade, (prevent or reduce possibility of buckling).
3- To reduce the excess pore water pressure developed in clay subgrade.
4- To provide good drainage of track structure.
5- To reduce dust.
6- To prevent growth of brash and weeds.
7- Reduce frost heave.
8- Simplify the maintenance operations.

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.

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.

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.

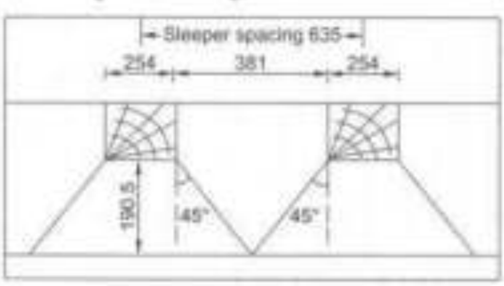
d) It should be non-porous and should not absorb water. e) It should resist both attrition and abrasion.

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

FORMATION

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

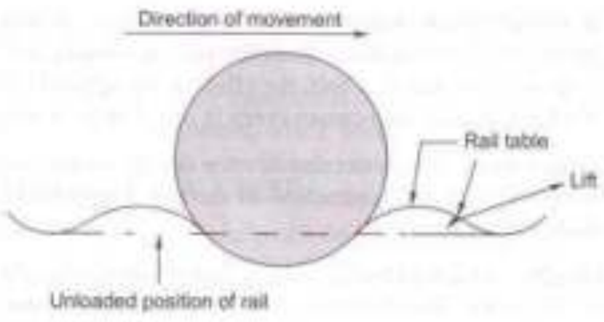
CREEP OF RAIL

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

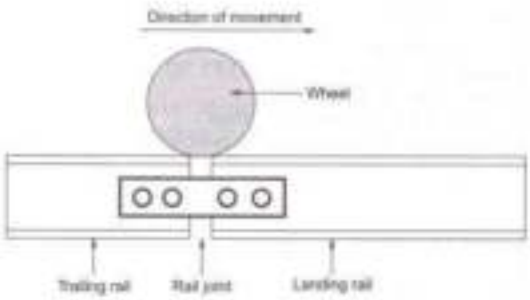
Various theories have been put forward to explain the phenomenon of creep and its causes, but none of them have proved to be satisfactory. The important theories are briefly discussed in the following subsections.

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

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

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.

Q: What should be the actual ruling gradient, if the ruling is°gradient is 1 in 200 on a B.G. track and a curve of 3 superimposed on it ? Ruling gradient = 1 in 200 = 0.50% °Degree of curve = 3 Grade Compensation = 0.04% per degree of curve = 0.04 x 3 = 0.12%

Actual ruling gradient = 0.5 – 0.12 = 0.38% or 1 in 264

Curves

Necessity of Curvesθ

- To connect important places
- To avoid obstructions
- To have longer and easier gradients
- To balance earthwork in excavation and cutting
- Minimize construction cost

Objections for providing curves

- Speed is to be restricted
- Possibility of accident/ derailment/ collision
- Unequal distribution of loads on rails
- More fittings are needed to prevent lateral bending of rails

TYPES OF CURVE

Horizontal Curves • Provided when there is change in alignment of the track • Circular or parabolic transition curves are provided at either ends Vertical Curvesθ • Provided when there is change in gradient • Parabolic curves

CLASSIFICATION OF CURVE

Simple Curve

- An arc of a circle

Compound Curve

- Composed of two or more simple curves of different radii
- Have a common tangent at the point of common radius Parabolic Curves
- Used for vertical curves
- Can be easily laid by offset method Transition Curvesθ

Marin's formulae for safe speed on curves

A. When transition curves exists

- For B.G. & M.G. :-

$$V = 4.35\sqrt{R-67} \quad = 4.4\sqrt{R-70}$$

- For N.G. :-

$$V = 3.65\sqrt{R-6} \quad = 3.6\sqrt{R-6.1}$$

- Maximum = **50 km/h**

V - speed in km/h
R - Radius of curve in m

B. Transition curves are absent

- Speed is reduced by **20%** i.e. **(4/5) of speed calculated in Step-A**
- For B.G. & M.G. :-

$$V = 3.52\sqrt{R-70}$$

- For N.G.:-

$$V = 2.92\sqrt{R-6}$$

- Max. speed = **40 km/h**

C. For high speeds (V > 100 km/h)

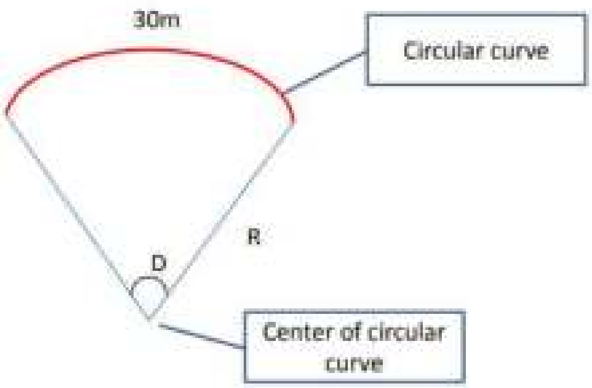
$$V = 4.58\sqrt{R}$$

Radius or Degree of Curve

- Degree of curve (D) is defined as the angle subtended at the center by a chord of length 100ft or 30.48m

$$\frac{D}{30} = \frac{360^\circ}{2\pi R}$$

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



Curves with smallest radius & largest degree of curvature are restricted on the basis of two factors:-

• Wheel base: If degree of curve is large than for the length of wheel base which forms a chord of curve, vehicle does not run freely round the curve and is liable to derailment

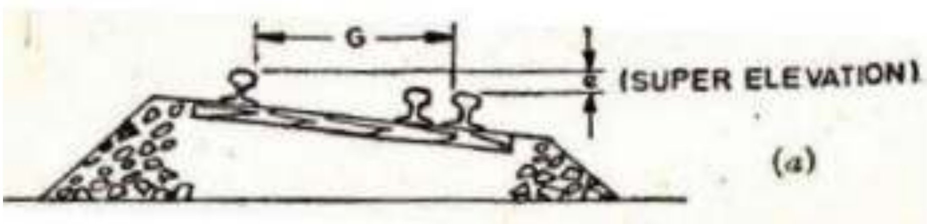
• Sharpness of curve: Greater effort is required on sharp curves in hauling the vehicles than on straights Super-elevation also increases with degree of curveθ and should be limited to keep vehicles stable

Track	Max. Degree of Curve, D (°)	Min. Radius, R (m)
B.G.	10	175
M.G.	16	109
N.G.	40	44

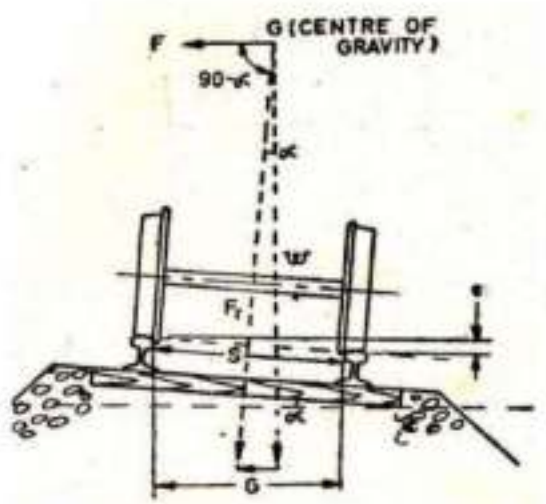
SUPER ELEVATION

Vehicle negotiating a curve is subjected to centrifugal force acting radially outwards Increases weight on outer railθ Provided to counteract the centrifugal forceθ Super-elevation (e) : Raising the level of outer railθ above the inner rail at a horizontal curve so as to introduce centripetal force Equalize the weight on either rail

Necessity of providing super-elevation on curves • To counteract centrifugal force • For faster movement of trains on curves • Reduce wear and creep of rails • Equal distribution of wheel loads on two rails • To provide an even and smooth running track to ensure comfortable ride to passengers & safe movement of goods



Relationship between *e*, *G*, *V* & *R*



W = weight of vehicle, kg
v = speed of vehicle, m/s
V = speed of vehicle, km/h
R = radius of curve, m
G = gauge of track, m
g = acceleration due to gravity
α = angle of inclination
S = length of inclined surface, m

Centrifugal force, $F = \dfrac{Wv^2}{gR}$

Resolving forces, $F\cos\alpha = W\sin\alpha$ $\qquad \cos\alpha = \dfrac{G}{S}$

Substituting we get, $e = \dfrac{Gv^2}{gR}$ metres $\qquad \sin\alpha = \dfrac{e}{S}$

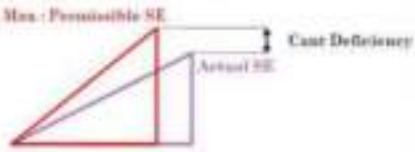
$$= \frac{GV^2}{127R}$$

Put, G = 1.676 for B.G., 1.0 for M.G. & 0.762 for N.G.

Equilibrium Cant: When lateral forces and wheel loads are almost equal, the cant is said to be in equilibrium. It is provided on the basis of avg. speed of trains. Super-elevation should be provided in such a way that faster trains may travel safely without the danger of overturning or discomfort to the passengers & slower trains may run safely without fear of derailment due to excessive super-elevation

Cant Deficiency

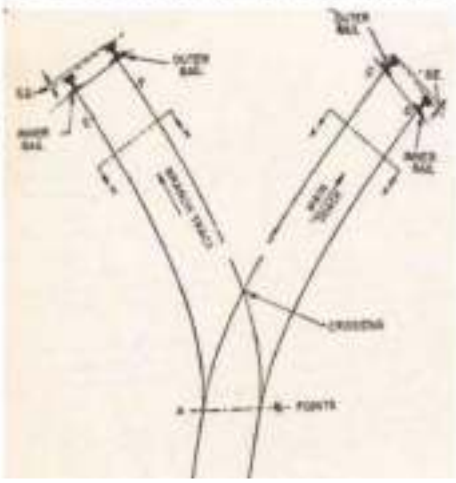
- Difference between equilibrium cant necessary for the max. permissible speed on a curve and the actual cant provided
- Cant deficiency is limited due to two reasons:
  - Higher cant deficiency cause higher discomfort
  - Higher cant deficiency cause extra pressure & lateral force on outer rails



Track	Max. Cant Deficiency (cm)
B.G.	7.6 cm
M.G.	5.1 cm
N.G.	3.8 cm

Negative Super-elevation

- Occur when a branch line diverges out of main line



- For main line curve, outer rail AC must be higher than inner rail BD; i.e. **A is higher than B**
- For branch line curve, outer rail BF should be higher than inner rail AE; i.e. **B is higher than A**
- This **contrary conditions** cannot be met at same time

Max. Permissible Speed on Curve

- Max. permissible speed on curve is the minimum of below:-
  - A. Max. sanctioned speed of the section
  - B. Safe speed over that curve given by Martin's formula
  - C. Speed based on the consideration of equilibrium cant
  - D. Speed from the length of transition curve (L)
    - For normal speed upto 100km/h

$$V_{max} = \frac{134 \times L}{e} \qquad V_{max} = \frac{134 \times L}{D}$$

    - For high speeds above 100km/h

$$V_{max} = \frac{198 \times L}{e} \qquad V_{max} = \frac{198 \times L}{D} \qquad e, D \text{ in mm}$$

- **Q:** If an 8° curve track diverges from a main curve of 5° in an opposite direction in the layout of a B.G. yard. Calculate the super-elevation and the speed on the branch line, if the max. speed permitted on the main line is 45km/h.

i. Calculate equilibrium cant

G = 1.676, V = 45km/h, D = 5°

$$R = \frac{1720}{5}$$

$$e = \frac{1.676 \times 45^2}{1.27} \times \frac{5}{1720} = 7.78cm$$

ii. Deduct permissible cant deficiency from equilibrium cant

Permissible cant deficiency for B.G. track = 7.6cm

Cant for main track = 7.78 – 7.6 = 0.18cm

iii. Difference of equilibrium cant and permissible cant deficiency will give negative super-elevation for branch

Negative cant provided for branch track = – 0.18cm

iv. Calculate restricted speed on curved track by adding permissible cant deficiency and negative cant

Cant provided = 7.6 + (– 0.18) = 7.42cm

Permissible speed on branch line:

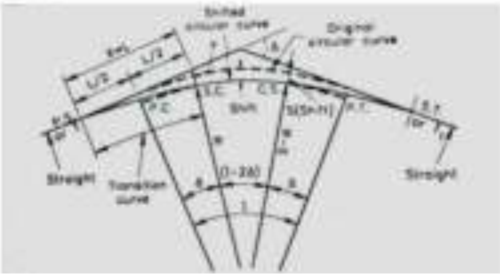
$$7.42 = \frac{1.676 \times V^2}{1.27} \times \frac{8}{1720}$$

$$V^2 = \frac{7.42 \times 1.27 \times 1720}{1.676 \times 8} = 1210\ km/h$$

$$V = 34.7 km/h \cong \mathbf{34 km/h}$$

Length of Transition Curve

- It is the length along the centre line of the track from its meeting point with the straight to that of the circular curve
- Half of this length is provided in the straight and half in the curve



- Length of transition curve is **greatest** of following:-
  - **Approach-1**

A. Based on arbitrary gradient (1 in 720)

$$L = 7.20\ e$$

B. Based on rate of change of cant deficiency

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

C. Based on rate of change of super-elevation

$$L = 0.073\ e \times V_{max}$$

* **Approach-2**
    A. As per Railway Code

    $$L = 4.4\sqrt{R}$$

    B. At the rate of change of super-elevation of 1 in 360 i.e., 1 cm for every 3.6m
    C. Rate of change of cant deficiency is not exceeded
    D. Based on rate of change of radial acceleration – with radial acceleration of 0.3048m/sec^2

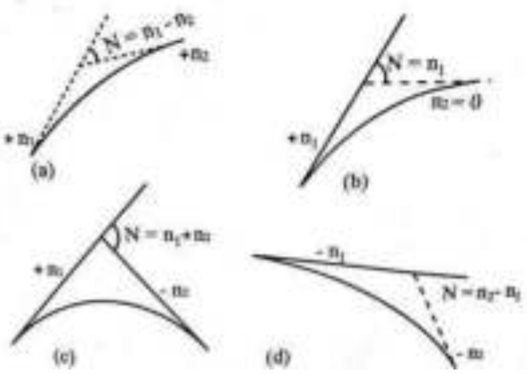
    $$L = \frac{3.28\, v^2}{R}$$

Vertical Curves

- ❑ Change in gradient of the track forms a vertical kink at the junction
- ❑ Kink is smoothened by curves
- ❑ Parabolic curves are used
- ❑ Length of vertical curve depends on algebraic difference in grades & rate of change of gradient
- ❑ Two types
    * Summit Curves
    * Sag or Valley Curves

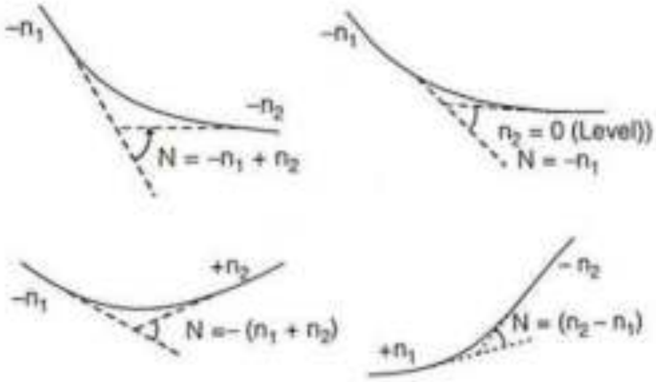
Summit Curves

❑ Rate of change of grade = **0.1% or 1 in 1000m**



Sag or Valley Curves

- Rate of change of grade = **0.05% or 1 in 2000m**



Widening of Gauge on Curves

- Due to rigidity of wheel base
- Outer wheel of front axle strikes the outer rail
- Outer wheel of inner axle bears a gap with the outer rail
- Provision for this gap is made by widening the gauge

$$d = \frac{13\,(B + L)^2}{R}$$

$$d = 2\sqrt{D.h + h^2}$$

B = Rigid wheel base, m
R = radius of curve, m
L = lap of flanges, m
d = extra width of gauge, cm
h = depth of wheel flange below rail top level, cm
D = diameter of wheel, cm

Shift

- Original curve is shifted inwards by some distance
- Occur when a transition curve is fitted in between straight and circular curve
- Shift: Distance by which the circular curve is shifted to a new position
- For cubic parabola,

$$S = \frac{L^2}{24\,R}$$

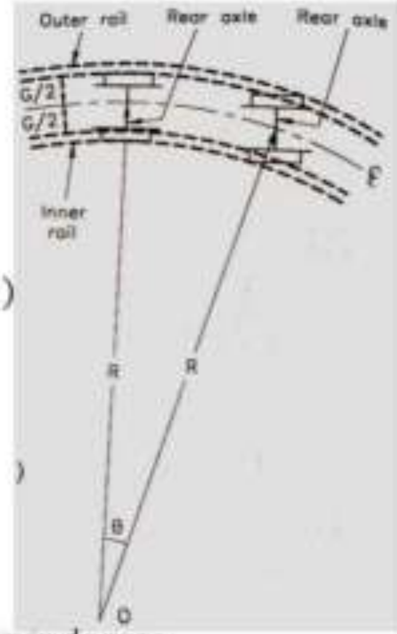
S = shift, m
L = length of transition curve, m
R = radius of circular curve, m

Coning of Wheels

- Distance between inner edges of wheel flanges is kept 1cm less than gauge (running edge of rail) on either side
- Tread of wheels is at dead center of head of rail
- Wheel is coned to keep in central position
- Wheels are coned at a slope of 1: 20
- **Advantages**
  - Reduce the wear and tear of wheel flanges & rails
  - Provide lateral movement of axle
  - Prevent slipping

Theory of Coning

- Level Track
  - As axle moves towards one rail, diameter of wheel tread increases, while it decreases over the other rail
  - Prevents further movement and retreats back to original position, with equal diameter and pressure n both rails
- Curved Track
  - Due to rigidity, wheels slip by an amount equal to difference of length or axle slightly move outwards to provide a tread of longer diameter over outer rail and smaller diameter over the inner rail



- If tread diameter on both rails are same, amount of slip is given by

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

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

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

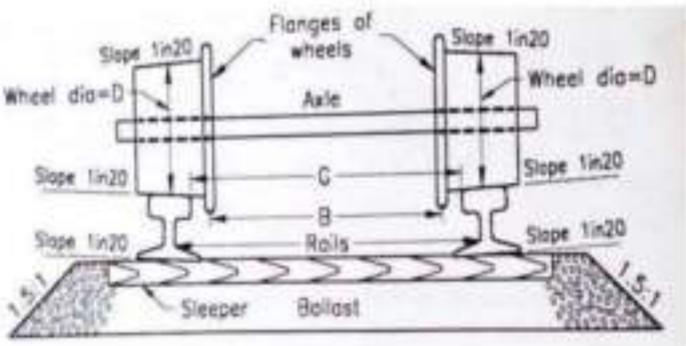
$$Slip = \theta \times G$$

- For G = 1.676m & $\theta = 1°$

$$Slip = \frac{2\pi\theta}{360} \times 1.676 = 0.029\ m\ per\ degree$$

Tilting of Rails

- Issues due to coning of wheels
  - Pressure on outer rail is more resulting in wear
  - Horizontal component of centrifugal force turn the rail out
  - Gauge has widening tendency
  - If base plate is not used under the voids, sleeper under the edge of rail are damaged
- Tilting of rails is done to avoid these issues
- Base plate or sleeper is not laid horizontal, but at a slope of 1 in 20 inwards
- Also called *"Adzing of Sleepers"*



AIRPORT ENGINEERING

DEVELOPMENT OF AIR TRANSPORT IN INDIA

- ✓ The first air flight in India was performed in the year 1911 when a Frenchman carried mail from Allahabad to Naini.
- ✓ The first commercial air service was established in 1930 as Tata Airlines.
- ✓ Air India entered into Jet age in 1960 when Boeing 707 Services were started between India and London and subsequently extended to New York.
- ✓ India's first Boeing 747 (Jumbo-Jet) which is two and a half times the size of Boeing 707 – Emperor Ashoka was procured in 1971.

AIRPORT ENGINEERING

- ✓ Airport Engineering encompasses the planning, design, and construction of terminals, runways, and navigation aids to provide for passenger and freight service.
- ✓ Airport engineers design and construct airports. They must account for the impacts and demands of aircraft in their design of airport facilities.
- ✓ These engineers must use the analysis of predominant wind direction to determine runway orientation, determine the size of runway border and safety areas, different wing tip to wing tip clearances for all gates and must designate the clear zones in the entire port.

The International Civil Aviation Organization (ICAO)

- ✓ The International Civil Aviation Organization (ICAO), an agency of the United Nations, codifies the principles and techniques of international air navigation and fosters the planning and development of international air transport to ensure safe and orderly growth.

TYPES OF AIRPORT

International Airports

- ✓ An international airport has direct service to many other airports.
- ✓ Handle scheduled commercial airlines both for passengers and cargo.
- ✓ Many international airports also serve as "HUBS", or places where non-direct flights may land and passengers switch planes.
- ✓ Typically equipped with customs and immigration facilities to handle international flights to and from other countries.

- ✓ Such airports are usually larger, and often feature longer runways and facilities to accommodate the large aircraft. (FBO, MRO etc..)

Domestic Airports

- ✓ A domestic airport is an airport which handles only domestic flights or flights within the same country.
- ✓ Domestic airports don't have customs and immigration facilities and are therefore incapable of handling flights to or from a foreign airport.
- ✓ These airports normally have short runways which are sufficient to handle short/medium haul aircraft.

Regional Airports

- ✓ A regional airport is an airport serving traffic within a relatively small or lightly populated geographical area.
- ✓ A regional airport usually does not have customs and immigration facilities to process traffic between countries.
- ✓ Aircraft using these airports tend to be smaller business jets or private aircraft (general aviation).

AIRCRAFT CHARACTERISTICS

- **The size;**

– **Span of wings:** This decides the width of taxiway, size of aprons and hangers.

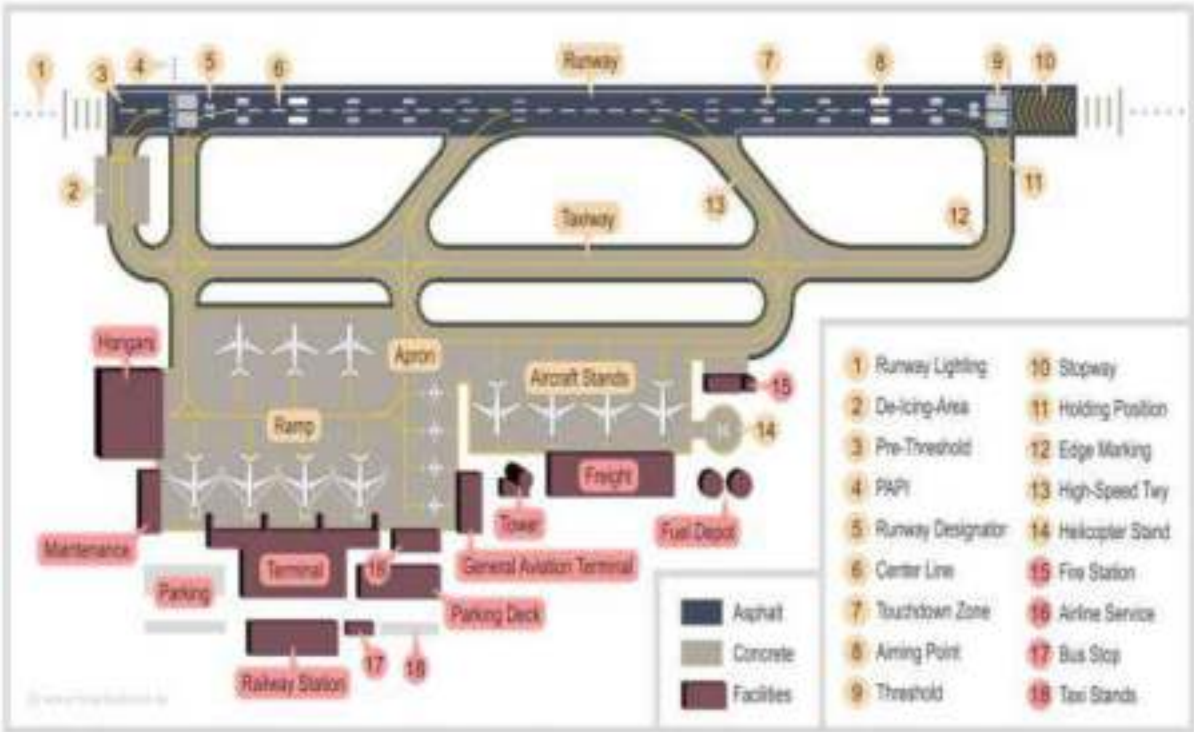
– **Height:** This decides the height of hanger gate and miscellaneous installations inside the hanger.

– **Wheel base:** This decides minimum taxiway radius.

– **Tail width**: Required for size of parking and apron.

- **Minimum turning radius:** To determine the radii at the ends of the taxiways and to ascertain the position on the loading apron.
- **Gross Take-off weight:** It governs the thickness of runway
- **Take-off and landing distances**: A number of factors such as altitude of the airport, gradient of runway, direction and intensity of wind, temperature and the manner of landing and take-off which influence the take-off and landing distances.
- **Tyre pressure and contact area:** It governs the thickness of the pavement.
- **Range**: The frequency of operations and hence the peak traffic volume and the runway capacity depend upon the normal haul length or the range.

TYPICAL LAYOUT OF AN AIRPORT



SURVEYS FOR SITE SELECTION

Some of the main survey work is to be done while selecting the site for airport are as

<u>Traffic survey</u>

- To determine the amount of air traffic including the anticipated traffic for future. Meteorological survey:
- To determine direction, duration and intensity of wind, rainfall, fog, temperature and barometric pressure etc

<u>Topographical survey</u>

- To prepare contour map showing other natural features such as trees, streams etc.
- To prepare a map showing such constructed objects aspole lines, building, roadsetc.
- These maps will be helpful in the jobs of clearing, grading and drainage.

<u>Soil survey</u>

- To determine soil type and ground water table.
- This assists in the design of runway, taxiway, terminal building and the drainagesystem.

<u>Drainage survey</u>

- To determine the quantity of storm water for drainage. This can be obtained from the rainfall intensity and the contour maps
- To locate possible outlets for drain water in the vicinity of he site.
- To study the possibility of intercepting or diverting the natural streams of nallasflowing towards the site under consideration.

Material survey

- To ascertain the availability of suitable construction materials at a reasonable costand the mode of transportation of these materials to the site.ground contours and the cross-sections and longitudinal profiles

The emphasis in airport planning is normally on the expansion and improvement of existing airports. However if an existing airport cannot be expanded to meet the future demand or the need for a new airport is identified in an airport system plan, a process to select a new airport site may be required.

- ✓ Identification
- ✓ Screening
- ✓ Operational capability
- ✓ Capacity potential
- ✓ Ground access
- ✓ Development costs
- ✓ Environmental consequences
- ✓ Compatibility with area-wide planning
- ✓ Selection

THE AIRPORT MASTER PLAN

An airport master plan is a concept of the ultimate development of a specific airport. The term development includes the entire airport area, both for aviation and nonaviation uses, and the use of land adjacent to the airport. It presents the development concept graphically and contains the data and rationale upon which the plan is based. Master plans are prepared to support expansion and modernization of existing airports and guide the development of new airports. The overall objective of the airport master plan is to provide guidelines for future development which will satisfy aviation demand in a financially feasible manner and be compatible with the environment, community development, and other modes of transportation. More specifically it is a guide for

1. Developing the physical facilities of an airport

2. Developing land on and adjacent to the airport

3. Determining the environmental effects of airport construction and operations

4. Establishing access requirements

5. Establishing the technical, economic and financial feasibility of proposed developments through a thorough investigation of alternative concepts

6. Establishing a schedule of priorities and phasing for the improvements proposed in the plan

7. Establishing an achievable financial plan to support the implementation schedule

8. Establishing a continuing planning process which will monitor conditions and adjust plan recommendations as circumstances warrant

Guidelines for completing an airport master plan are described by ICAO and in the United States by. A master plan report is typically organized as follows:

- ✓ Master plan vision, goals, and objectives
- ✓ Inventory of existing conditions
- ✓ Forecast of aviation demand
- ✓ Demand/capacity analysis and facility requirements
- ✓ Alternatives development
- ✓ Preferred development plan
- ✓ Implementation plan
- ✓ Environmental overview
- ✓ Airport plans package
- ✓ Stakeholder and public involvement

RAINAGE

Drainage on the airport surface is a prime requisite for operational safety and pavement durability. The drainage design is handled like most drainage for streets and highways. Avoidance of ponding and erosion of slopes that would weaken pavement foundations is critical for design. Because of the need for quick and total water removal over the vast, relatively flat airport surface, an integrated drainage system is a must. Runoff is removed from the airport by means of surface gradients, ditches, inlets, an underground system of pipes, and retention ponds. One portion of an airport drainage system. Because of their large contiguous area, aprons are critical and must have an adequate sewer system. Runoff water treatment is required when there are fuel spills or during the winter, when a deicing chemical is used.

AIRPORT LAYOUT PLAN

The airport layout plan is a graphic representation to scale of existing and future airport facilities on the airport. It will serve as the airport's public document, giving aeronautical requirements as well as pertinent clearance and dimensional data and relationships with the external area. The airfield configuration of runways, taxiways, aprons, and the terminal are shown schematically.

Approach and Runway Clear Zone Plan

The approach and clear zone drawing permits the planner to determine how the airport will interface with the surrounding area in terms of safe flight. It includes:

• Area under the imaginary surfaces defined in U.S. Code FAR, Part 77 *1975+

• Existing and ultimate approach slopes or slope protection established by local ordinance

• Runway clear zones and approach zones showing controlling objects in the airspace

• Obstructions that exceed the criteria

• Tall smokestacks, television towers, garbage dumps, landfills, or other bird habitats that could pose a hazard to flight

Other Plans

Terminal Area Plan

The terminal area plan usually consists of a conceptual drawing showing the general plan for the terminal, including its possible expansion. Under some changes the terminal modification will have a major impact on the taxiway and apron and will be reflected in an altered ALP.

Noise Compatibility Plan

Using future airport traffic, noise contours should be generated to identify future impacts of noise in the community. The plan would include alternative takeoff tracks and operational constraints. It would also identify buildings and other facilities that might potentially need to be moved or soundproofed.

Runway and Taxiway Width and Clearance Design Standards

The FAA has developed a set of standard dimensions that determine runway width, separations between runways and taxiways, safety areas around runways and taxiways, shoulder width (possible areas of lessthan- full-strength pavement), pads to deflect jet blast, object-free areas, and the like. These standards are a function of approach speed and aircraft size.

Runway Gradients

Longitudinal Gradient

The desire at any airport site is to have the runways and taxiways as level as possible, allowing for drainage with the design of the transverse grade. In many locations the grading for a perfectly level site would be too expensive when most aircraft can easily accept 1% grade. Where longitudinal grades are used, parabolic vertical curves are used for geometric design. The penalty for gradients is to reduce the effective runway length by *10 feet per foot of difference between maximum and minimum* elevation of the runway [FAA, 1992]. and the lowest point along the runway of 70 feet, the effective runway length for MATOW calculations would be 9500 (10,200 – 70 □ □ 10) feet.

Line of Sight

The line-of-sight requirements also determine the acceptable profile of the runway. Any two points 5 feet above the runway centerline must be mutually visible for the entire runway or if on a parallel runway or taxiway for one half of the runway. Likewise, there needs to be a clear line of sight at the intersection of two runways, two taxiways, and taxiways that cross an active runway. Most line-of-sight requirements are within 800 to 1350 feet of the intersection, depending on the configuration.

Transverse Gradients

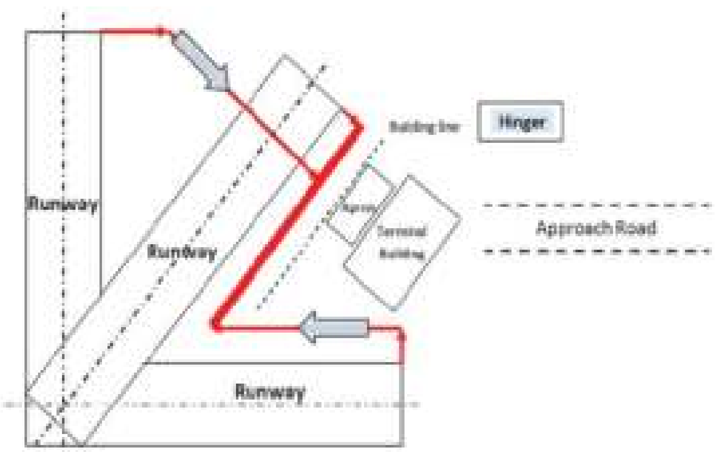
The transverse gradients are important to ensure adequate drainage from the runways and the taxiways.

Airport Plans

Upon completion of the inventory, forecasting, requirements analysis, and site evaluation, the master planning proceeds to the synthesis of airside and landside concepts and plans. These include an airport layout plan and an approach and clear zone plan. Other plans could include the site plan, the access plan, and the environmental plan.

<u>GEOMETRIC DESIGN</u>

AIRPORT COMPONENTS:



A typical airport, there are terminal buildings and hangars; pavements for aircraft runways, taxiways, and aprons; roads, bridges, and tunnels for automobiles and walks for pedestrians; automobile parking areas; drainage structures; and underground storage tanks. Aircraft include airplanes, helicopters, and the anticipated tilt rotor aircraft. Airport engineers have the responsibility of determining the size and arrangement of these facilities for safe, efficient, low-cost functioning of an airport.

ELEMENTS OF AN AIRPORT;

Runway:- Area for landing and take-off operations.

Taxiway:- Connection between apron and runway

Apron:- Planes parking are next to the building s line in which loading takes place

Hanger: Building for storage of airplanes al so maintenance ; hangers for repair and servicing of longer planes will usually be built for a specific air line according to its specification and most major repairs will be done at a planes home base.

Terminal Building Consists of an administration facility and passenger services building. (Ticket offices, Rest rooms, waiting rooming).

1-Runway length: As the first step, a basic length should be selected of a runway adequate to meet the operation requirement of the airplanes for which the runway is intended.

Basic Runway:- LBRW Is a runway length selected for aerodrome planning purposes which are required for landing or takeoff under standards atmospheric conditions for; (according to ICAO)

1) Sea level elevation.

2) Standard sea level temperature 59 F (15Co).

3) Zero percent of effective gradient.

FACTORS THAT INFLUENCE REQUIRED RUNWAY LENGTH:

1- Performance characteristics of aircraft using airport.

2- Landing & takeoff grass weight of the aircraft.

3- Elevation of the airport.

4- Air temp.

5- Runway gradient.

6- Humidity.

7- Wind.

8- Natural & condition of runway surface

$$\text{reference field length} = \frac{\text{planned or existing field length}}{F_e \times F_t \times F_g}$$

$$F_e = 0.07 \times E + 1$$

where E = airport elevation (thousands of feet)

$$F_t = 0.01[T(^\circ C) - (15 - 1.981E)] + 1$$

$$F_g = (0.10G + 1)$$

Correction to Basic Runway length due to; 1) Correction due to Elevation: Standard lengths must increase by 7% per each 1000 ft of elevation above sea level

$$L_{RW} = L_{BRW} + L_{BRW} * 0.07 * E$$

2) Correction due to Temperature: Standard lengths must increase by 0.5 % for each 1 Fo which the mean temperature at the site for the no hot month of the year. Average of over expressed of years exceeds the standard temp. for that elevation. Standard temperature site is obtained by reducing the standard sea level temp. of 59 F o at the rate of 3.566 Fo per 1000 ft elevation.

T_s=59-3.566 *E (elevation greater than 1000 (above or down M.S.L))

$$\Delta T = T_m - T_s$$

$$L_{RW} = L_{RW} + L_{RW} * \Delta T * 0.005$$

$$C^{o} = 5/9 * (F^{o} - 32)$$

3) Correction due to Effective Gradient:- The effective runway gradient is found by dividing the max. different in elevation by the total length of the runway, should be noted that the developed as the result of experience with many different types on takeoff and landing .

$$L_{RW} = L_{RW} + L_{RW} * G\% * 0.2$$

Example:-

Pre limiting investigation indicates that aircraft to service a particular town will require a truck line airport with runways 4100 ft long under standard conditions. The airport site is located 2700 ft above M.S.L, the av. Temp. during the hottest month is 67 F° and the effective gradient is 0.18 % . Find the required length of runways.

Solution:-

L_{BRW}=4100ft

1) Correction due to Elevation:

$L_{RW}= L_{BRW} + L_{BRW}*0.07*E = L_{BRW}*1.07$

$=4100 +4100* (2700/1000)*0.07= 4875$ ft.

2) Correction due to Temperature:

$T_s=59- 3.566*(2700/1000)= 49.4$ F°

$\Delta T=T_m-T_s = 67 - 49.4 = 17.6$ F°

$L_{RW}= L_{RW} + L_{RW}*\Delta T*0.005$

$L_{RW}= 4875 + 4875*17.6*0.005=5304$ ft.

3) Correction due to Effective Gradient:

$L_{RW} = L_{RW} + L_{RW}* G\% * 0.2$

$L_{RW}= 5304 +5304* 0.18 * 0.2= 5495$ ft . =5500 ft.

The selected length would normally be multiple of 100 ft

4) % of correction = (planned length-basic length) / basic length *100%

= 5500-4100/4100*100%

= 34% < 35% O.K

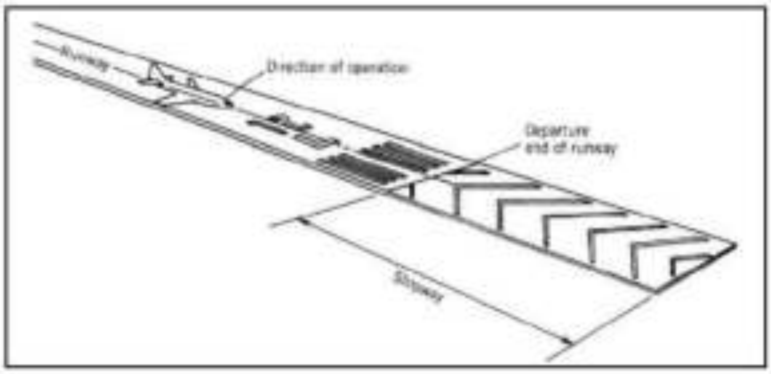
Field runway required based on the

1) Aircraft characterize.

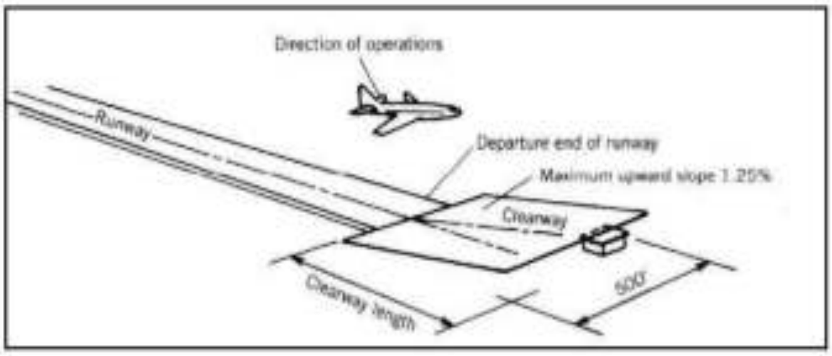
2) Safety regulation.

STOP WAY;

An area beyond the runway not less in width than the width of the runway and designed by the airport authorities for use in decelerating the aircraft during on aborted takeoff to be considered as such the stop way must be capable of supporting the aircraft without in during structural.



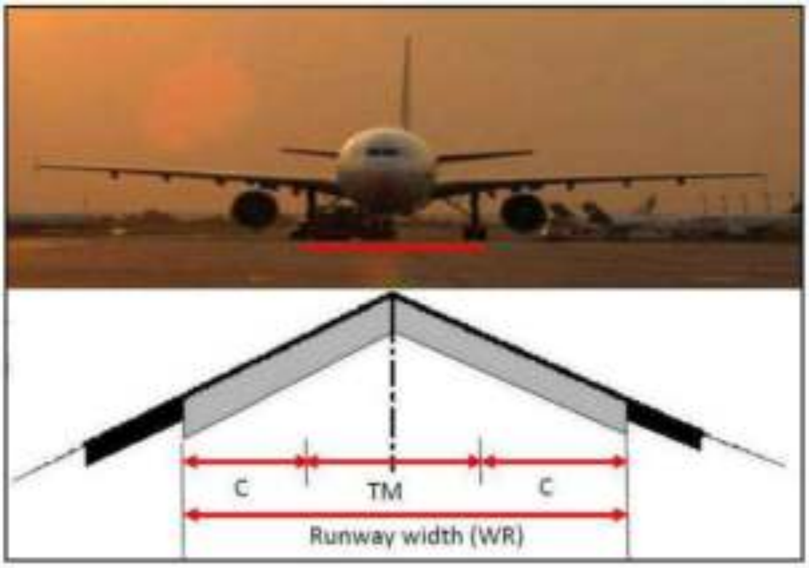
Clear way; An area beyond the runway not less than 500 centrally located about the extended center line of the runway and under control of the airport authorities.



Note:

*The field length includes the runway length plus the stopway and/or clearway lengths, if provided.

2-Runway Width:



WR=TM+2C

Where; TM= Outer main gear wheel span.

C= Clearance between the outer main gear wheel and the runway edge.

2-1-Runway Width Requirements:

The width of a runway is one of the elements that is affected by several geometrical characteristics of aeroplanes:

1. The distance between the outside edges of the main gear wheels.
2. The distance between wing mounted engines and the longitudinal axis of an aeroplane.
3. The wing span.

However, the required runway width is also affected by the operational elements:

1. The approach speed of the aeroplane
2. The prevailing meteorological conditions.•

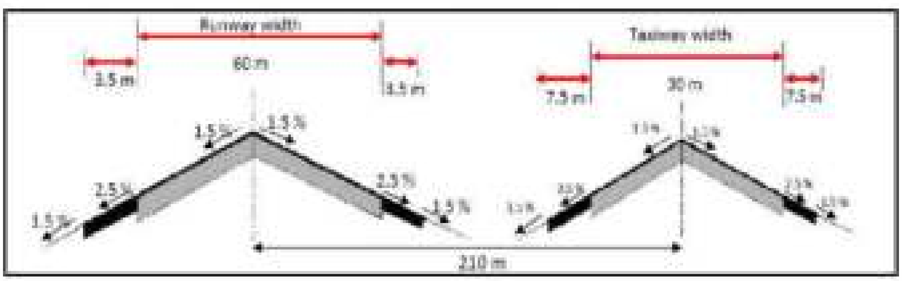
Lack of sufficient width will cause constraints on the operations. The minimum runway width is therefore specified in Annex 14 by interrelating both of the code elements, see Table (2) Under normal conditions, the width of a runway should ensure that an aeroplane does run off from the side of the runway during the take-off or landing, even after a critical engine failure causing the aircraft to yaw towards the failed engine.

Table Minimum runway width

Code number	Code letter					
	A	B	C	D	E	F
1^x	18 m	18 m	23 m	-	-	-
2^x	23 m	23 m	30 m	-	-	-
3	30 m	30 m	30 m	45 m	-	-
4	-	-	45 m	45 m	45 m	60 m

x/ The width of a precision approach runway should be not less than 30 m where the code number is 1 or 2.

Example : Baghdad International Airport (WR=60 m)



2-3 Runway Shoulders:

The runway is a paved load-bearing area that varies in width from about 60 ft at the smallest general aviation airports to 150 ft or more at the largest air carrier airports. Studies have shown that the distribution of wheel load applications occurring during landings and takeoffs approximates a normal

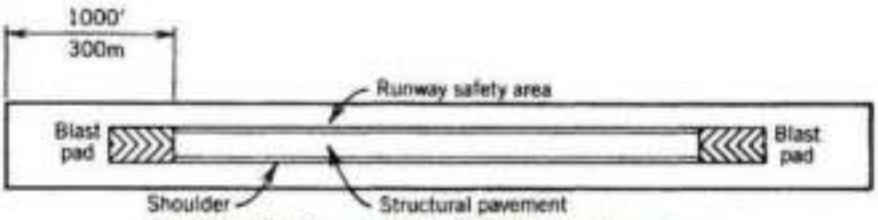


Figure (3) Plane view of runway elements

distribution centered about the runway centerline. Virtually all the load applications are concentrated in a central width of about 100 ft. The additional 50 ft of width on major runways protects jet aircraft engines from ingestion of loose material and also provides an added measure of safety for errant aircraft.

The FAA recommends shoulder widths ranging form 10 ft to 40 ft for transport airports (4). The ICAO recommends that the overall width of the runway plus its shoulders be not less than 60 m or approximately 200 ft (1).

Airports serving military aircraft may require runways and runway safety areas wider than those provided at civilian airports. For example, the Air Force (5) requires a runway width of 150 ft for runways serving fighter and trainer aircraft but a width of 300 ft for those serving heavy bombers. A graded area bordering the runway 200 ft in width is uniformly specified for conventional aircraft. The Navy (6) specifies a 200 ft runway and a 500 ft runway safety area width.

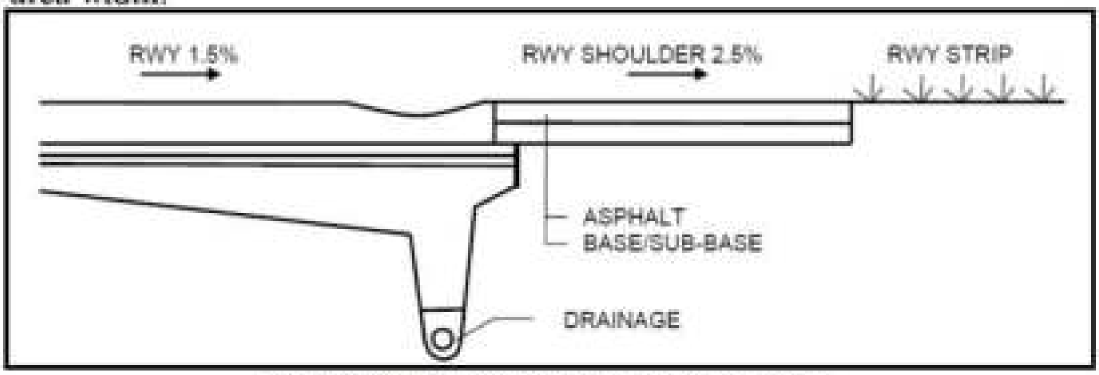
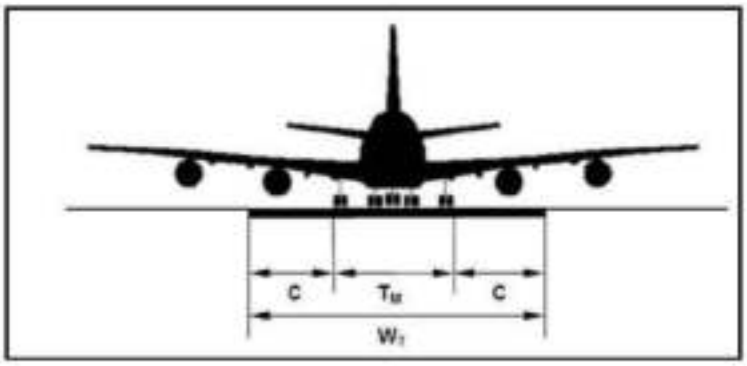


Figure (4) Runway with runway shoulder

3-Taxiways: 3-1 Taxiway Width;



The taxiway width, WT is based on a formula: WT = TM + 2C where: WT - taxiway width on the straight parts of the taxiway TM - outer main gear span C - clearance between the outer main gear wheel and the taxiway edge The clearance value depends on the taxiway code letter.

In cross-section, a taxiway is similar in appearance to a runway. The dimen sions are, of course, much smaller. The taxiway structural pavement is typi cally 20 to 60 ft wide at general aviation airports and 50 to 125 ft wide at ai carrier airports. Both the Air Force and the Navy specify a standard taxiwa width of 75 ft.

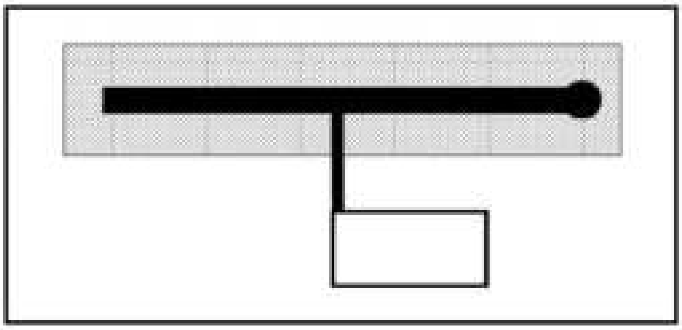
Table (3) ICAO Recommended Practices-width of Taxiways

Code Letter	Taxiway Width
A	7.5 m*
B	10.5 m
C	15 m if the taxiway is intended to be used by airplanes with a wheel base less than 18 m
	18 m if the taxiway is intended to be used by airplanes with a wheel base equal to or greater than 18 m
D	18 m if the taxiway is intended to be used by airplanes with an outer main gear wheel span of less than 9 m
	23 m if the taxiway is intended to be used by airplanes with an outer main gear wheel span equal to or greater than 9 m.
E	23 m

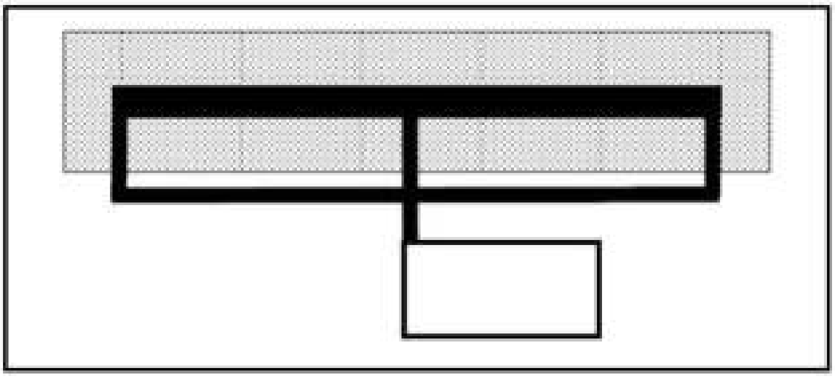
* 1 m = 3.2808 ft.

Taxiway System Design: It is often difficult to design an optimum system of taxiways. The taxiway system may have a decisive influence on the capacity of the runway system, and thereby also the overall capacity of the aerodrome.

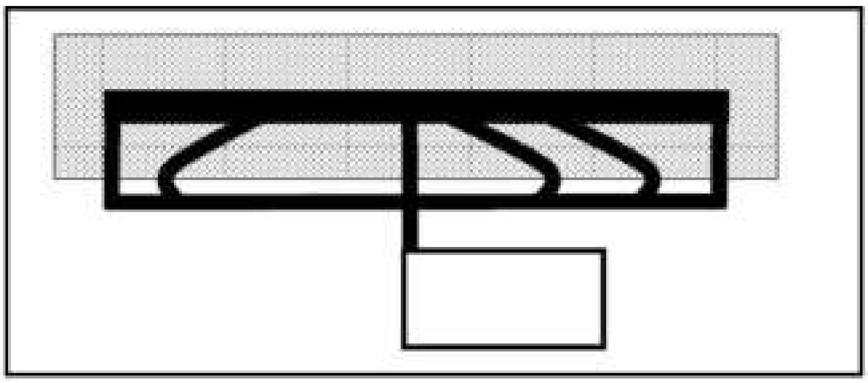
1**- Runway and apron connected with short right angle taxiway**: In those aerodromes where the number of aircraft movements during the peak hour traffic is relatively small, it is usually sufficient to provide only a short taxiway at right angles to the runway to connect it to the apron. To cope with larger airplanes, it is then usually necessary to provide additional pavement at the ends of the runway to allow the aircraft to turn round. The runway occupancy time is then considerable.



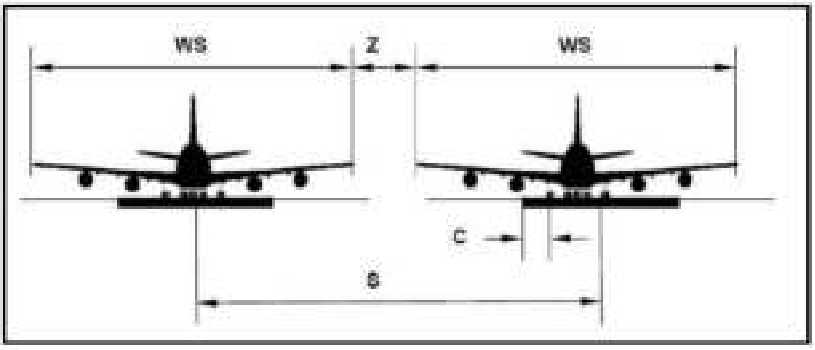
2- System of a parallel taxiway with right angle connections: If the number of movements during the peak hour traffic exceeds about 12, consideration may have to be given to construction of a taxiway parallel to the runway, and right angle connecting taxiways at the ends of the runway. In addition, in the event of a longer runway, several right angle connecting taxiways may be constructed, usually at one third or quarter of the runway length. The system of a parallel taxiway with right angle connections may be sufficient for up to 25 movements during the peak hour



3-System of a parallel taxiway with right angle connections and high-speed exit taxiway: To improve the capacity further, it is necessary to construct one or more rapid exit (high-speed exit) taxiways, usually from the preferred direction of the main runway, whose parameters and location need to correspond to the type of operation on the given runway



-**3 Taxiway Separation**: The minimum safe separation distance between the centre line of a taxiway and the centre line of a runway



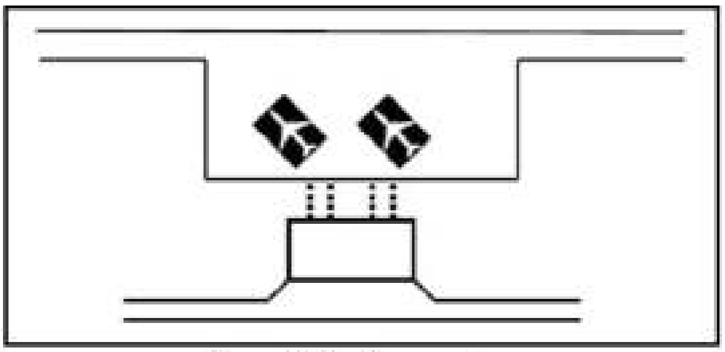
The formula for the separation distance in this case is:

S = WS + C + Z

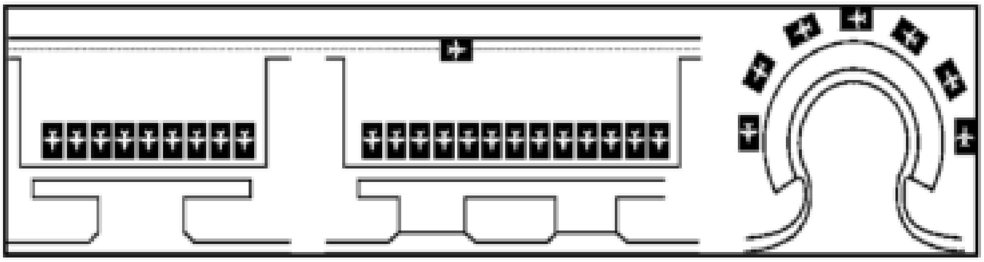
Where: WS - Wing span C - Clearance between the outer main gear wheel and the taxiway edge (maximum allowable lateral deviation). Z - Wing tip clearance.

4**- Aprons:** 4-1 Apron Requirements Aprons are designed for parking airplanes and turning them around between flights. They should permit the on and off loading of passengers, baggage and cargo, and the technical servicing of airplanes including refueling. 4-2 Apron Concepts: The geometric and maneuvering characteristics of airplanes make it practically impossible in most cases to locate all the stands required for peak traffic directly adjacent to the central processing part of the terminal building. It is therefore necessary to generate other solutions. Several basic concepts that have developed over time may be identified, depending on the total size of the airport. Each concept has its advantages and disadvantages, so the solution is often a compromise and a combination of the basic concepts discussed below. Apron design must be consistent with the adjacent terminal. Apron and terminal design is an iterative process where the optimum combination of apron and terminal concepts are analyzed at the same time.

4**.2.1 Simple Concept**: This concept is used normally at very small airports with a few movements of commercial aircraft a day.

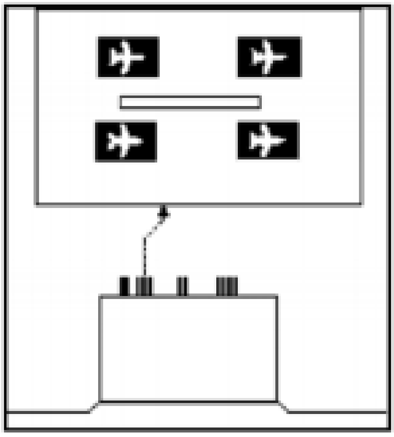


4.3.2 Linear Concept At many airports the simple concept develops gradually to the linear concept. Individual stands are located along the terminal building.

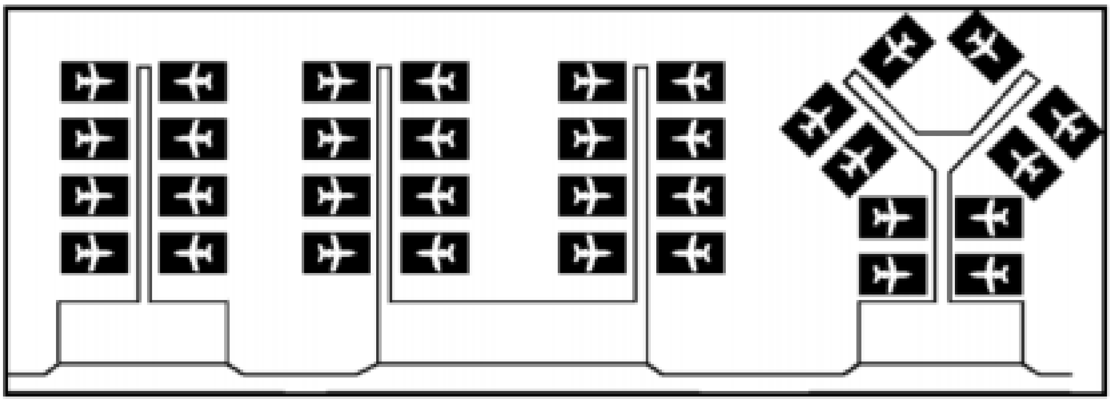


4.3.3 **Open Concept**: In this concept, the stands are located on one or more rows in front of the building Figure.

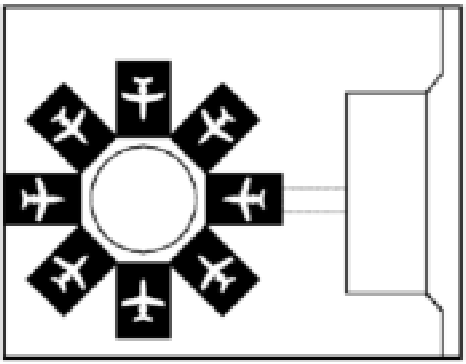
One of the rows may be close-in, but most will be a long way from the terminal. The transport of passengers to the distant stands is provided by buses or mobile lounges, with only a short walk for passengers.



4.3.4 Pier Concept: In many large airports, the introduction or extension of piers was the most convenient way of providing a greater number of contact stands and to increase the capacity of the airport while providing weather protection for the passengers.



4.3.5 Satellite Concept: In this concept, each of the remote passenger loading satellites is connected with the terminal building by underground tunnels or by overhead corridors, as in Figure.



4.3.6 Hybrid Concept: At many airports combination of two or more above mentioned concepts is usual. During the summer peak season it is quite common to park some, especially charter aircraft, on the remote apron and transport passengers by busses or transporters to the aircraft stands.

Obstruction Clearance Requirements

Aircraft landing to or taking off from a runway need an area free of obstructions to safely operate. The Federal Aviation Administration (FAA) defines a series of imaginary surfaces that define the maximum allowable height of any structures that may be placed in the vicinity of an active runway.

IMAGINARY SURFACES

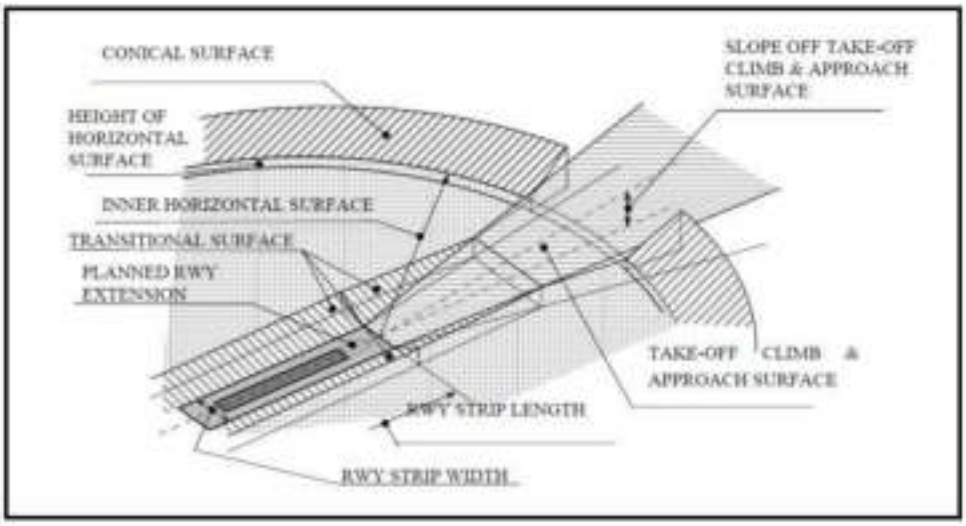
In order to determine whether an object is an obstruction to air navigation, several imaginary surfaces are established with relation to the airport and to each end of a runway. The size of the imaginary surfaces depends on the category of each runway (e.g., utility or transport) and on the type of approach planned for that end of the runway (e.g., visual, nonprecision instrument, or precision instrument). The principal imaginary surfaces are described as follows:

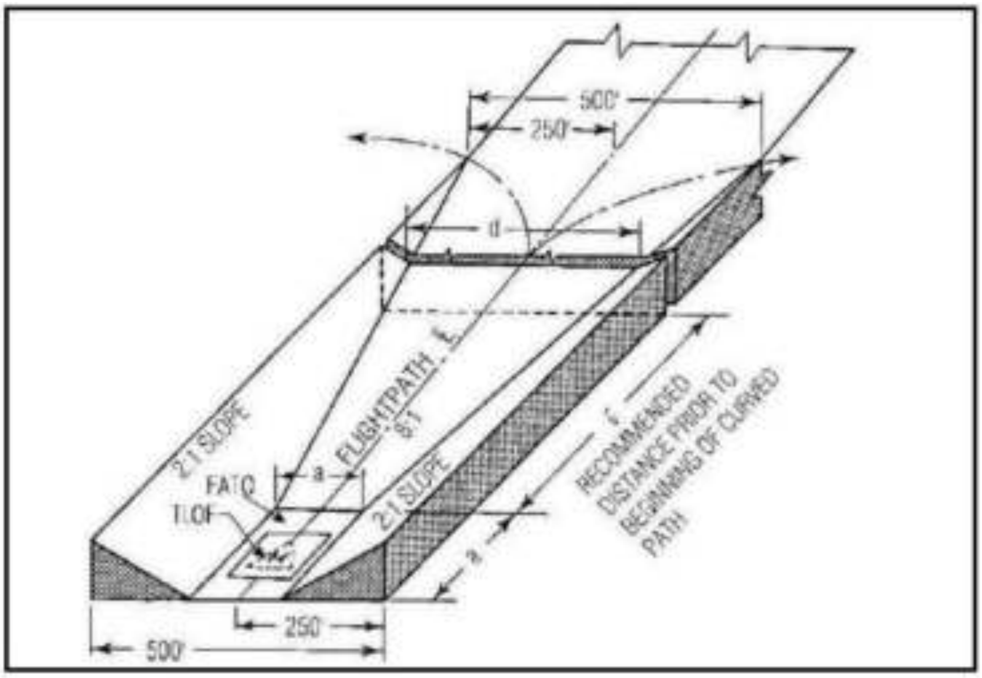
1-Primary surface: The primary surface is a surface that is longitudinally centered on the runway, extends 200 feet beyond the threshold in each direction in the case of paved runways.

2-Approach surface: The approach surface is an inclined plane or combination of planes of varying width running from the ends of the primary surface (40:1).

3-Horizontal surface: The horizontal surface is a horizontal plane 150 feet above the established airport elevation. The plane dimensions of the horizontal surface are set by arcs of specified dimensions from the end of the primary surfaces, which are connected by tangents.
4-Transitional surface: Transitional surface is an inclined plane with slope of (7:1) extending upward and outward from the primary and approach surfaces terminating at the horizontal surface where these planes meet.

5-Conical surface: The conical surface is an inclined plane at a slope of (20:1) extending upward and outward from the periphery of the horizontal surface for a horizontal distance of 4,000 feet.





ZONING LAWS

- The permissible height of structures depends upon the airport and the aircrafttypes which would use the airport.
- The use of land for manufacture of certain items which may result in smokenuisance, foul odour etc. is also controlled by the zoning laws; It should, however,be con that all

zoning ordinances are reasonable and the application is fair;otherwise they are likely to create resentment from t public and may result inmass disobedience.

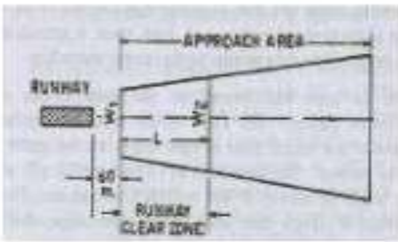
- Whenever it is felt that the zoning laws are provocative, sufficient compensation should be announced in order to ascertain its effective implementation.

APPROACH ZONE

- During landing, the glide path of an aircraft varies from a steep to fiat slope. But
- during take-off, the rate of climb of aircraft is limited by its wing loading and engine power.
- As such wide clearance areas, known as approach zones are required on either side of runway along the direction of landing and take-off of aircraft.
- Over this area, the aircraft can safety gain or loose altitude.
- The whole of this area has to be kept free of obstructions and as such zoning laws are implemented in this area.
- The plan of approach zone is the same as that of the approach surface. , The only
- difference between the two is that while approach surface is an imaginary surface,
- the approach area indicates the actual ground area.

CLEAR ZONE

- The inner most portion of approach zone which is the most critical portion fromobstruction view-point is known as clear zone.
- Its configuration and dimensions are shown in Figure



	W_1	W_2	L
Instrument runway	300 m	525 m	750 m
Non-instrument runway			
(a) Large airport	150 m	270 m	600 m
(b) Small airport	75 m	135 m	300 m

AIRCRAFT CHARACTERISTICS

These are of prime importance to the airport planning and design. The following characteristics need to be studied.

- ➢ Type of Propulsion (piston engine, jet engine and ram engine)
- ➢ Size of aircraft
- ➢ Minimum turning radius
- ➢ Minimum circling radius
- ➢ Speed of aircraft
- ➢ Capacity of aircraft
- ➢ Aircraft weight & wheel configuration
- ➢ Jet Blast
- ➢ Fuel Spillage

❑ **Type of Propulsion:**

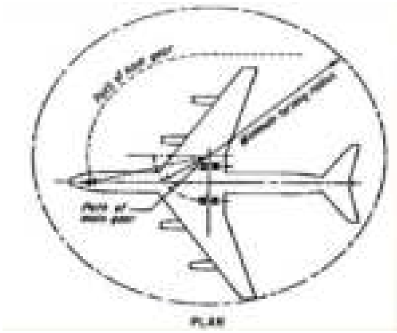
- ✓ The size of aircraft, its circling radius, speed characteristics, weight carrying capacity, noise nuisance etc. depend upon the type of propulsion of the aircraft.
- ✓ the basic runway length also depends on the type of propulsion used in aircraft.

❑ **Size of aircraft:**

- ✓ The Size of aircraft involves following important dimensions, (i) wing span
- ✓ (ii) height (iii) distance b/w main gears i.e. gear tread (iv) wheel base & tail width.

❑ **Minimum Turning radius:**

- ✓ In order to decide the radius of taxiway, its very essential to study the geometry of turning movement of aircraft.



- **Minimum Turning radius:**

  - While taking a turn, the nose gear is steered and therefore, makes an angle with the axis of the main gear, called angle of rotation. The point of intersection of main gear and line through axis of steered nose gear is called point of rotation.
  - The maximum angle of rotation is $50^\circ - 60^\circ$
  - The line joining the center of rotation and the tip of the farthest wing of the aircraft is known minimum turning radius

- **Minimum Circling Radius:**

  - ✓ There is certain minimum radius with which the aircraft can take turn in space.
  - ✓ Its radius depends upon the type of aircraft, air traffic volume & weather conditions.
  - ✓ The radii recommended for different types of aircraft are as follows.
  - ✓ Small general aviation aircraft = 1.6 km
  - ✓ Bigger aircraft = 3.2 km
  - ✓ Piston engine aircraft = 13 km
  - ✓ Jet engine aircraft = 80 km

- **Speed of Aircrafts:**

  - ✓ The speed of aircraft can be defined in two ways. i.e. Cruising speed or air speed.
  - ✓ Cruising speed is the speed of aircrafts with respect to the ground, when the aircrafts is flying in air at its maximum speed.
  - ✓ Air speed is the speed of aircraft relative to the wind.

- ✓ If the aircraft is flying at a speed of 500 kmph & there is a head wind of 50 kmph, air speed will be 450 kmph.

- **Aircraft capacity:**

  - ✓ The number of passengers, baggage & fuel that can be accommodated in the aircrafts depends upon the capacity of aircraft.
  - ✓ No of passengers and amount of cargo it can handle
  - ✓ Dependant on
    - Size
    - Propulsive power of aircraft
    - Speed of air craft

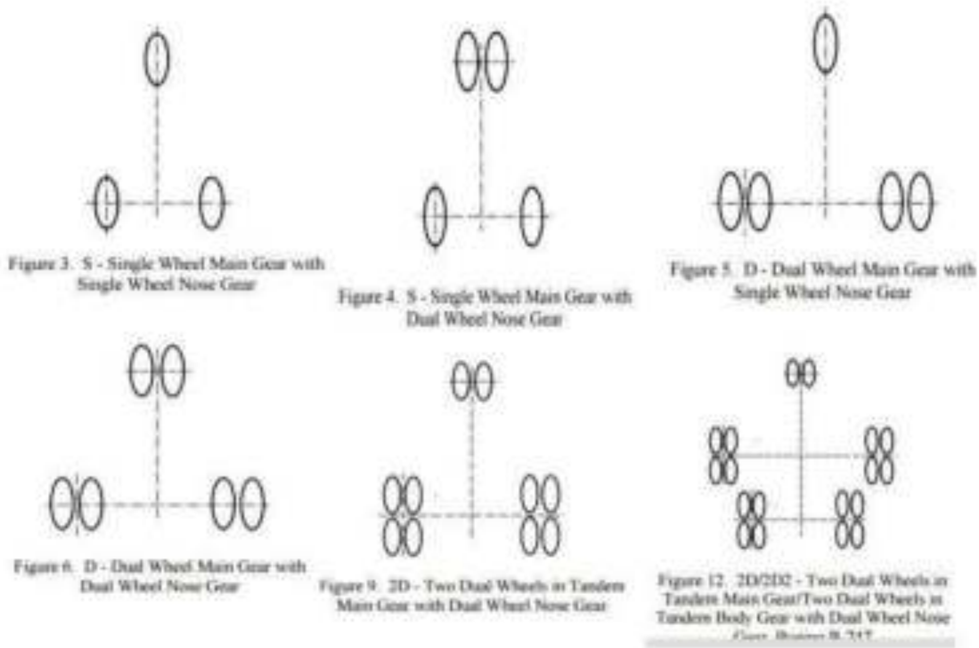
- **Weight of aircraft & wheel configuration:**

  - ➢ Weight of the aircraft directly influence the length of the runway as well as the structural requirements i.e. the thickness of the runway, taxiway, apron & hangars.
  - ➢ Pavement thickness, design, materials etc., depend on the weight and wheel distribution of aircraft.

- ➢ **Different types of weights**

  - ✓ Maximum gross take-off weight :Total amount of weight when it is taking off from runway
  - ✓ Maximum standard landing weight :Fuel consumed during transport will be deducted from take-off weight
  - ✓ Operating empty weight : Operating at zero pay load
  - ✓ Pay load n Load for which revenues are generated (passengers + freight)
  - ✓ Zero-fuel weight n Air craft reaching destination and fuel is getting empty Note: (maximum is taken considering biggest aircraft allowed at airport
  - ✓ More the no of wheels, lesser the stress, hence less thickness enough.
  - ✓ Different wheel combinations available based on size of aircraft.

- ✓ Single tandem, duel tandem and multi axle tandems are used based on the size and weight of air craft.
- ✓ Some wheel configurations are shown in the next slide.



❑ Jet Blast:

- ✓ This is the blast that comes out of the jet engine at the rear of the aircraft and provides the force movement of the aircraft.
- ✓ But, if we consider it in case where the aircraft is standing and the jet blast is coming from the rear, that is so hot and it creates a severe condition for the things on which it will be falling.
- ✓ So the severity is going to depend on two things; one is the

• height of the tail pipe from the round

• angle of the tail pipe through which this jet blast will be coming out at the tail end.

So if it is in the upward direction then it will go up if it is in the downward direction it will create a pro effect on the pavement on which the aircraft is standing and therefore there is a need to erect the blast fences which can control the damage to the building or damage to the pavement.

- ✓ **Fuel spillage:**

- ✓ At loading aprons & shelter it is difficult to avoid spillage completely, but effort should be made to bring it within minimum limit.

The flexible pavements are seriously affected by the fuel spillage.

- ❑ **Wind Coverage:** Wind coverage or usability factor of airport is the percentage of time in a year during which the cross wind component remains within the limits as specified above is wind coverage. .

- ❑ **Calm Period:** This is the period for which the wind intensity remains below 6.4 km/hr. QThis is common to all direction & hence can be added to wind coverage

for that direction.

- ❑ The maximum permissible cross wind component QIt depends upon the size of the aircraft and the wind configuration.

- ❑ FAA - 15 kmph for small aircrafts ,

  - 25 kmph for mixed traffic

ICAO – 35 kmph for big aircrafts

AIRPORT CAPACITY AND CONFIGURATION

Airport capacity analyses are made for two purposes:

1- To measure the ability of various components of the airport system of heading passengers and aircraft flow.

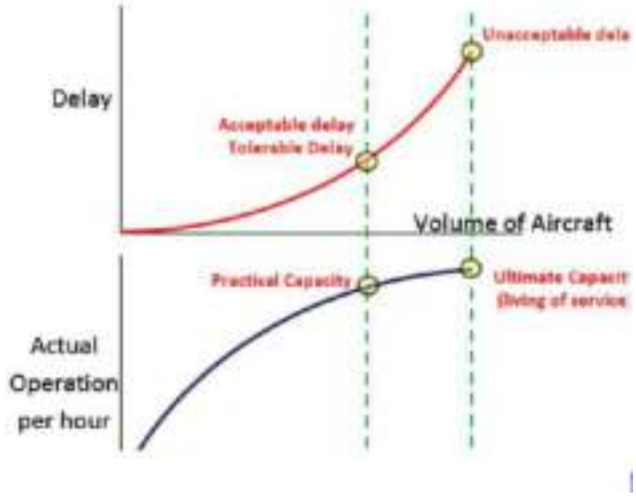
2- To estimate the delay experiment in the system at different level of demand. Capacity analysis is required for: 1- For determining the No. of required runways.

2- To identify potentially suitable configuration.

3- To compare alternative design.

4- To estimate the delay experienced in the system at different levels of demand.

** Delay can results from problems in the airside or landside.



Runway Capacity: is the ability of runway system to accommodate aircraft operations (landing or takeoff) per unit time (op/hr) or (op/yr).

Ultimate or Saturation Capacity of Runway: The max. number of aircraft that can be handled during a given period under conditions at continuous demand.

Factors Effecting on Runway Capacity

1- Characteristics of demand (Traffic Mix):

Categories of aircraft for determination of airport capacity are generally as follows:

a) Type A ; 4-engine jet and larger .

b) Type B ; 2 to 3 engine jet and 4 engine piston and Turbo prop.

c) Type C ; Executive jet and transport type twin engine piston.

d) Type D; Light twin engine piston and single –engine piston.

2- Aircraft Control:

a) VFR (Operation by Visual Flight Rule).

Or **VAW** (Visual Airport Weather).

b) IFR (Operation by Instrument Flight Rule).

Or **IAW** (Instrument Airport Weather).

VFR ; Operation are made in good weather conditions.

IFR ; Operation are made in the period of bad weather conditions or poor visually under these conditions positive traffic control is maintained by Radar and others elec-tronic devices.

3- Environmental Condition in the airport vicinity

1- **PHOCAP** (Practical Hourly Capacity).

2- **PANCAP** (Practical Annual Capacity).

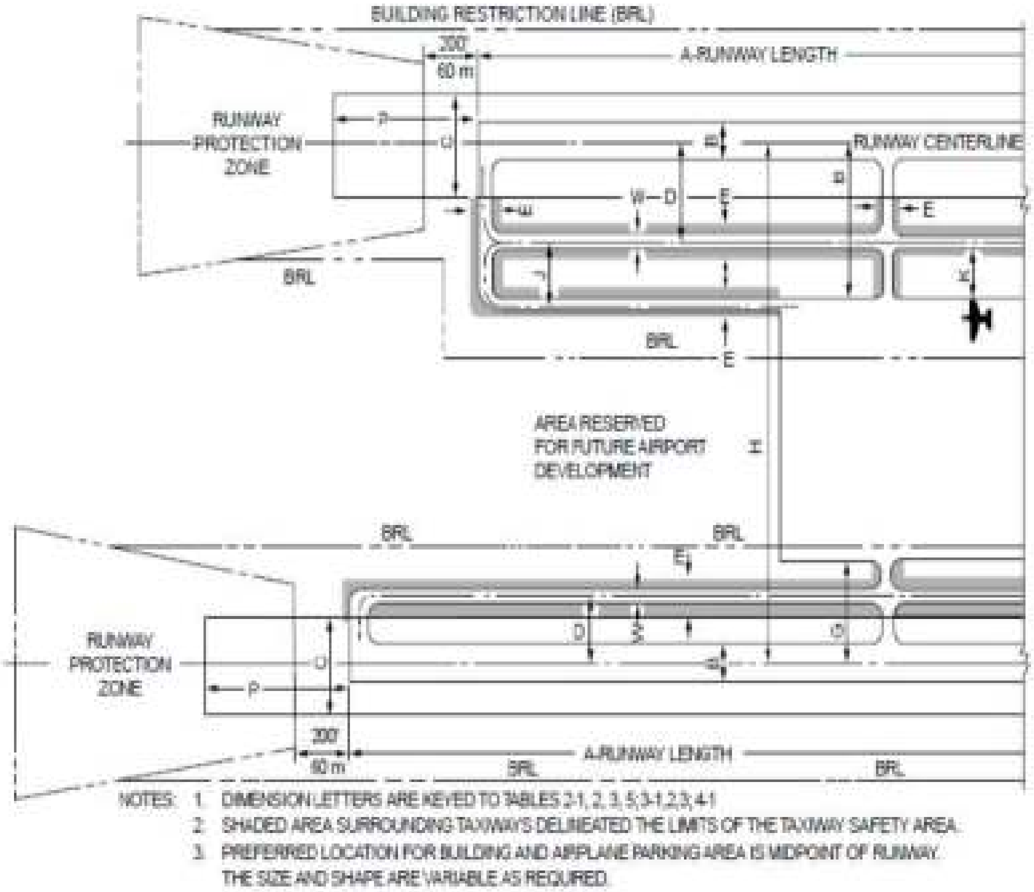
There are three categories of airports according to its airspace:

a- Unrestricted airspace.

b- Normal.

c- Restricted airspace.

runways and taxiways. The chief concern is drainage and the line of sight to adjacent runways or taxiways.



DRAINAGE

Drainage on the airport surface is a prime requisite for operational safety and pavement durability. The drainage design is handled like most drainage for streets and highways. Avoidance of ponding and erosion of slopes that would weaken pavement foundations is critical for design. Because of the need for quick and total water removal over the vast, relatively flat airport surface, an integrated drainage system is a must. Runoff is removed from the airport by means of surface gradients, ditches, inlets, an underground system of pipes, and retention ponds. Because of their large contiguous area, aprons are critical and must have an adequate sewer system. Runoff water treatment is required when there are fuel spills or during the winter, when a deicing chemical is used.

ORIENTATION AND CONFIGURATION

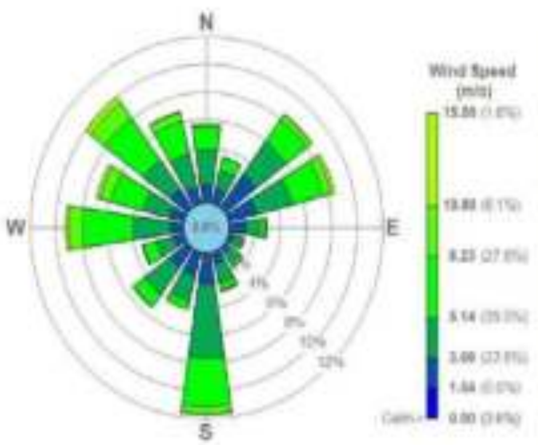
The orientation of a runway is defined by the direction, relative to magnetic north, of the operations performed by aircraft on the runway. Typically, but not always, runways are oriented in such a manner that they may be used in either direction. It is less preferred to orient a runway in such a way that operating in one direction is precluded, normally due to nearby obstacles. In addition to obstacle clearance considerations, which will be discussed later in this chapter, runways are typically oriented based on the area‘s wind conditions. As such, an analysis of wind is essential for planning runways. As a general rule, the primary runway at an airport should be oriented as closely as practicable in the direction of the prevailing winds. When landing and taking off, aircraft are able to maneuver on a runway as long as the wind component at right angles to the direction of travel, the crosswind component, is not excessive. The FAA recommends that runways should be oriented so that aircraft may be landed at least 95 percent of the time with allowable crosswind components not exceeding specified limits based upon the airport reference code associated with the critical aircraft that has the shortest wingspan or slowest approach speed. When the wind coverage is less than 95 percent a crosswind runway is recommended. The allowable crosswind is 10.5 kn (12 mi/h) for Airport Reference Codes A-I and B-I, 13 kn (15 mi/h) for Airport Reference Codes A-II and B-II, 16 kn (18.5 mi/h) for Airport Reference Codes A-III, B-III, C-I, C-II, C-III and C-IV, and 20 knots (23 mph) for Airport Reference Codes A-IV through D-VI [5]. ICAO also specifies that runways should be oriented so that aircraft may be landed at least 95 percent of the time with crosswind components of 20 kn (23 mph) for runway lengths of 1500 m more, 13 kn (15 mi/h) for runway lengths between 1200 and 1500 m, and 10 kn (11.5 mi/h) for runway lengths less than 1200 m.

Once the maximum permissible crosswind component is selected, the most desirable direction of runways for wind coverage can be determined by examination of the average wind characteristics at the airport under the following conditions:

1. The entire wind coverage regardless of visibility or cloud ceiling 2. Wind conditions when the ceiling is at least 1000 ft and the visibility is at least 3 mi 3. Wind conditions when ceiling is between 200 and 1000 ft and/or the visibility is between . and 3 mi. The first condition represents the entire range of visibility, from excellent to very poor, and is termed the all weather condition. The next condition represents the range of good visibility conditions not requiring the use of instruments for landing, termed visual meteorological condition (VMC). The last condition represents various degrees of poor visibility requiring the use of instruments for landing, termed instrument meteorological conditions (IMC). The 95 percent criterion suggested by the FAA and ICAO is applicable to all conditions of weather; nevertheless it is still useful to examine the data in parts whenever this is possible. In the United States, weather records can be obtained from the Environmental Data and Information Service of the National Climatic Center at the National Oceanic and Atmospheric Administration located in Ashville, N.C., or from various locations found on the Internet. Weather data are collected from weather stations throughout the United States on an hourly basis and recorded for analysis. The data collected include ceiling, visibility, wind speed, wind direction, storms, barometric pressure, the amount and type of liquid and frozen precipitation, temperature, and relative humidity. A report illustrating the tabulation and representation of some of the data of use in airport studies was prepared for the FAA. The weather records contain the percentage of time certain combinations of ceiling and visibility occur (e.g., ceiling, 500 to 900 ft; visibility, 3 to 6 mi), and the percentage of time winds of specified velocity ranges occur from different directions (e.g., from NNE, 4 to 7 mi/h). The directions are referenced to true north.

THE WIND ROSE

- ✓ The appropriate orientation of the runway or runways at an airport can be determined through graphical vector analysis using a wind rose.
- ✓ A standard wind rose consists of a series of concentric circles cut by radial lines using polar coordinate graph paper. The radial lines are drawn to the scale of the wind magnitude such that the area between each pair of successive lines is centered on the wind direction.
- ✓ The wind data i.e direction, duration & intensity are graphically represented by a diagram called wind rose diagram.
- ✓ Application of Wind Rose diagram is for finding the orientation of the runway to achieve wind coverage.
- ✓ The area is divided in to 16 parts using an angle of 22.5^{0} .
- ✓ Average wind data of 5 to 10 years is used for preparing wind rose diagram.



WIND ROSE – METHODS;

Type – I: Showing direction & duration of wind.

Type –II: Showing direction, duration & intensity of wind.

- ❑ **Type – I : Showing direction & duration of wind.**

- ✓ The radial lines indicate the wind direction and each circle represents the duration of wind.
- ✓ From the wind data it is observed that the total % of time in a year during which the wind blows from north direction is 10.3%.

- ✓ This value is plotted along the north direction in figure.
- ✓ Similarly other values are also plotted along the respective directions.
- ✓ All plotted points are then joined by straight lines.
- ✓ The best direction of runway usually along the direction of the longest line on wind rose diagram.
- ✓ In the figure the best orientation of runway is NS direction.

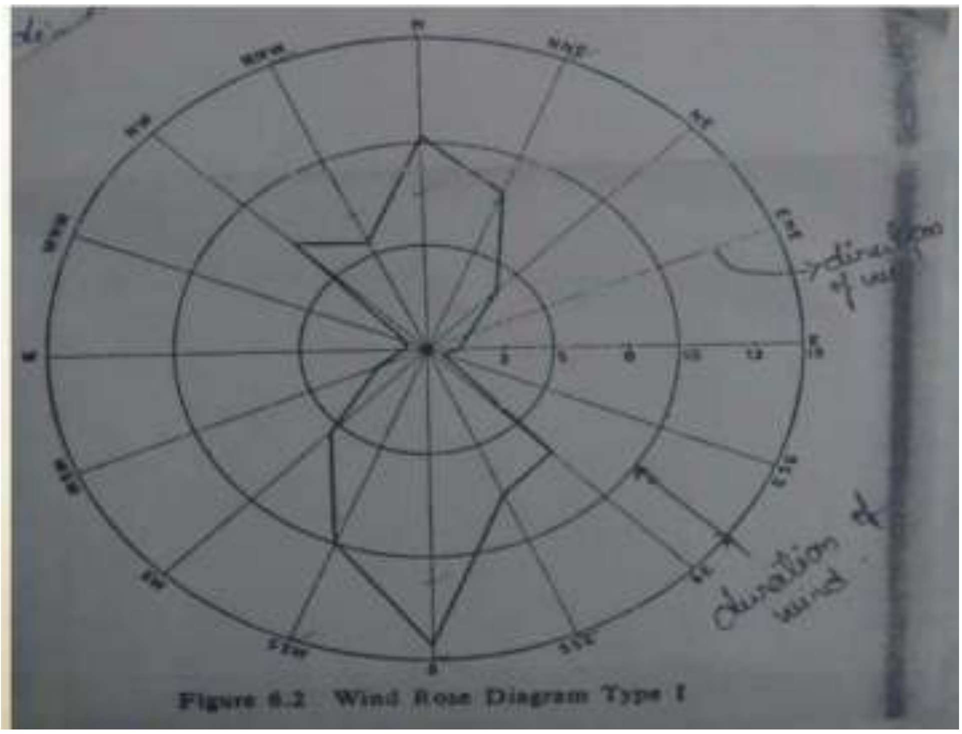


Figure 6.2 Wind Rose Diagram Type I

- ❑ **Type –II ;Showing direction, duration & intensity of wind.**

- ✓ Each circle represents the wind intensity to some scale. The values entered in each segment represents the % of time in a year during which the wind having a particular intensity.
- ✓ **Procedure:** draw 3 equi-spaced parallel lines on a transparent paper strip.
- ✓ Place the transport paper strip over the wind rose diagram in such a way that the central line passes through the centre of the diagram.
- ✓ With the centre of wind rose, rotate the tracing paper & place it in such a position that the sum of all the values indicating the duration of wind, within the two outer parallel lines, oriented is the maximum.
- ✓ The runway should be thus oriented along the direction indicated by the centre line. The wind coverage con be calculated by summing up all the % shown in segment.

- ✓ Read the bearing of the runway on the outer scale of the wind rose where the central line on the paper. That is the best orientation of runway.

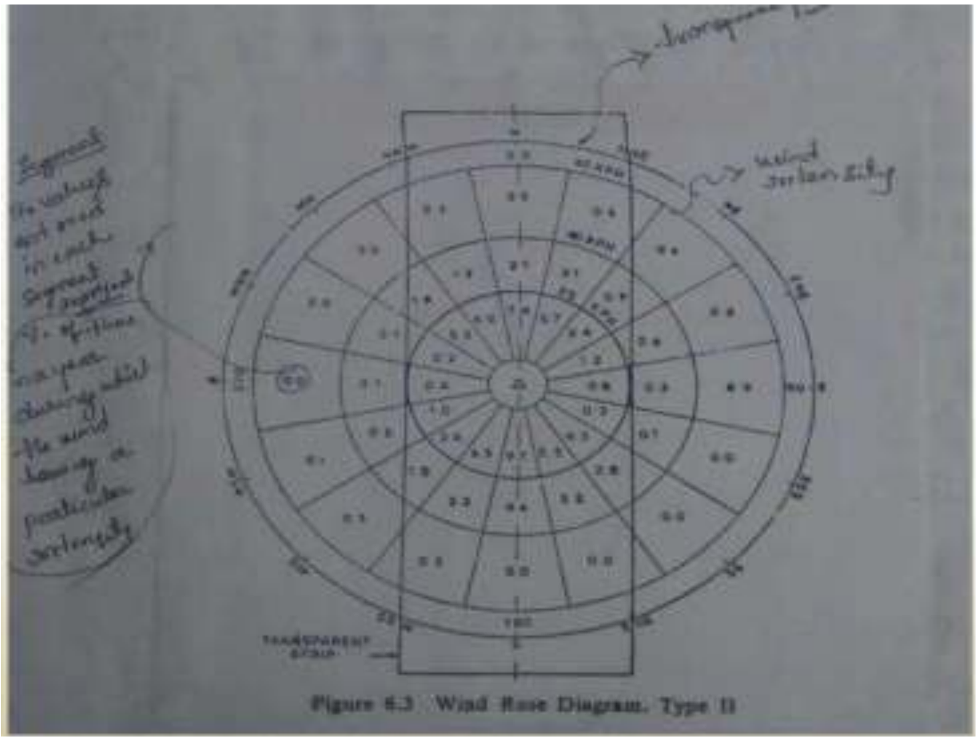


Figure 6.3 Wind Rose Diagram, Type II

BASIC RUNWAY LENGTH AND CORRECTIONS

Length of runway decided taking following assumptions:

- Airport altitude at sea level
- Temperature at airport is standard (150C)
- Runway is level in longitudinal direction
- No wind is blowing on runway
- No wind is blowing enroute to destination
- Aircraft is loaded to its full capacity
- Enroute temperature standard

The basic runway length is determined form the performance characteristics of aircraft using airport. The following cases are usually considered *Normal landing case Normal takeoff case Engine failure case* For jet engine aircraft all three cases are considered but for piston engine air craft first and third case are usually considered. The longest runway length is finally adopted. The landing case require that aircraft should come to stop within 60% of the landing distance. The full strength pavement is provided for entire landing distance. The normal takeoff requires a clear way which is an area beyond the runway and is alignment with the centre line of the runway. The width of the clear way is not less than 150m (500 ft) and is kept free from obstruction. The clearway ground area any object should not protrude a plane upward at a slope of 1.25% from the runway end.

Engine failure case may require either a clearway or a stop way or both. Stopway is defined as the area beyond runway and centrally located in alignment with the centreline of the runway. It is used for decelerating the aircraft to stop during aborted takeoff. The strength of the stopway should be sufficient to carry the weight of the aircraft without casing any structural damage. If engine fail at a speed less than the designated engine failure speed, the pilot decelerate the aircraft and use the stopway. If however engine fails at a speed higher than the designated speed, there is no other option to pilot take-off. The pilot may latter take turn and make a landing. For piston engine aircrafts full strength pavement is provided for entire takeoff distance and the accelerated stop distance.

Correction for elevation, temperature and gradient Airports are constructed in different elevation different atmospheric temperature and gradient, in contrast to the assumption made for basic runway length. Therefore correction required for changes in each components.

Correction in elevation All other things being equal, the higher the field elevation of the airport, results the less dense the atmosphere, requiring longer runway lengths for the aircraft to get to the appropriate groundspeed to achieve sufficient lift for takeoff. For airports at elevation above sea level, the design runway length is 300 ft plus 0.03 ft for every foot above sea level. ICAO recommends the basic runway length should increase at rate of 7% per 100 m rise in elevation over MSL.

Correction in temperature With rise of reference temperature same effect is there as that of elevation. The airport reference temperature defined as monthly mean of average daily temperature (Ta) for the hottest month of the year plus one third the difference of this temperature and monthly mean of the maximum daily temperature(Tw) for same month of the year.

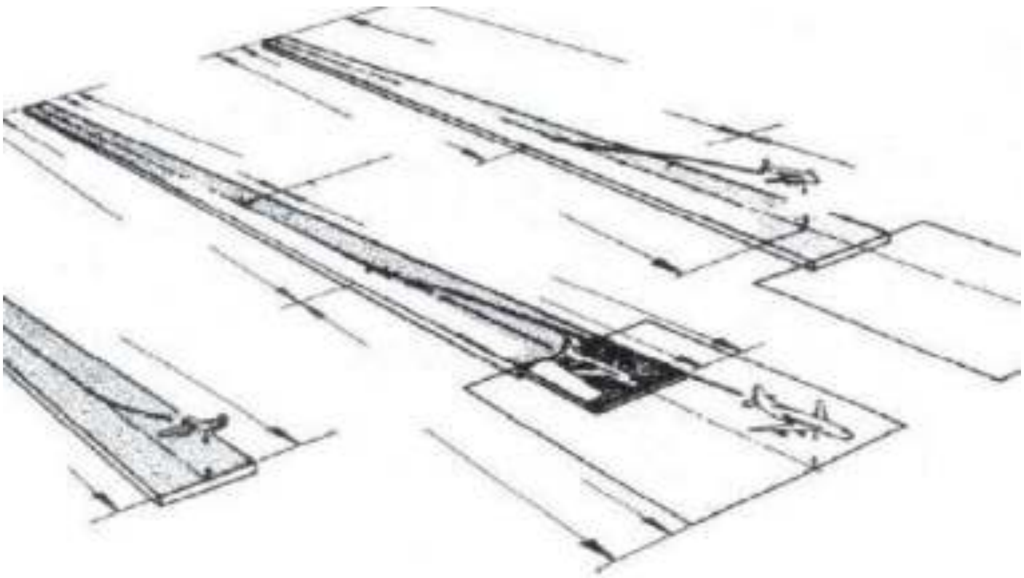
Reference Temperature = Ta + (Tw – Ta)/3

ICAO recommends the basic runway length after have been corrected for elevation, should further increase at the rate of 1% for every 10C increase of reference temperature. If both correction increases more than 35% ICAO recommended specific site study should be conducted.

Correction for gradient Steeper gradient require greater consummation of energy and longer length of runway to attain the desired speed. ICAO does not recommend any correction. FAA recommend after correction for elevation and temperature a further increase in runway length at arte of 20% for every 1 percent effective gradient.

Effective gradient is defined taking maximum difference between elevation between lowest point and highest point in the runway divided by length of the runway.

Surface Wind Wind speed and direction at an airport also have a significance on runway length requirements. Simply, the greater the headwind the shorter the runway length required, and the greater the tailwind the longer the runway required. Further, the presence of crosswinds will also increase the amount of runway required for takeoff and landing. From the perspective of the planner, it is often estimated that for every 5 km of headwind, required runway length is reduced by approximately 3 percent and for every 7 km of tailwind, runway length requirements increase by approximately 7 percent. For airport planning purposes runway lengths are often designed assuming calm wind conditions.



GEOMETRIC ELEMENTS DESIGN

Taxiways and Taxi lanes

Taxiways are defined paths on the airfield surface which are established for the taxiing of aircraft and are intended to provide a linkage between one part of the airfield and another. Basically it established the connection between runway, terminal building and hanger. The term ―dual parallel taxiways‖ refers to two taxiways parallel to each other on which airplanes can taxi in opposite directions. An apron taxiway is a taxiway located usually on the periphery of an apron intended to provide a through taxi route across the apron. A taxi lane is a portion of the aircraft parking area used for access between the taxiways and the aircraft parking positions. ICAO defines an aircraft stand taxi lane as a portion of the apron intended to provide access to the aircraft stands only. In order to provide a margin of safety in the airport operating areas, the traffic ways must be separated sufficiently from each other and from adjacent obstructions. Minimum separations between the centerlines of taxiways, between the centerlines of taxiways and taxi lanes, and between taxiways and taxi lanes and objects are specified in order that aircraft may safely maneuver on the airfield.

TAXIWAY AND TAXILANE SEPARATION REQUIREMENTS (FAA SEPARATION CRITERIA)

The separation criteria adopted by the FAA are predicated upon the wingtips of the aircraft for which the taxiway and taxilane system have been designed and provide a minimum wingtip clearance on these facilities. The required separation between taxiways, between a taxiway and a taxilane, or between a taxiway and a fixed or movable object requires a minimum wingtip clearance of 0.2 times the wingspan of the most demanding aircraft in the airplane design group plus 10 ft. This clearance provides a minimum taxiway centerline to a parallel taxiway centerline or taxilane centerline separation of 1.2 times the wingspan of the most demanding aircraft plus 10 ft, and between a taxiway centerline and a fixed or movable object of 0.7 times the wingspan of the most demanding aircraft plus 10 ft. The taxilane centerline to a parallel taxilane centerline or fixed or movable object separation in the terminal area is predicated on a wingtip clearance of approximately half of that required for an apron taxiway. This reduction in clearance is based on the consideration that taxiing speed is low in this area, taxiing is precise, and special guidance techniques and devices are provided. This requires a wingtip clearance or wingtip-to-object clearance of 0.1 times the wingspan of the most demanding aircraft plus 10 ft.

SIGHT DISTANCE AND LONGITUDINAL PROFILE

As in the case of runways, the number of changes in longitudinal profile for taxiways is limited by sight distance and minimum distance between vertical curves. The FAA does not specify line of sight requirements for taxiways other than those discussed earlier related to runway and taxiway intersections. However, the sight distance along a runway from an intersecting taxiway needs to be sufficient to allow a taxiing aircraft to enter or cross the runway safely. The FAA specifies that from any point on the taxiway centerline the difference in elevation between that point and the corresponding point on a parallel runway, taxiway, or apron edge is 1.5 percent of the shortest distance between the points. ICAO requires that the surface of the taxiway should be seen for a distance of 150 m from a point 1.5 m above the taxiway for aerodrome code letter A runways, for a distance of 200 m from a point 2 m above the taxiway for aerodrome code letter B runways, and for a distance of 300 m from a point 3 m above the taxiway for aerodrome code letter C, D, or E runways. In regard to longitudinal profile of taxiways, the ICAO does not specify the minimum distance between the points of intersection of vertical curves. The FAA specifies that the minimum distance for both utility and transport category airports should be not less than the product of 100 ft multiplied by the sum of the absolute percentage values of change in slope.

EXIT TAXIWAY

The function of exit taxiways, or runway turnoffs as they are sometimes called, is to minimize runway occupancy by landing aircraft. Exit taxiways can be placed at right angles to the runway or some other angle to the runway. When the angle is on the order of 30°, the term high-speed exit is often used to denote that it is designed for higher speeds than other exit taxiway configurations. In this chapter, specific dimensions for high-speed exit, right-angle exit (low-speed) taxiways are presented.

Aircraft paths in the test approximated a spiral. A compound curve is relatively easy to establish in the field and begins to approach the shape of a spiral, thus the reason for suggesting a compound curve. The following pertinent conclusions were reached as a result of the tests [13]: 1. Transport category and military aircraft can safely and comfortably turn off runways at speeds on the order of 60 to 65 mi/h on wet and dry pavements. 2. The most significant factor affecting the turning radius is speed, not the total angle of turn or passenger comfort. 3. Passenger comfort was not critical in any of the turning movements. 4. The computed lateral forces developed in the tests were substantially below the maximum lateral forces for which the landing gear was designed. 5. Insofar as the shape of the taxiway is concerned, a slightly widened entrance gradually tapering to the normal width of taxiway is preferred. The widened entrance gives the pilot more latitude in using the exit taxiway. 6. Total angles of turn of 30° to 45° can be negotiated satisfactorily. The smaller angle seems to be preferable because the length of the curved path is reduced, sight distance is improved, and less concentration is required on the part of the pilots. 7. The relation of turning radius versus speed expressed by the formula below will yield a smooth, comfortable turn on a wet or dry pavement when f is made equal to 0.13. 8. The curve expressed by the equation for $R2$ should be preceded by a larger radius curve $R1$ at exit speeds of 50 to 60 mi/h. The larger radius curve is necessary to provide a gradual transition from a straight tangent direction section to a curved path section. If the transition curve is not provided tire wear on large jet transports can be excessive. 9. Sufficient distance must be provided to comfortably decelerate an aircraft after it leaves the runway. It is suggested that for the present this distance be based on an average rate of deceleration of 3.3 ft/s2. This applies only to transport category aircraft. Until more experience is gained with this type of operation the stopping distance should be measured from the edge of the runway.

LOCATION OF EXIT TAXIWAYS

The location of exit taxiways depends on the mix of aircraft, the approach and touchdown speeds, the point of touchdown, the exit speed, the rate of deceleration, which in turn depends on the condition of the pavement surface, that is, dry or wet, and the number of exits. While the rules for flying transport aircraft are relatively precise, a certain amount of variability among pilots is bound to occur especially in respect to braking force applied on the runway and the distance from runway threshold to touchdown. The rapidity and the manner in which air traffic control can process arrivals is an extremely important factor in establishing the location of exit taxiways. The location of exit taxiways is also influenced by the location of the runways relative to the terminal area.

HOLDING APRONS

Holding aprons, holding pads, run-up pads, or holding bays as they are sometimes called, are placed adjacent to the ends of runways. The areas are used as storage areas for aircraft prior to takeoff. They are designed so that one aircraft can bypass another whenever this is necessary. For piston-engine aircraft the holding apron is an area where the aircraft instrument and engine operation can be checked prior to takeoff. The holding apron also provides for a trailing aircraft to bypass a leading aircraft in case the takeoff clearance of the latter must be delayed for one reason or another, or if it experiences some malfunction. There are many configurations of holding aprons. The important design criteria are to provide adequate space for aircraft to maneuver easily onto the runway irrespective of the position of adjacent aircraft on the holding apron and to provide sufficient room for an aircraft to bypass parked aircraft on the holding apron. The recommendations for the minimum separation between aircraft on holding aprons are the same as those specified for the taxiway object-free area. Holding pads must be designed for the largest aircraft which will use the pad. The holding pad should be located so that all aircraft using the pad will be located outside both the runway and taxiway object-free area and in a position so as not to interfere with critical ILS signals.

AIRPORT LAYOUTS AND TERMINAL BUILDING Terminal building

The terminal area is the major interface between the airfield and the rest of the airport. It includes the facilities for passenger and baggage processing, cargo handling, and airport maintenance, operations, and administration activities. The passenger processing system is discussed at length in this chapter. Baggage processing, cargo handling, and apron requirements are also discussed relative to the terminal system.

The Passenger Terminal System

The passenger terminal system is the major connection between the ground access system and the aircraft. The purpose of this system is to provide the interface between the passenger airport access mode, to process the passenger for origination, termination, or continuation of an air transportation trip, and convey the passenger and baggage to and from the aircraft.

Components of the System

The passenger terminal system is composed of three major components. These components and the activities that occur within them are as follows: 1. The access interface where the passenger transfers from the access mode of travel to the passenger processing component. Circulation, parking, and curbside loading and unloading of passengers are the activities that take place within this component. 2. The processing component where the passenger is processed in preparation for starting, ending, or continuation of an air transportation trip. The primary activities that take place within this component are ticketing, baggage check-in, baggage claim, seat assignment, federal inspection services, and security. 3. The flight interface where the passenger transfers from the processing component to the aircraft. The activities that occur here include assembly, conveyance to and from the aircraft, and aircraft loading and unloading. A number of facilities are provided to perform the functions of the passenger terminal system. These facilities are indicated for each of the components identified above.

The access interface

This component consists of the terminal curbs, parking facilities, and connecting roadways that enable originating and terminating passengers, visitors, and baggage to enter and exit the terminal. It includes the following facilities: 1. The enplaning and deplaning curb frontage which provide the public with loading and unloading for vehicular access to and from the terminal building 2. The automobile parking facilities providing short-term and long-term parking spaces for passengers and visitors, and facilities for rental cars, public transit, taxis, and limousine services 3. The vehicular roadways providing access to the terminal curbs, parking spaces, and the public street and highway system 4. The designated pedestrian walkways for crossing roads including tunnels, bridges, and automated devices which provide access between the parking facilities and the terminal building 5. The service roads and fire lanes which provide access to various facilities in the terminal and to other airport facilities, such as air freight, fuel truck stands, and maintenance. The ground access system at an airport is a complex system of roadways, parking facilities, and terminal access curb fronts.

The Processing System

The terminal is used to process passengers and baggage for the interface with aircraft and the ground transportation modes. It includes the following facilities:

1. The airline ticket counters and offices used for ticket transactions, baggage check-in, flight information, and administrative personnel and facilities

2. The terminal services space which consists of the public and nonpublic areas such as concessions, amenities for passengers and visitors, truck service docks, food preparation areas, and food and miscellaneous storage

3. The lobby for circulation and passenger and visitor waiting

4. Public circulation space for the general circulation of passengers and visitors consisting of such areas as stairways, escalators, elevators, and corridors

5. The outbound baggage space which is a nonpublic area for sorting and processing baggage for departing flights

6. The intraline and interline baggage space used for processing baggage transferred from one flight to another on the same or different airlines

7. The inbound baggage space which is used for receiving baggage from an arriving flight, and for delivering baggage to be claimed by the arriving passenger

8. Airport administration and service areas used for airport management, operations, and maintenance facilities

9. The federal inspection service facilities which are the areas for processing passengers arriving on international flights, as well as performing agricultural inspections, and security functions.

AIRPORT MAKING AND LIGHTING-

Visual aids assist the pilot on approach to an airport, as well as navigating around an airfield and are essential elements of airport infrastructure. As such, these facilities require proper planning and precise design. These facilities may be divided into three categories: lighting, marking, and signage. Lighting is further categorized as either approach lighting or surface lighting. Specific lighting systems described in this chapter include 1. Approach lighting 2. Runway threshold lighting 3. Runway edge lighting 4. Runway centerline and touchdown zone lights 5. Runway approach slope indicators 6. Taxiway edge and centerline lighting The proper placement of these systems is described in this chapter but no attempt has been made to describe in detail the hardware or its installation. Airfield marking and signage includes

1. Runway and taxiway pavement markings
2. Runway and taxiway guidance sign systems Airfield lighting, marking, and signage facilities provide the following functions:

1. Ground to air visual information required during landing
2. The visual requirements for takeoff and landing
3. The visual guidance for taxiing

THE REQUIREMENTS FOR VISUAL AIDS

Since the earliest days of flying, pilots have used ground references for navigation when approaching an airport, just as officers on ships at sea have used landmarks on shore when approaching a harbor. Pilots need visual aids in good weather as well as in bad weather and during the day as well as at night. In the daytime there is adequate light from the sun, so artificial lighting is not usually required but it is necessary to have adequate contrast in the field of view and to have a suitable pattern of brightness so that the important features of the airport can be identified and oriented with respect to the position of the aircraft in space. These requirements are almost automatically met during the day when the weather is clear. The runway for conventional aircraft always appears as a long narrow strip with straight sides and is free of obstacles. It can therefore be easily identified from a distance or by flying over the field. Therefore, the perspective view of the runway and other identifying reference landmarks are used by pilots as visual aids for orientation when they are approaching the airport to land. Experience has demonstrated that the horizon, the runway edges, the runway threshold, and the centreline of the runway are the most important elements for pilots to see. In order to enhance the visual information during the day, the runway is painted with standard marking patterns. The key elements in these patterns are the threshold, the centerline, the edges, plus multiple parallel lines to increase the perspective and to define the plane of the surface. During the day when visibility is poor and at night, the visual information is reduced by a significant amount over the clear weather daytime scene. It is therefore essential to provide visual aids which will be as meaningful to pilots as possible.

THE AIRPORT BEACON

Beacons are lighted to mark an airport. They are designed to produce a narrow horizontal and vertical beam of high-intensity light which is rotated about a vertical axis so as to produce approximately 12 flashes per minute for civil airports and 18 flashes per minute for military airports. The flashes with a clearly visible duration of at least 0.15 s are arranged in a white-green sequence for land airports and a white yellow sequence for landing areas on water. Military airports use a double white flash followed by a longer green or yellow flash to differentiate them from civil airfields. The beacons are mounted on top of the control tower or similar high structure in the immediate vicinity of the airport.

OBSTRUCTION LIGHTING

Obstructions are identified by fixed, flashing, or rotating red lights or beacons. All structures that constitute a hazard to aircraft in flight or during landing or takeoff are marked by obstruction lights having a horizontally uniform intensity duration and a vertical distribution design to give maximum range at the lower angles (1.5° to 8°) from which a colliding approach would most likely come.

THE AIRCRAFT LANDING OPERATION

An aircraft approaching a runway in a landing operation may be visualized as a sequence of operations involving a transient body suspended in a three-dimensional grid that is approaching a fixed two-dimensional grid. While in the air, the aircraft can be considered as a point mass in a three-dimensional orthogonal coordinate system in which it may have translation along three coordinate directions and rotation about three axes. If the three coordinate axes are aligned horizontal, vertical, and parallel to the end of the runway, the directions of motion can be described as lateral, vertical, and forward. The rotations are normally called pitch, yaw, and roll, for the horizontal, vertical, and parallel axes, respectively. During a landing operation, pilots must control and coordinate all six degrees of freedom of the aircraft so as to bring the aircraft into coincidence with the desired approach or reference path to the touchdown point on the runway. In order to do this, pilots need translation information regarding the aircraft‘s alignment, height, and distance, rotation information regarding pitch, yaw, and roll, and information concerning the rate of descent and the rate of closure with the desired path.

ALIGNMENT GUIDANCE

Pilots must know where their aircraft is with respect to lateral displacement from the centerline of the runway. Most runways are from 75 to 200 ft wide and from 3000 to 12,000 ft long. Thus any runway is a long narrow ribbon when first seen from several thousand feet above. The predominant alignment guidance comes from longitudinal lines that constitute the centerline and edges of the runway. All techniques, such as painting, lighting, or surface treatment that develop contrast and emphasize these linear elements are helpful in providing alignment information.

HEIGHT INFORMATION

The estimation of the height above ground from visual cues is one of the most difficult judgments for pilots. It is simply not possible to provide good height information from an approach lighting system. Consequently the best source of height information is the instrumentation in the aircraft. However, use of these instruments often requires the availability of precision ground or satellite based navigation technologies.

APPROACH LIGHTING

Approach lighting systems (ALS) are designed specifically to provide guidance for aircraft approaching a particular runway under night time or other low-visibility conditions. While under night time conditions it may be possible to view approach lighting systems from several miles away, under other low-visibility conditions, such as fog, even the most intense ALS systems may only be visible from as little as 2500 ft from the runway threshold. Studies of the visibility in fog have shown that for a visual range of 2000 to 2500 ft it would be desirable to have as much as 200,000 candelas (cd) available in the outermost approach lights where the slant range is relatively long. Under these same conditions the optimum intensity of the approach lights near the threshold should be on the order of 100 to 500 cd. A transition in the intensity of the light that is directed toward the pilot is highly desirable in order to provide the best visibility at the greatest possible range and to avoid glare and the loss of contrast sensitivity and visual acuity at short range.

SYSTEM CONFIGURATIONS

The configurations which have been adopted are the Calvert system‘ which has been widely used in Europe and other parts of the world, the ICAO category II and category III system shown in and the four system configurations which have been adopted by the FAA in the United States. The FAA publishes criteria for the establishment of the approach lighting systems and other navigation facilities at airports. Approach lights are normally mounted on frangible pedestals of varying height to improve the perspective of the pilot in approaching a runway.

MALSR SYSTEM.

At smaller airports where precision approaches are not required, a medium ALS with sequential flashers (MALSF) or with sequenced flashers (MALS) is adequate. The system is only 1400 ft long compared to a length of 2400 ft for a precision approach system. It is therefore much more economical, an important factor at small airports. The runway alignment indicator lights and these are only provided in the outermost 400 ft of the 1400-ft system to improve pilot recognition of the runway approach in areas where there are distracting lights in the vicinity of the airport. The MALS system does not have the runway alignment indicator lights or the sequential flashers. At international airports in the United States, the 2400-ft ALSs are often extended to a distance of 3000 ft to conform to international specifications. Sequenced-flashing high-intensity lights are available for airport use and are installed as supplements to the standard approach lighting system at those airports where very low visibilities occur frequently. These lights operate from the stored energy in a capacitor which is discharged through the lamp in approximately 5 ms and may develop as much as 30 million cd of light. They are mounted in the same pedestals as the light bars. The lights are sequence-fired, beginning with the unit farthest from the runway. The complete cycle is repeated every 2s. This results in a brilliant ball of light continuously moving toward the runway. Since the very bright light can interfere with the eye adaptation of the pilot, condenser discharge lamps are usually omitted in the 1000 ft of the approach lighting system nearest the runway.

VISUAL APPROACH SLOPE AIDS

Visual approach slope aids are lighting systems designed to provide a measure of vertical guidance to aircraft approaching a particular runway. The principle of these aids is to provide color-based identification to the pilot indicating their variation from a desired altitude and descent rate while on approach. The two most common visual approach slope aids are the visual approach slope indicator (VASI), and the precision approach path indicator (PAPI).

VISUAL APPROACH SLOPE INDICATOR

The visual approach slope indicator (VASI) is a system of lights which acts as an aid in defining the desired glide path in relatively good weather conditions. VASI lighting intensities are designed to be visible from 3 to 5 mi during the day and up to 20 mi at night. There are a number of different VASI configurations depending on the desired visual range, the type of aircraft, and

whether large wide bodied aircraft will be using the runway. Each group of lights transverse to the direction of the runway is referred to as a *bar*. The downwind bar is typically located between 125 and 800 ft from the runway threshold, each subsequent bar is located between 500 and 1000 ft from the previous bar. A bar is made up of one, two, or three light units, referred to as *boxes*. The basic VASI-2 system, is a two-bar system consisting of four boxes. The bar that is nearest to the runway threshold is referred to as the *downwind bar*, and the bar that is farthest from the runway threshold is referred to as the *upwind bar*. If pilots are on the proper glide path, the downwind bar appears white and the upwind bar appears red; if pilots are too low, both bars appear red; and if they are too high both bars appear white. In order to accommodate large wide bodied aircraft where the height of the eye of the pilot is much greater than in smaller jets, a third upwind bar is added. For wide bodied aircraft the middle bar becomes the downwind bar and the third bar is the upwind bar. In other words, pilots of large wide bodied aircraft ignore the bar closest to the runway threshold and use the other two bars for visual reference.. The more common systems in use in the United States are the VASI-2, VASI-4, VASI-12, and VASI-16. VASI systems are particularly useful on runways that do not have an instrument landing system or for aircraft not equipped to use an instrument landing system

PRECISION APPROACH PATH INDICATOR

The FAA presently prefers the use of another type of visual approach indicator called the *precision approach path indicator* (PAPI) [20]. This system gives more precise indications to the pilot of the approach path of the aircraft and utilizes only one bar as opposed to the minimum of two required by the VASI system. The system consists of a unit with four lights on either side of the approach runway.

THRESHOLD LIGHTING

During the final approach for landing, pilots must make a decision to complete the landing or ―execute a missed approach.‖ The identification of the threshold is a major factor in pilot decisions to land or not to land. For this reason, the region near the threshold is given special lighting consideration. The threshold is identified at large airports by a complete line of green lights extending across the entire width of the runway, and at small airports by four green lights on each side of the threshold. The lights on either side of the runway threshold may be elevated.

Threshold lights in the direction of landing are green but in the opposite direction these lights are red to indicate the end of the runway.

RUNWAY LIGHTING

After crossing the threshold, pilots must complete a touchdown and roll out on the runway. The runway visual aids for this phase of landing are be designed to give pilots information on alignment, lateral displacement, roll, and distance. The lights are arranged to form a visual pattern that pilots can easily interpret. At first, night landings were made by floodlighting the general area. Various types of lighting devices were used, including automobile headlights, arc lights, and search lights. Boundary lights were added to outline the field and to mark hazards such as ditches and fences. Gradually, preferred landing directions were developed, and special lights were used to indicate these directions. Floodlighting was then restricted to the preferred landing directions, and runway edge lights were added along the landing strips. As experience was developed, the runway edge lights were adopted as visual aids on a runway. This was followed by the use of runway center line and touchdown zone lights for operations in very poor visibility. FAA Advisory Circular 150/5340-30C provides guidance for the design and installation of runway and taxiway lighting systems.

RUNWAY EDGE LIGHTS

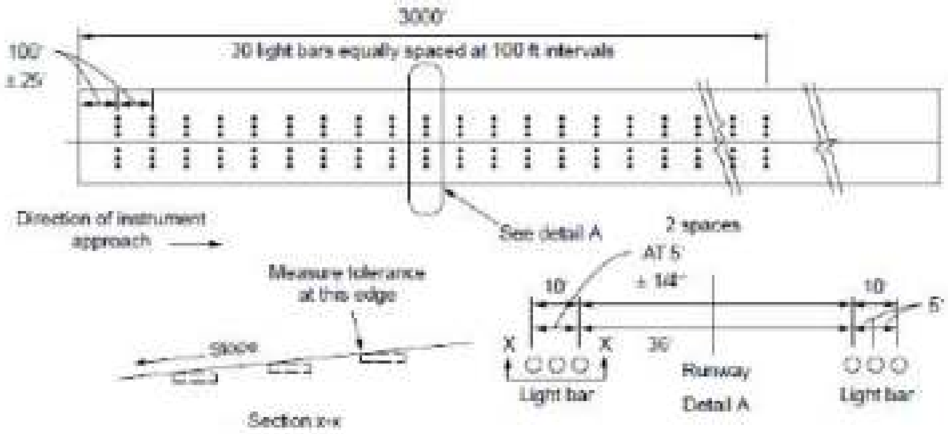
Runway edge lighting systems outline the edge of runways during night time and reduced visibility conditions. Runway edge lights are classified by intensity, high intensity (HIRL), medium intensity (MIRL), and low intensity (LIRL). LIRLs are typically installed on visual runways and at rural airports. MIRLs are typically installed on visual runways at larger airports and on non-precision instrument runways, HIRLs are installed on precision-instrument runways. Elevated runway lights are mounted on frangible fittings and project no more than 30 in above the surface on which they are installed. They are located along the edge of the runway not more than 10 ft from the edge of the full-strength pavement surface. The longitudinal spacing is not more than 200 ft. Runway edge lights are white, except that the last 2000 ft of an instrument runway in the direction of aircraft operations these lights are yellow to indicate a caution zone.

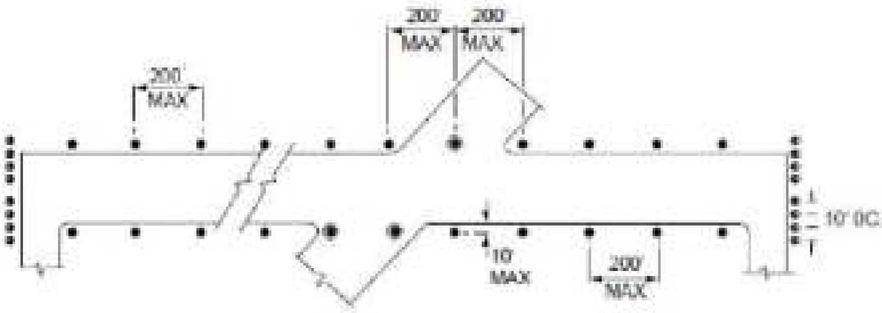
RUNWAY CENTER LINE AND TOUCHDOWN ZONE LIGHTS

As an aircraft traverses over the approach lights, pilots are looking at relatively bright light sources on the extended runway center line. Over the runway threshold, pilots continue to look along the center line, but the principal source of guidance, namely, the runway edge lights, has moved far to each side in their peripheral vision. The result is that the central area appears excessively black, and pilots are virtually flying blind, except for the peripheral reference information, and any reflection of the runway pavement from the aircraft‗s landing lights. Attempts to eliminate this ―black hole‖ by increasing the intensity of runway edge lights have proven ineffective. In order to reduce the black hole effect and provide adequate guidance during very poor visibility conditions, runway center line and touchdown zone lights are typically installed in the pavement.

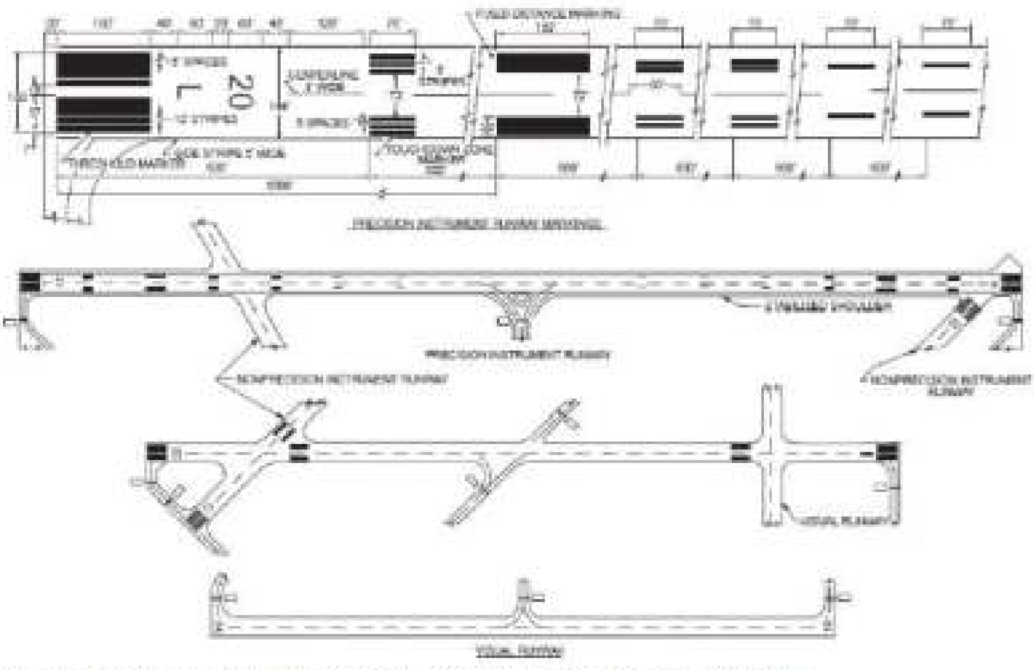
RUNWAY END IDENTIFIER LIGHTS

Runway end identifier lights (REIL) are installed at airports where there are no approach lights to provide pilots with positive visual identification of the approach end of the runway. The system consists of a pair of synchronized white flashing lights located on each side of the runway threshold and is intended for use when there is adequate visibility.





Runway lighting. (From FAA, *Standards for Airport Markings*, Advisory Circular AC150/5340-1G.



Marking along the runway. (From FAA, *Standards for Airport Markings*.

TAXIWAY LIGHTING

Either after a landing or on the way to takeoff, pilots must maneuver the aircraft on the ground on a system of taxiways to and from the terminal and hangar areas. Taxiway lighting systems are provided for taxiing at night and also during the day when visibility is very poor, particularly at commercial service airports. The following overall guidance should be applied in determining the lighting, marking, and signing visual aid requirements for taxiways:

- In order to avoid confusion with runways, taxiways must be clearly identified.

- Runway exits need to be readily identified. This is particularly true for high-speed runway exits so that pilots can be able to locate these exits 1200 to 1500 ft before the turnoff point.

- Adequate visual guidance along the taxiway must be provided.

- Specific taxiways must be readily identified.

- The intersections between taxiways, the intersections between runways and taxiways, and runway-taxiway crossings need to be clearly marked.

- The complete taxiway route from the runway to the apron and from the apron to the runway should be easily identified. There are two primary types of lights used for the designation of taxiways. One type delineates the edges of taxiways and the other type delineates the center line of the taxiway.

TAXIWAY EDGE LIGHTS

Taxiway edge lights are elevated blue colored bidirectional lights usually located at intervals of not more than 200 ft on either side of the taxiway. The exact spacing is influenced by the physical layout of the taxiways. Straight sections of taxiways generally require edge light spacing in 200-ft intervals, or at least three lights equally spaced for taxiway straight line sections less than 200 ft in length.

Closer spacing is required on curves. Light fixtures are located not more than 10 ft from the edge of full strength pavement surfaces. Taxiway centerline lights are in-pavement bidirectional lights placed in equal intervals over taxiway centerline markings. Taxiway centreline lights are green, except in areas where the taxiway intersects with a runway, where the green and yellow lights are placed alternatively. Research and experience have demonstrated that guidance from centerline lights is superior to that from edge lights, particularly in low visibility conditions. For normal exits, the centerline lights are terminated at the edge of the runway. At taxiway intersections the lights continue across the intersection. For long-radius high-speed exit taxiways, the taxiway lights are extended onto the runway from a point 200 ft back from the point of curvature (PC) of the taxiway to the point of tangency of the central curve of the taxiway. Within these limits the spacing of lights is 50 ft. These lights are offset 2 ft from the runway centerline lights and are gradually brought into alignment with the centerline of the taxiway. Where the taxiways intersect with runways and aircraft are required to hold short of the runway, several yellow lights spaced at 5-ft intervals are placed transversely across the taxiway.

RUNWAY GUARD LIGHTS

Runway guard lights (RGLs) are in-pavement lights located on taxiways at intersections of runways to alert pilots and operators of airfield ground vehicles that they are about to enter onto an active runway. RGLs are located across the width of the taxiway, approximately 2 ft from the entrance to a runway, spaced at approximately 10-ft intervals,

RUNWAY STOP BAR

Similar to runway guard lights, runway stop bar lights are in-pavement lights on taxiways at intersections with runways. As opposed to RGLs that provide warning to pilots approaching a runway, runway stop bar lights are designed to act as ―stop‖ lights, directing aircraft and vehicles on the taxiway not to enter the runway environment. Runway stop bar lights are activated with red illuminations during periods of runway occupancy or other instances where entrance from the taxiway to the runway is prohibited. In-pavement runway stop bar lighting is typically installed in conjunction with elevated runway guard lights located outside the width of the pavement.

RUNWAY AND TAXIWAY MARKING

In order to aid pilots in guiding the aircraft on runways and taxiways, pavements are marked with lines and numbers. These markings are of benefit primarily during the day and dusk. At night, lights are used to guide pilots in landing and maneuvering at the airport. White is used for all markings on runways and yellow is used on taxiways and aprons.

RUNWAYS

The FAA has grouped runways for marking purposes into three classes: (1) Visual, or ―basic‖ runways, (2) Nonprecision instrument runways, and (3) Precision instrument runways. The visual runway is a runway with no straight-in instrument approach procedure and is intended solely for the operation of aircraft using visual approach procedures. The nonprecision instrument runway is one having an existing instrument approach procedure utilizing air navigation facilities with only horizontal guidance (typically VOR or GPS-based RNAV approaches without vertical guidance) for which a straight-in nonprecision approach procedure has been approved. A precision instrument runway is one having an existing instrument approach procedure utilizing a precision instrument landing system or approved GPS-based RNAV (area navigation) or RNP (required navigation performance) precision approach. Runways that have a published approach based solely on GPS-based technologies are known as GPS runways. Runway markings include runway designators, center lines, threshold markings, aiming points, touchdown zone markings, and side stripes. Depending on the length and class of runway and the type of aircraft operations intended for use on the runway, all or some of the above markings are required.

RUNWAY DESIGNATORS

The end of each runway is marked with a number, known as a runway designator, which indicates the approximate magnetic azimuth (clockwise from magnetic north) of the runway in the direction of operations. The marking is given to the nearest 10° with the last digit omitted. Thus a runway in the direction of an azimuth of 163° would be marked as runway 16 and this runway would be in the approximate direction of south-south-east. Therefore, the east end of an east-west runway would be marked 27 (for 270° azimuth) and the west end of an east-west runway would be marked 9 (for a 90° azimuth). If there are two parallel runways in the east-west direction, for example, these runways would be given the designation 9L-27R and 9R-27L to indicate the direction of each runway and their position (L for left and R for right) relative to each other in the direction of aircraft operations. If a third parallel runway existed in this situation it has traditionally been given the designation 9C-27C to indicate its direction and position relative (C for center) to the other runways in the direction of aircraft operations.

RUNWAY THRESHOLD MARKINGS

Runway threshold markings identify to the pilot the beginning of the runway that is safe and available for landing. Runway threshold markings begin 20 ft from the runway threshold itself. Runway threshold markings consist of two series of white stripes, each stripe 150 ft in length and 5.75 ft in width, separated about the centerline of the runway. On each side of the runway centerline, a number of threshold marking stripes are placed, For example, for a 100-ft runway, eight stripes are required, in two groups of four are placed about the centerline.

Stripes within each set are separated by 5.75 ft. Each set of stripes is separated by 11.5 ft about the runway centerline.

Centerline MARKINGS

Runway centerline markings are white, located on the centerline of the runway, and consist of a line of uniformly spaced stripes and gaps. The stripes are 120 ft long and the gaps are 80 ft long. Adjustments to the lengths of stripes and gaps, where necessary to accommodate runway length, are made near the runway midpoint. The minimum width of stripes is 12 in for visual runways, 18 in for nonprecision instrument runways, and 36 in for precision instrument runways. The purpose of the runway centerline markings is to indicate to the pilot the center of the runway and to provide alignment guidance on landing and takeoff.

AIMING POINTS

Aiming points are placed on runways of at least 4000 ft in length to provide enhanced visual guidance for landing aircraft. Aiming point markings consist of two bold stripes, 150 ft long, 30 ft wide, spaced 72 ft apart symmetrically about the runway centerline, and beginning 1020 ft from the threshold.

TOUCHDOWN ZONE MARKINGS

Runway touchdown zone markings are white and consist of groups of one, two, and three rectangular bars symmetrically arranged in pairs about the runway centerline. These markings begin 500 ft from the runway threshold. The bars are 75 ft long, 6 ft wide, with 5 ft spaces between the bars, and are longitudinally spaced at distances of 500 ft along the runway. The inner stripes are placed 36 ft on either side of the runway centerline. For runways less than 150 ft in width, the width and spacing of stripes may be proportionally reduced. Where touchdown zone markings are installed on both runway ends on shorter runways, those pairs of markings which would extend to within 900 ft of the runway midpoint are eliminated.

SIDE STRIPES

Runway side stripes consist of continuous white lines along each side of the runway to provide contrast with the surrounding terrain or to delineate the edges of the full strength pavement. The maximum distance between the outer edges of these markings is 200 ft and these markings have a minimum width of 3 ft for precision instrument runways and are at least as wide as the width of the centerline stripes on other runways.

DISPLACED THRESHOLD MARKINGS

At some airports it is desirable or necessary to ―displace‖ the runway threshold on a permanent basis. A displaced threshold is one which has been moved a certain distance from the end of the runway. Most often this is necessary to clear obstructions in the flight path on landing. The displacement reduces the length of the runway available for landings, but takeoffs can use the entire length of the runway. These markings consist of arrows and arrow heads to identify the displaced threshold and a threshold bar to identify the beginning of the runway threshold itself. Displaced threshold arrows are 120 ft in length, separated longitudinally by 80 ft for the length of the displaced threshold. Arrow heads are 45 ft in length, placed 5 ft from the threshold bar. The threshold bar is 5 ft in width and extends the width of the runway at the threshold.

BLAST PAD MARKINGS

In order to prevent erosion of the soil, many airports provide a paved *blast pad* 150 to 200 ft in length adjacent to the runway end. Similarly, some airport runways have a *stopway* which is only designed to support aircraft during rare aborted takeoffs or landing overruns and is not designed as a full strength pavement. Since these paved areas are not designed to support aircraft and yet may have the appearance of being so designed, markings are required to indicate this.

CENTERLINE AND EDGE MARKINGS

The centerline of the taxiway is marked with a single continuous 6-in yellow line. On taxiway curves, the taxiway centerline marking continues from the straight portion of the taxiway at a constant distance from the outside edge of the curve. At taxiway intersections which are designed for aircraft to travel straight through the intersection, the centerline markings continue straight through the intersection. At the intersection of a taxiway with a runway end, the centerline stripe of the taxiway terminates at the edge of the runway.

TAXIWAY HOLD MARKINGS

For taxiway intersections where there is an operational need to hold aircraft, a dashed yellow holding line is placed perpendicular to and across the centerline of both taxiways. When a taxiway intersects a runway or a taxiway enters an instrument landing system critical area, a holding line is placed across the taxiway. The holding line for a taxiway intersecting a runway consists of two solid lines of yellow stripes and two broken lines of yellow stripes placed perpendicular to the centerline of the taxiway and across the width of the taxiway. The solid lines are always placed on the side where the aircraft is to hold. The holding line for an instrument landing system critical area consists of two solid lines placed perpendicular to the taxiway centerline and across the width of the taxiway joined with three sets of two solid lines symmetrical about and parallel to the taxiway center line.

TAXIWAY SHOULDERS

In some areas on the airfield, the edges of taxiways may not be well defined due to their adjacency to other paved areas such as aprons and holding bays. In these areas, it is prudent to mark the edges of taxiways with shoulder markings. Taxiway shoulder markings are yellow in

colour, and are often painted on top of a green background. The shoulder markings consist of 3-ft-long yellow stripes placed perpendicular to the taxiway edge stripes, On straight sections of the taxiway, the marks are placed at a maximum spacing of 100 ft. On curves, the marks are placed on a maximum of 50 ft apart between the curve tangents.

ENHANCED TAXIWAY MARKINGS

Beginning in 2008, all airports serving commercial air carriers are required to mark certain critical areas of the airfield with enhanced taxiway markings. These markings are designed to provide additional guidance and warning to pilots of runway intersections. Enhanced markings consist primarily of yellow-painted lines, using paint mixtures with imbedded glass beads to enhance visibility. In addition, yellow markings must be marked on top of a darkened black background. Taxiway centerlines are enhanced for 150 ft from the runway hold-short markings. The centerline enhancements include dashed yellow lines 9 ft in length, separated longitudinally by 3 ft. These yellow lines are placed 6 in from each end of the existing centerline.

Closed Runway and Taxiway Markings When runways or taxiways are permanently or temporarily closed to aircraft, yellow crosses are placed on these trafficways. For permanently closed runways, the threshold, runway designation, and touchdown markings are obliterated and crosses are placed at each end and at 1000 ft intervals. For temporarily closed runways, the runway markings are not obliterated, the crosses are usually of a temporary type and are only placed at the runway ends. For permanently closed taxiways, a cross is placed on the closed taxiway at each entrance to the taxiway. For temporarily closed taxiways barricades with orange and white markings are normally erected at the entrances.

Runway Pavement Design

Pavement design methods are based on the gross weight of the aircraft. Since it is impracticable to develop design curves for each type of aircraft, composite aircraft are determined and loads are converted from the actual aircraft to the design aircraft, the design aircraft being the one that requires the greatest thickness of pavement. The traffic forecast, which includes the mix of aircraft anticipated, is converted to a traffic forecast of equivalent annual departures. FAA Advisory Circular AC150/5320-6C CHG 2 [1978] presents a number of curves to be used to design the pavement thickness for both flexible and rigid pavements.

INSTRUMENTAL LANDING SYSTEMS AND AIR NAVIGATION AIDS

Aids to navigation, known as NAVAIDS, can be broadly classified into two groups, ground-based systems and satellite-based systems. Each system is complimented by systems installed in the cockpit.

GROUND-BASED SYSTEMS NON DIRECTIONAL BEACON

The oldest active ground-based navigational aid is the nondirectional beacon (NDB). The NDB emits radio frequency signals on frequencies between 400 and 1020 Hz modulation. NDBs are typically mounted on a pole approximately 35 ft tall. They may be located on or off airport property, at least 100 ft clear of metal buildings, power lines, or metal fences. While the NDB is quickly being phased out in the United States, it is still a very common piece of navigational equipment in other parts of the world, particularly in developing nations. Aircraft navigate using the NDB by referencing an automatic direction finder (ADF) located on the aircraft‘s panel. The ADF simply points toward the location of the NDB.

VERY HIGH FREQUENCY OMNIRANGE RADIO

The advances in radio and electronics during and after World War II led to the installation of the very high frequency omnirange (VOR) radio stations. These stations are located on the ground and send out radio signals in all directions. Each signal can be considered as a course or a route, referred to as a radial that can be followed by a aircraft. In terms of 1° intervals, there are 360 courses or routes that are radiated from a VOR station, from 0° pointing toward magnetic north increasing to 359° in a clockwise direction. The VOR transmitter station is a small square building topped with what appears to be a white derby hat. It broadcasts on a frequency just above that of FM radio stations. The very high frequencies it uses are virtually free of static. The system of VOR stations establish the network of airways and jet routes and are also essential to area navigation. The range of a VOR station varies but is usually less than 200 nm.

Aircraft equipped with a VOR receiver in the cockpit have a dial for tuning in the desired VOR frequency. A pilot can select the VOR radial or route he wishes to follow to the VOR station. In the cockpit there is also an omnibearing selector (OBS) which indicates the heading of the aircraft relative to the direction of the desired radial and whether the aircraft is to the right or left of the radial.

DISTANCE MEASURING EQUIPMENT

Distance measuring equipment (DME) has traditionally been installed at VOR stations in the United States. The DME shows the pilot the slant distance between the aircraft and a particular VOR station. Since it is the air distance in nautical miles that is measured, the receiving equipment in an aircraft flying at 35,000 ft directly over the DME station would read 5.8 nm. An en route air navigation aid which best suited the tactical needs of the military was developed by the Navy in the early 1950s. This aid is known as TACAN, which stands for tactical air navigation. This aid combines azimuth and distance measuring into one unit instead of two and is operated in the ultra-high-frequency band. As a compromise between civilian and military requirements, the FAA replaced the DME portion of its VOR facilities with the distance measuring components of TACAN. These stations are known as VORTAC stations. If a station has full TACAN equipment, both azimuth and distance measuring equipment, and also VOR, it is designated as VORTAC. NDB and VOR systems are often located on airport airfields. The location of these systems on airport, known as TVORs, are significant to airport planners and designers, as the location of other facilities, such as large buildings, particularly constructed of metal, may adversely affect the performance of the navaid. TVORs should be located at least 500 ft from any runways and 250 ft from any taxiways. Any structures or trees should be located at least 1000 ft from the TVOR antenna. There should also be a clearance angle of at least 2.5° for any structures and 2.0° for any trees beyond 1000 ft.

AIRPORT TRAFFIC CONTROL

Air traffic control facility provide the basis for communication with aircraft and the relay and clearance of flight plans for air traffic. There are three basic types of facilities: air route traffic control centre, airport traffic control tower and flight service station. The first attempt to set up rules for air traffic control was made by the International Commission for Air Navigation (ICAN), which was under the direction of the League of Nations. The procedures which the commission promulgated in July of 1922 were adopted by 14 countries. Although the United States was not a member of the League of Nations, and therefore did not officially adopt the rules, many of the procedures established by ICAN were used in the promulgation of air traffic procedures in the United States as well as in most regions of the world. Construction and operation of the airways system in the United States prior to 1926 were controlled by the military and by the Post Office Department. The formal entry of the federal government into the regulation of air traffic came with the passage of the Air Commerce Act of 1926 (Public Law 64-254). This act directed the Bureau of Air Commerce to establish, maintain, and operate lighted civil airways. At the present time the Federal Aviation Administration maintains and operates the airways system of the United States.

AIR ROUTE TRAFFIC CONTROL CENTRE (ARTCC)

There are several domestic air route traffic control the movement of aircraft along the airways. Each centre has control of a definite geographical area and is concern primarily with the control of aircraft. At the boundary limit of the control area of the centre, aircraft is released either to adjacent centre or to an airport control tower. Nowadays most of the aircraft separation is maintained by radar. Each ARTCC is broken down into sectors in order to increase efficiency of the personnel in the centre. Each sector are smaller geographical areas, air traffic is monitored in each sector by remote radar unit at the geographical location. In the process aircraft flight plan is transferred between the sectors within an air route traffic control centre and between the air tarfic control centre when crossing the ARTCC boundary.

AIRPORT TRAFFIC CONTROL TOWER

Airport control towers are the facilities that supervise, direct and monitor traffic within the airport area. The control tower provides a traffic control function for aircraft arriving or departing from an airport for 5 to 20km radius. Some control tower have approach control facilities and associated airport surveillance radar (ASR) which guide aircraft to the airport from a number of specific positions, called ―fixes‖ within approximately 40 km of airport. Aircraft are brought to this position by ARTCCs. It is often at these fixes; aircraft are held or ―stacked‖ for landing during periods of heavy traffic.

FLIGHT SERVICE STATION (FSS)

FSS which are nowadays fully automated, are located long the airways and at airports. Thir main functions are

- Relay traffic control messages between en route aircraft and air route traffic control centre.
- Brief pilots, before flight and in flight, on weather, navigational aids, airports that are out of commission, and changes in procedure and new facilities.
- Disseminate weather information.
- Monitor navigation aids.

DOCK & HARBOUR ENGINEERING

➢ HARBOUR

It is partly enclosed area which provides safe and suitable accommodation for supplies, refueling, repair, loading and unloading cargo.

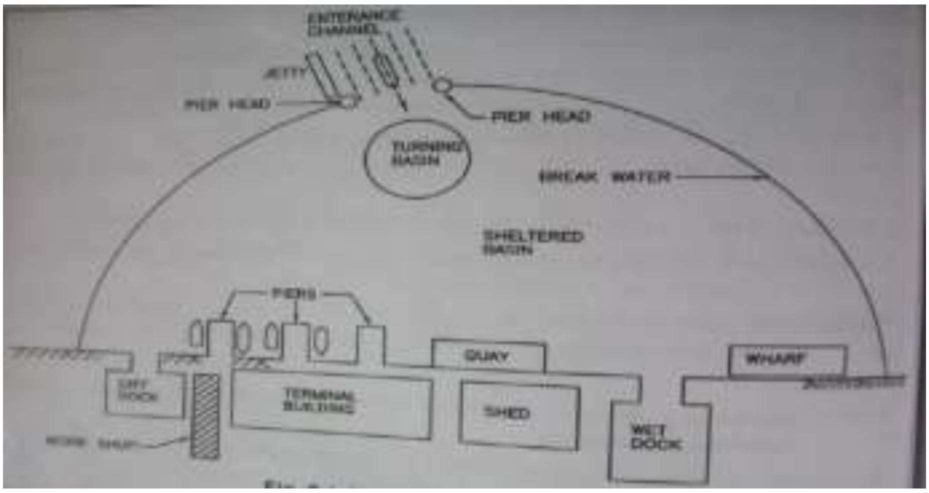
➢ PORT

A port is a harbour where marine terminal facilities are provided. A port is a place which regularly provides accommodation for the transfer of cargo and passengers to and from the ships.

Port = Harbour + Storage Facility + Communication Facility + Other Terminal Facility.

a port includes a harbour i.e. every port is a harbour.

Harbour Components



- ✓ Entrance Channel
- ✓ Break Water
- ✓ Turning Basin
- ✓ Shelter Basin
- ✓ Pier
- ✓ Wharf
- ✓ Quay
- ✓ Dry Dock

- ✓ Wet Dock
- ✓ Jetty

- **ENTRANCE CHANNEL:-**

Water area from which ships enter in the harbour and it should have sufficient width, 100 for small harbour, 100 to 160m for medium and 160 to 260m for large harbour.

- **BREAK WATER:-**

A protective barrier made up of **Concrete or Course Rubble Masonry** constructed from shore towards the sea to enclose harbour .

- **TURNING BASIN:-**

It is water area which is required for maneuvering the ship after entering to the harbour and it is large enough to permit free turning.

- **SHELTER BASIN:-**

It is area protected by shore and breakwater.

- **PIER:-**

It is a solid platform at which berthing of ships on both the sides are possible.

- **WHARF:-**

It is a docking platform constructed parallel to shoreline providing berthing facility on one side only.

- **QUAY:-**

It is also dock parallel to the shore which is solid structure providing berthing on one side and retaining the earth on the other.

- **DRY DOCK:-**

It is a chamber provided for maintenance, repairs and construction of ships. It includes walls, floor and gate.

- **WET DOCK:-**

Due to variation in tidal level, an enclosed basin is provided where in number of ships can be berthed. It has an entrance which is controlled by a lock gate.

- **JETTY:-**

It is a solid platform constructed perpendicular to the shoreline for berthing of ships.

- **QUAY:-**

It is also dock parallel to the shore which is solid structure providing berthing on one side and retaining the earth on the other.

- **DRY DOCK:-**

It is a chamber provided for maintenance, repairs and construction of ships. It includes walls, floor and gate.

2

Tides:

The level of sea undergoes a continuous oscillation, rising and falling generally twice within about 25 hours. This is due to difference in combined gravitational attraction of sun and moon upon various parts of the earth's surface.

Waves:

They are undulations caused on surface of sea water due to wind. It is the raised curvilinear caused on surface water. They are of 2 types. i) waves of oscillation ii) waves of translation

Satellite port:

It depends on resources and facilities of another. It is a small port which is subordinate to a major port and depends upon the latter for higher order facilities.

REQUIREMENTS OF GOOD HARBOUR

- ✓ It should be connected with roadway and railway.
- ✓ Surrounding land should be fertile and densely populated.
- ✓ Ship channels must have sufficient depth for draft or vessel.
- ✓ Breakwaters must be provided to protect against destructive wave action.
- ✓ The bottom should furnished secure anchorage to hold ships against the wind force.

- ✓ Numbers of quay, piers and wharfs should be sufficient for loading and unloading cargo.
- ✓ It should have facilities like fuel, repair and etc. for ships.
- ✓ Harbour area should be sufficiently large.
- ✓ It should have enough cold storage.

CLASSIFICATION OF HARBOURS

➢ **CLASSIFICATION BASED ON THE PROTECTION NEEDED**

➢ **Natural Harbour:-**

Harbour protected by storms and waves by natural land contours, rocky out crops, or island that is called Natural Contour. **(Eg. Kandla port, Cochin port & Mumbai Harbour)**

➢ **CLASSIFICATION BASED ON THE PROTECTION NEEDED**

➢ **Semi - Natural Harbour:-**

A semi – natural harbour is protected on the sides by the contours of land and requires manmade protection only to the entrance. **(Eg. Mandvi, Veraval & Visakhapatnam port)**

➢ **CLASSIFICATION BASED ON THE PROTECTION NEEDED**

- **Artificial Harbour:-**

An artificial harbour is one which is manmade and protected from storms and waves by engineering works. **(Eg. Chennai Harbour)**

- **CLASSIFICATION BASED ON UTILITY**
- **Commercial Harbour:-**

It is an harbour in which docks are provided with necessary facilities for loading and unloading of cargo. **(Eg. Chennai Harbour)**

- ✓ **Refuge Harbour:-**

These are used as a heaven for ships in a storm or it may be part of a commercial harbour. **(Eg. Chennai Harbour & Visakhapatnam Harbour)**

- **CLASSIFICATION BASED ON UTILITY**
- **Military Harbour:-**

It is a naval base for the purpose of accommodating naval ships or vessels and it serves as a supply depot. **(Eg. Mumbai Harbour & Cochin Harbour)**

- ✓ **Fishing Harbour:-**

These harbours have facilities for departure and arrival of fishing ships. They have also necessary arrangement to catch fish.

- **CLASSIFICATION BASED ON LOCATION**
  - ✓ Ocean Harbour
  - ✓ River Harbour
  - ✓ Canal Harbour
  - ✓ Lake Harbour

Classification of Ports

- ✓ **Ocean Port:-**

  This is a port intended for large ocean going ships.

- ✓ **River Port:-**

  River port is located on the banks of the river inside the land.

- ✓ **Entry Port:-**

  This is location where foreign citizens and goods are cleared through custom house.

- ✓ **Free Port:-**

This is an isolated and enclosed area within which goods may be landed, stored, mixed, repacked, manufactured and reshipped without payment of duties.

Harbour Planning

- ✓ It is necessary to carry out a topography survey of the neighborhood including the foreshore and the depths of water in the vicinity.
- ✓ The borings and soundings should be taken to ascertain the character of the ground.

- ✓ The borings on land should also be made so as to know the probable subsurface conditions on land. It will be helpful in locating the harbour works correctly.
- ✓ The nature of harbour, whether sheltered or not, should be studied.
- ✓ The existence of sea insects which undermine the foundations should be noted.
- ✓ The problem of silting or erosion of coastline should be carefully studied.
- ✓ The natural meteorological phenomena should be studied at site especially with respect to frequency of storms, rainfall, range of tides, maximum and minimum temperature, direction and intensity of winds, humidity, direction and velocity of currents, etc.

Site Selection For Harbour

Great care ahs to be exercised at the time of making selection of site for a harbour. The guiding factors which play a great role in choice of site for a harbour are as follows:

- ✓ Availability of cheap land and construction material;
    - ✓ Transport and communication facilities;
    - ✓ Natural protection from winds and waves;
    - ✓ Industrial development of the locality;
    - ✓ Sea – bed, subsoil and foundation conditions;
    - ✓ Traffic potentiality of harbour;
    - ✓ Availability of electrical energy and fresh water;
    - ✓ Favorable marine conditions;
    - ✓ Defense and strategic aspects; etc.

Size of Harbour

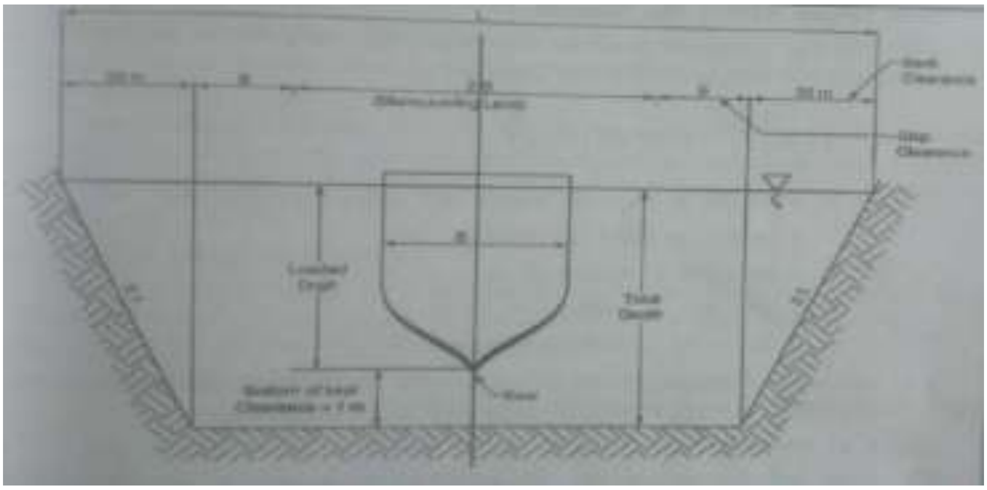
- Size of harbour depends upon the number and size of ships likely to use the harbour at one time. Some of the biggest modern ships are 275m to 300m long and about 30m wide.
- There should be sufficient area for maneuvering them without collision. Thus, the size is determined by:
- Accommodation required.
- Convenience for maneuvering and navigation.
- Adaptability to natural features.

- **WIDTH OF ENTRANCE TO THE HARBOUR:-**

The entrance width should be in proportion to the size of the harbour and ships using it. To reduce the wave height with in the harbour, the entrance width should not be more than that necessary to provide safe navigation and also to prevent dangerous currents, when the tide is coming in and going out.

- ✓ **For Small Harbours = 90m**
- ✓ **For Medium Harbours = 120 to 150m**
- ✓ **For Large Harbours = 150 to 250m**

WIDTH OF ENTRANCE CHANNEL:-



- **WIDTH OF ENTRANCE CHANNEL:-**

The entrance channel width is divided into:

(I) Manouvering lane width = 2B

(II) Ship clearance lane width = B

(III) Bank clearance-depends on the side slopes.

From Fig.,

The width of entrance channel for single lane traffic,

L = 4B + 2 (bank clearance)

- **TURNING BASIN:-**

The radius of turning basin should be equal to two times the length of the largest ship calling at the harbour.

R = 2l

Where, R = Radius of turning basin,

l = length of the largest ship

- **WAVE HEIGHT WITHIN THE HARBOUR:-**

$$h = H\left[\sqrt{\frac{B}{L}} - 0.27\sqrt{D}\left(1 + \sqrt{\frac{B}{L}}\right)\right]$$

Where, h = Height of reduced waves any point P in harbour, m

H = Height of wave at entrance, m

B = Breadth of entrance, m

L = Breadth of harbour at P, m

D = Distance of P from entrance, m

- **DEPTH OF HARBOUR:-**

The channel depth is generally determined by the following formula:

$$D = D' + \frac{H}{3} + D''$$

Where, D' = The draft of the largest ship to be accommodated

H = The height of storm waves, crest to trough

D'' = Allowance for squat.

Since harbour is designed and constructed for providing berthing and cargo handling facilities for the ships, it is necessary to be familiar with the various ship features related to harbour planning.

✓ **LOAD LINE:-**

It indicate a line showing the water level to which they may legally be loaded.

- **DISPLACEMENT LOAD:-**

The weight of ship and its contents when fully loaded with cargo to the load line is known as displacement load.

- **DISPLACEMENT LIGHT:-**

The weight of ship without cargo, fuel and stores is known as displacement light.

- **GROSS REGISTERED TOUNAGE (G. R. T):-**

This is the total measured internal capacity of a ship expressed in units of 2.83 m3 or 100cu.ft.

- **NET REGISTERED TOUNAGE (N. R. T):-**

This is the carrying capacity of a ship expressed in units of 2.83m3.

- **DEAD WEIGHT TOUNAGE (D. W. T):-**

This is the carrying capacity of a ship by weight. It is a weight of cargo, fuel, stores, passengers, crew etc.

D. W. T = Displacement Load – Displacement Light

- **DISPLACEMENT TOUNAGE:-**

This is the actual weight of the ship. It is the weight of water displaced when afloat and may be either loaded or light.

- **DRAFT:-**

It is the depth of the keel of the ship below water level.

- **CARGO TOUNAGE:-**

It is a commercial expression which forms the basis of freight charge. It can be measured by volume or weight.

- **BALLAST:-**

It is the weight added in the ballast compartments of a ship to increase its draft after it has discharged its cargo an dto improve its stability.

Breakwaters:

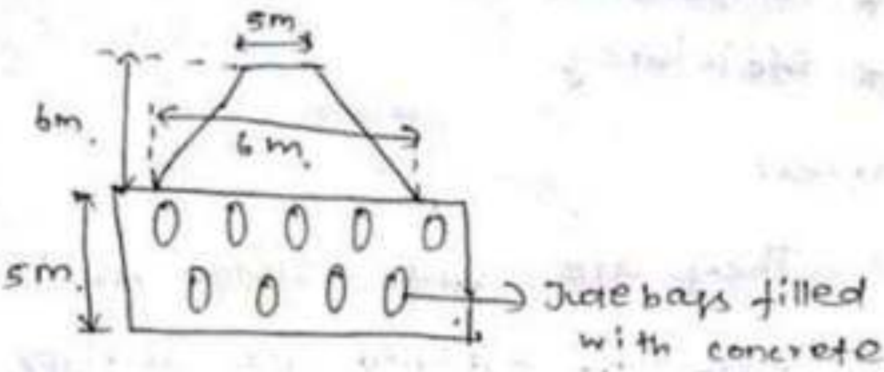
Its function is to breakup and disperse heavy seas.

It prevents waves from exerting their destructive influence within enclosed area of the harbour.

Classification of breakwaters:

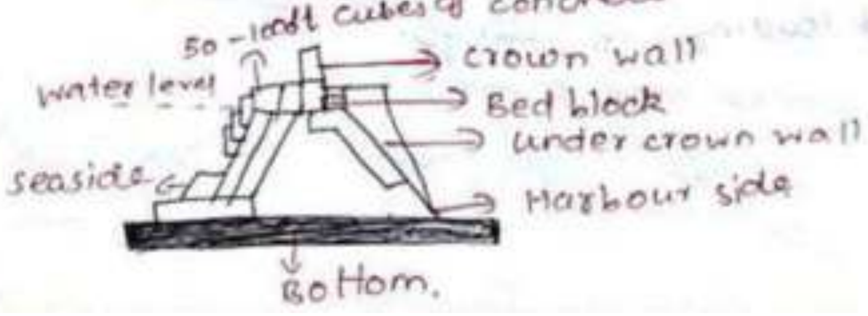
i) wall of masonry or concrete blocks or mass concrete.

a) Wall type / block breakwater.



b) Heap or mound breakwater.

c) Mound with Super Structure:



Advantages of Three types of breakwaters

* cost of construction
* comparative cost of Maintenance
* Efficiency

Jetties:

It denotes projecting structures built out into deep water from shore.

Structures in harbours which perform duties of loading and unloading platforms with break water are termed as jetties

Waves and their action on coastal structure

Types of waves

Types of waves

- Waves of oscillation
  - Ordinary unbroken waves
- Waves of Translation
  - When they enter shallow water
- Tidal waves
  - Frequently occurs as a result of [illegible] in seabed.

Points and crossings

Points and crossings are provided to transfer trains from one track to another:

- **POINT (SWITCH):** The device that is use to divert the wheels
- **CROSSING:** Gaps in the rail that enables the actual diversion
- **TURNOUT:** Complete set of points and crossing including the main (lead) rail

Necessity of Points & Crossings

1. Diversion of train from one track to another is controlled automatically by
2. wheel flanges, unlike steering the wheels of roadway vehicles.
3. Points and crossings are special arrangement for this diversion
4. Provide flexibility of movement by connecting one line to another
5. Helps to impose restrictions over turnouts to retard movement Weak kinks or points in the track and are susceptible to derailment
6. Simplest combination of points and crossings
7. Enables one track either a branch line or a siding, to take off from another track

Turnout - Definition

- Simple arrangement of points and crossings by the manipulation of which the train from one track may be diverted to the another track or branch line or to siding is known as turnout.
- 2 tracks either merge or diverge, or 2 tracks parallel to each other but are still connected to each other- This connection helps in changing the direction of trains.
- for this points and crossings are used.
- The combination of lead rails with curved rails (and fastenings) helps in diverting rolling stock from one track to another track.
- Rails depending on curvature
  - Lead rails are straight
  - Curved rails have curvature
- Turnouts are also provided in yards and sidings

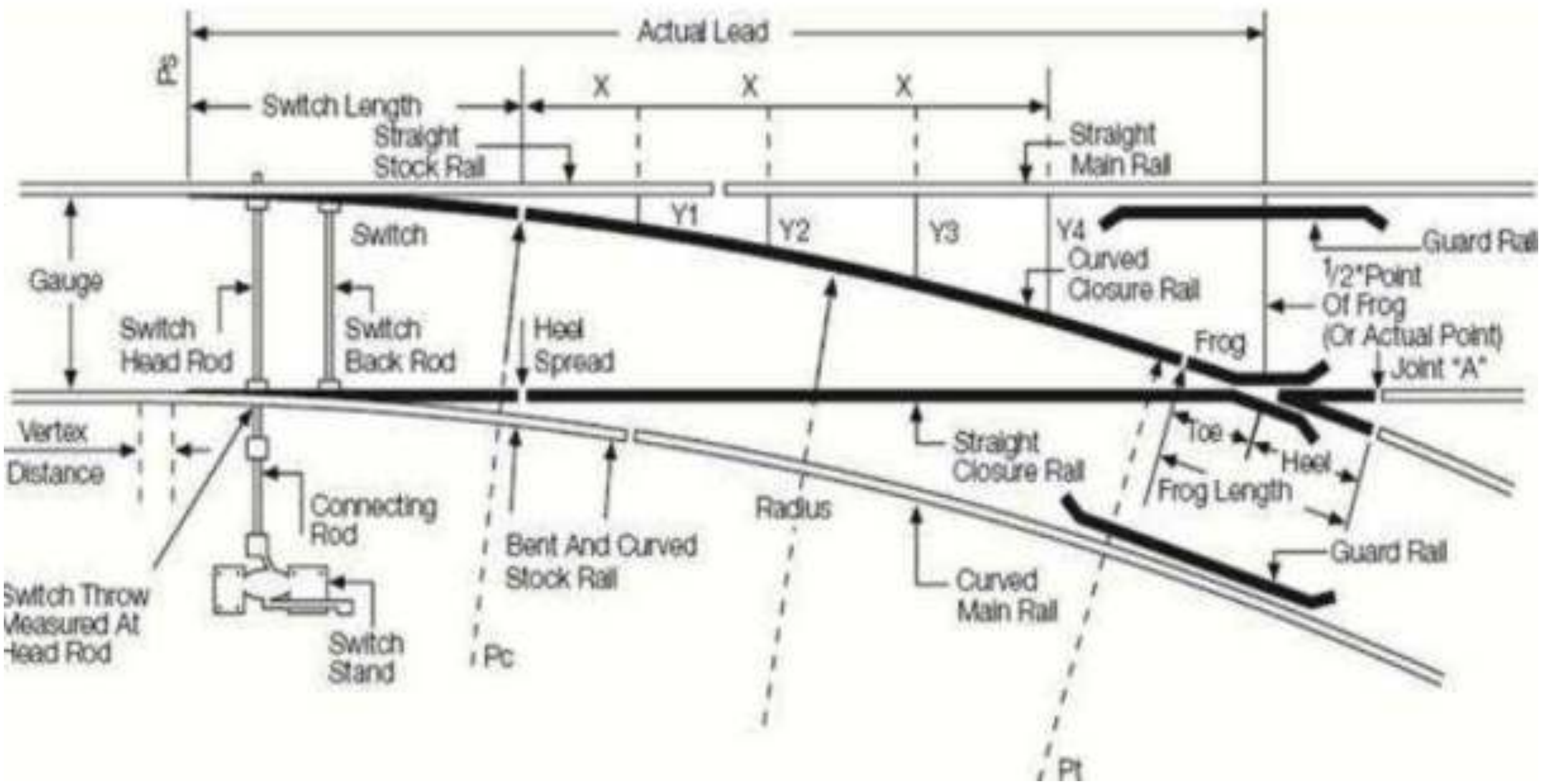
Right Hand Turnout:

If a train is diverted from main track is diverted to the right of the main route in the facing direction, then the diversion is known as Right Hand Turnout.

Left Hand Turnout:

If a train is diverted from main track is diverted to the left of the main route in the facing direction, then the diversion is known as Left Hand Turnout.

Right hand turnout with full components



Component Parts of a Turnout

1. A pair of tongue rails

2. A pair of stock rails

3. Two check rails

4. Four lead rails

5. A Vee crossing

6. Slide chairs

7. Stretcher bar

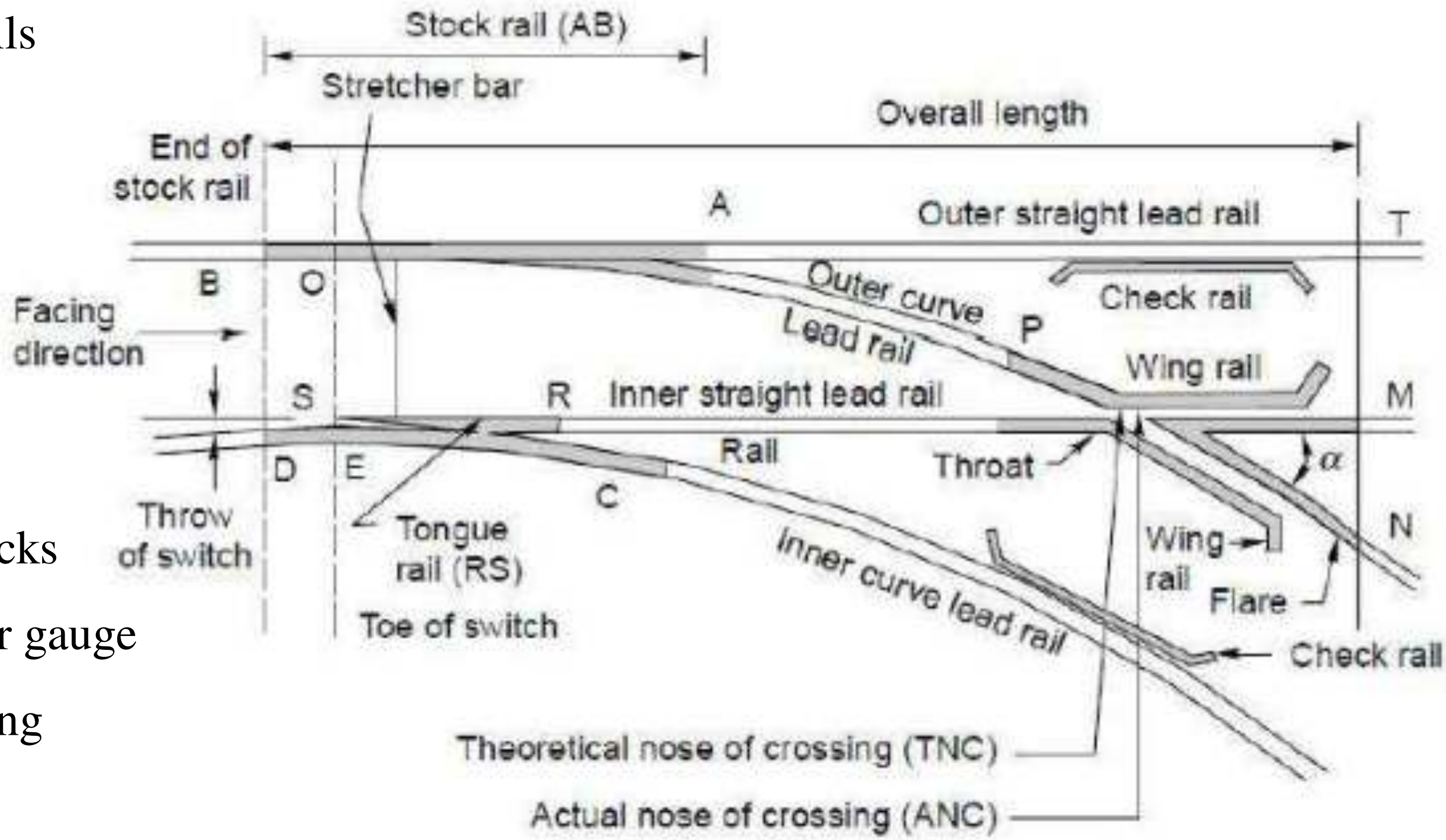
8. A pair of heel blocks

9. Switch tie plate or gauge

10. Parts for operating points-

Rods, cranks, levers etc

11. Locking system which includes locking box, lock bar, plunger bar etc



Facing direction:

– Standing at switch and looking towards crossing

Trailing direction:

– Standing at crossing and looking towards switches

Points:

– A pair of tongue rails with stock rails

– Train diverting from the main track will negotiate these points first.

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.

Switch angle:

– angle between the gauge face of the stock rail and tongue rail at the theoretical toe of switch.

Throw of switch:

– Distance by which the tongue rail moves laterally at the toe of switch

Types of Switches:

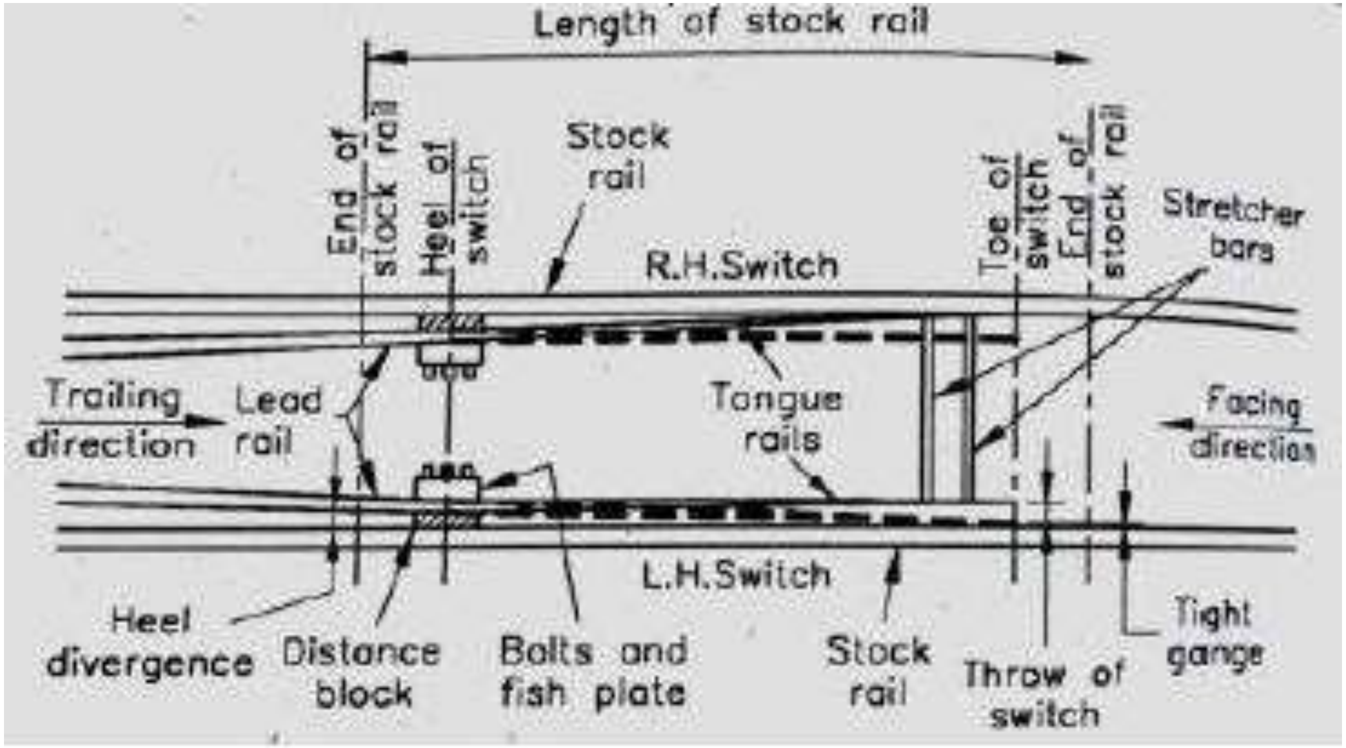
- There are two types of switches:
  - 1. Stub switch
  - 2. Split switch
- Split switch are of two types:
  - a. Loose heel type
  - b. Fixed heel type

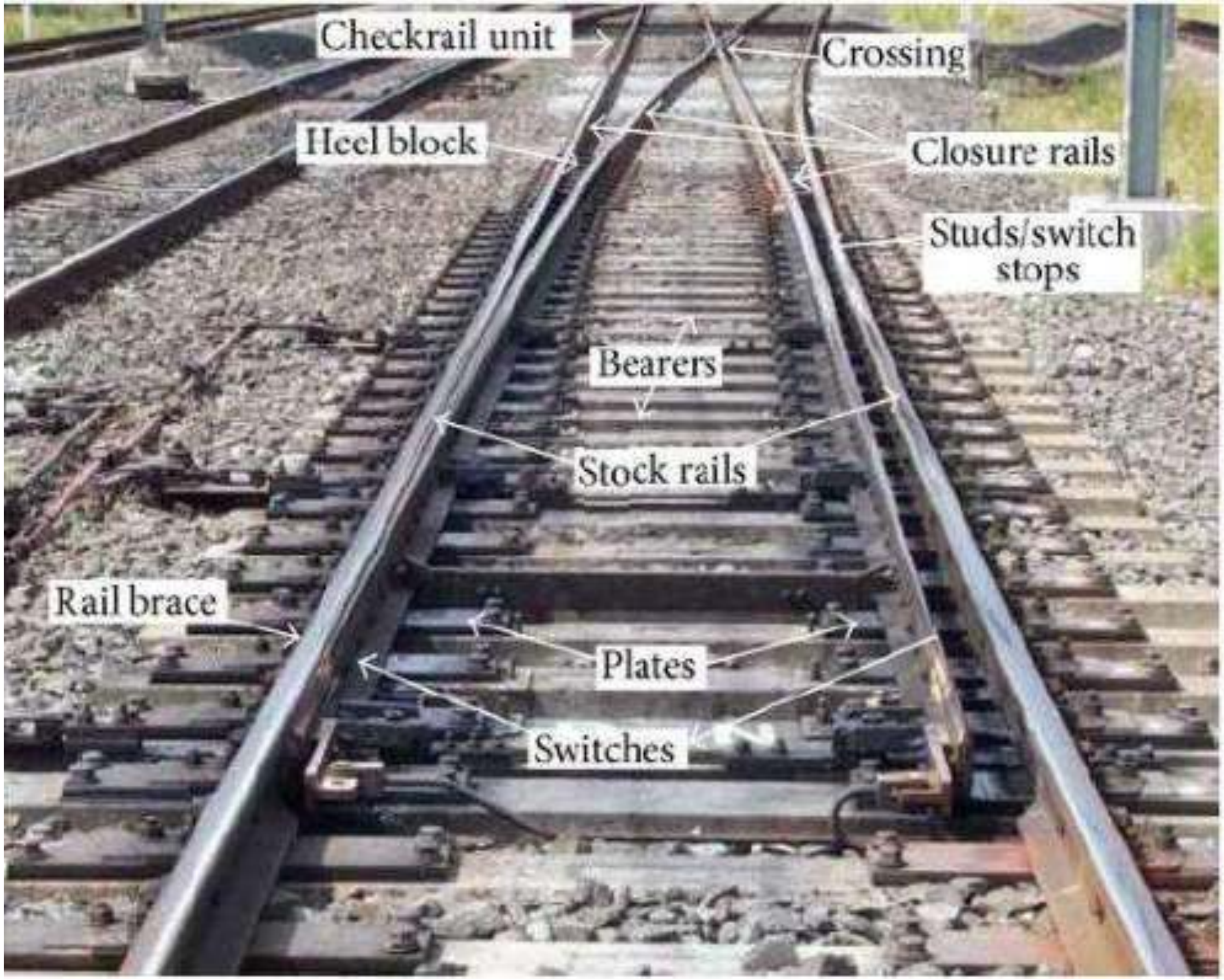
Stub Switch

Split Switch

POINTS OR SWITCHES

- Switch consists of a stock rail & a tongue rail
- Set of switches or points consists of a left-hand switch & a right-hand switch
- Heel – thicker end of tapered rail fixed to main track
- Toe – thinner end which is movable, to divert train from one route to another




Checkrail unit
Crossing
Heel block
Closure rails
Studs/switch
stops
Bearers
Stock rails
Rail brace
Plates
Switches

Point(Switches):-

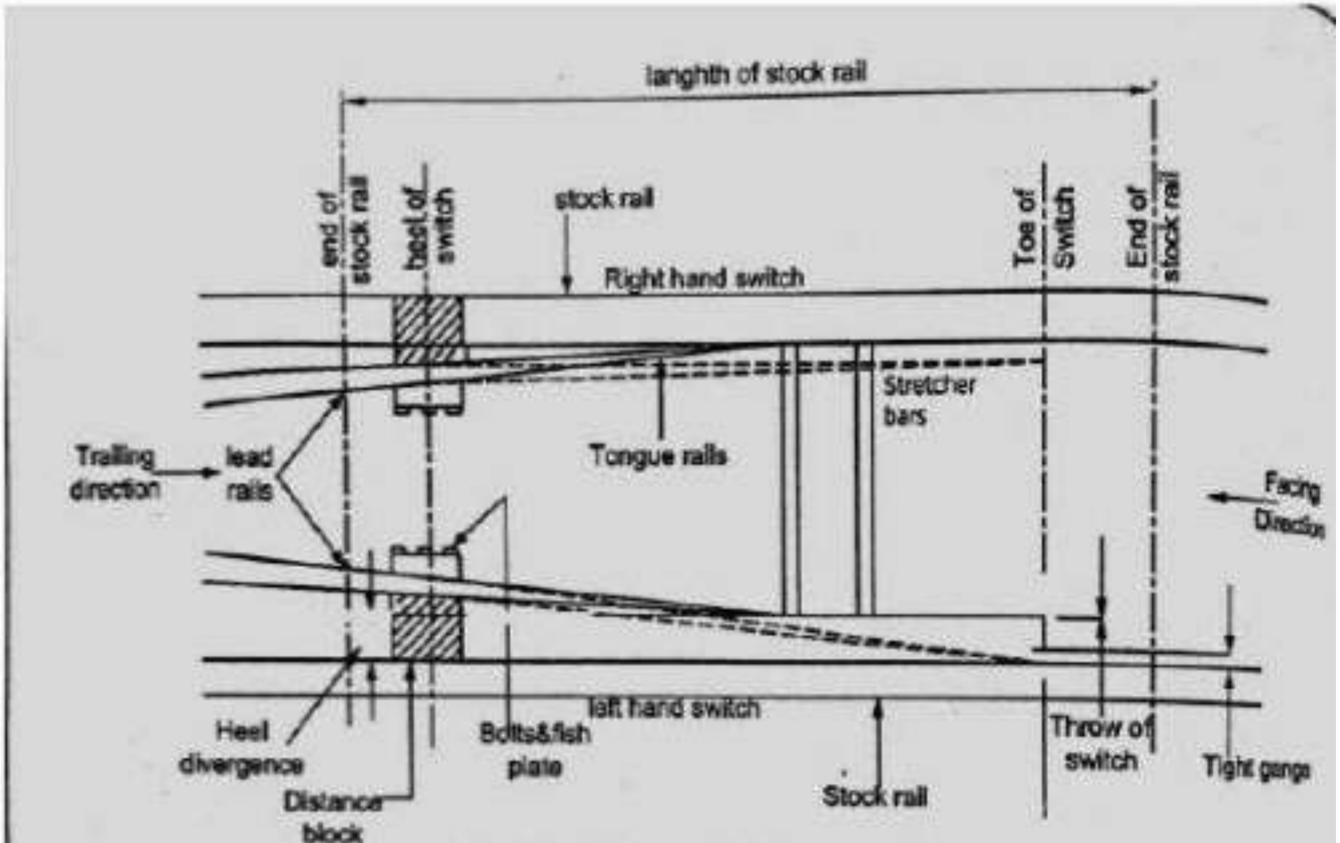


Fig. 11.4 Fixed heel type switch

- **Stock rail**: It is the running rail against which a tongue rail operates.
- **Tongue rail**: It is a tapered movable rail, made of high carbon or manganese steel to withstand wear. At this end, it is attached to a running rail. A tongue rail is also called a switch rail.
- **Heel Block:** These blocks are inserted between the heel of the tongue rail and stock rail. These are made of C.I. and are used to provide a clear gap for the wheel flange.

- **Switch tie plate**: This is provided below the slide chairs at the toe. There are two butt straps at the ends to ensure the definite location of slide chair and hence of the rails. Standard sections are 25×1.25 cm for BG and 22.5×0.9 cm for MG.
- **Stretcher bar**: The toes of both the tongue rails are connected together by means of stretcher bars, so that each tongue moves through the same distance or gap while changing the points. Generally two or three bars are used near the toe.

Design Calculations of Turnouts

- Design calculation are based on three factors
- Method of calculating various leads
- Method employed for crossing angle
- Type of tongue rail used

Curve Lead (CL)

Distance b/w TNC & tangent point ‘T’ measured along the length of main track

Switch Lead (SL)

Distance b/w tangent point ‘T’ & heel of the switch (H.S.) measured along the length of main track

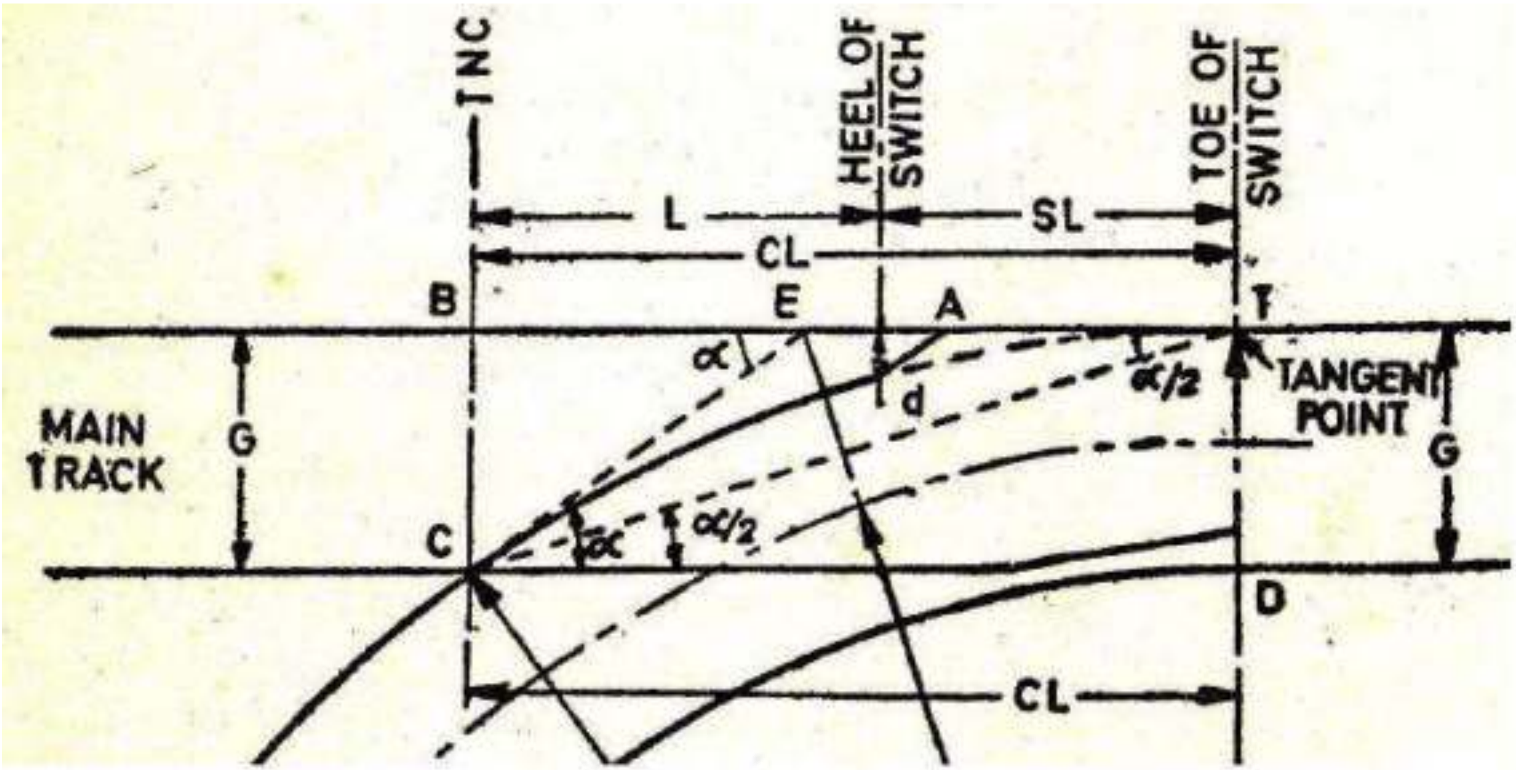
Crossing Lead (L)

Distance b/w TNC & heel of the switch (H.S.) measured along the length of main track

$$CL = SL + L$$

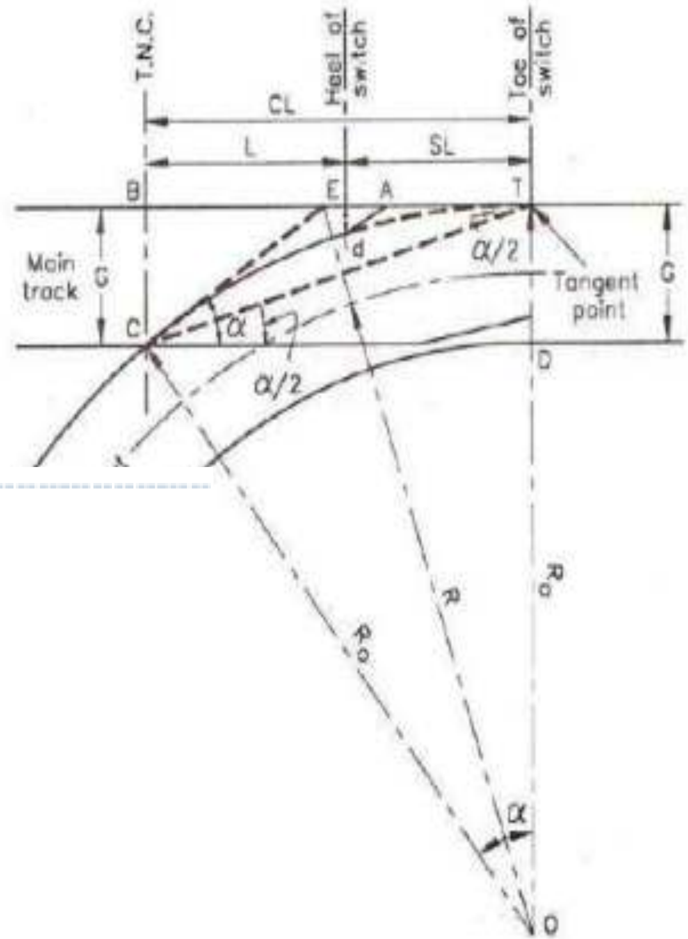
$$L = CL - SL$$

Note: Lead rails, being curved, *are not measured along curved length, but projected length on adjacent straight rail is measured*


TNC
HEEL OF SWITCH
TOE OF SWITCH
L
SL
CL
B
E
A
T
d
MAIN TRACK
G
TANGENT POINT
C
D
CL

Curve Lead (CL)

$$CL = G\ Cot\ \frac{\propto}{2} \qquad CL = \sqrt{2R_0G} \qquad CL$$



Radius (R)

$$R = R_0 - \frac{G}{2}$$

$$R_0 = \frac{CL}{Sin\ \propto} = CL.Cosec\ \propto$$

- Switch Lead (SL)

$$SL = \sqrt{2R_0d}$$

- Lead or Crossing Lead (L)

$$L = CL - SL = 2GN - \sqrt{2R_0.d}$$

- Heel Divergence (d)

$$d = \frac{(SL)^2}{2R_0}$$

- Ex. 1:-
  - Calculate all the necessary elements required to set out a 1 in 8.5 turnout, taking off from a straight BG track with its curve starting from the toe of the switch i.e. tangential to the gauge face of the outer main rail & passes through TNC. (Heel divergence, d = 11.4cm)
- Solution:-
  - Given, N = 8.5, G = 1.676m, d = 11.4cm = 0.114m
  - Curve Lead, CL = 2GN = 2 x 1.676 x 8.5 = **28.49m**
  - Radius, $R = R_0 - (G/2)$

    $R_0 = 1.5G + 2GN^2 = 244.69m$

    R = 244.69 – (1.676 / 2) = 243.85m
  - Switch Lead, SL = $\sqrt{2R_0 d} = \sqrt{2 \times 244.69 \times 0.114}$ **= 7.45m**
  - Lead, L = CL – SL = 28.49 – 7.45 = **21.04m**

- Only crossing lead **(L)** is calculated
- Curve is tangential to tongue rail, starting from heel of switch & ends at TNC
- Among the 3 kinks, the one at heel of switch is removed
- Used when **G, d,** α & β are given

Crossings

- A Crossing is a device which provide two flange ways through which the wheels of the flanges may move, when two rails intersect each other at an angle.

Types of crossings:

Based on shape of crossing:

1. Actual angle crossing
2. obtuse angle crossing
3. Right angle crossing

Based on assembly of crossing:

1. Spring crossing
2. Cross crossing
3. Diamond crossing
4. Scissors crossing
5. Ladder track or gathering line

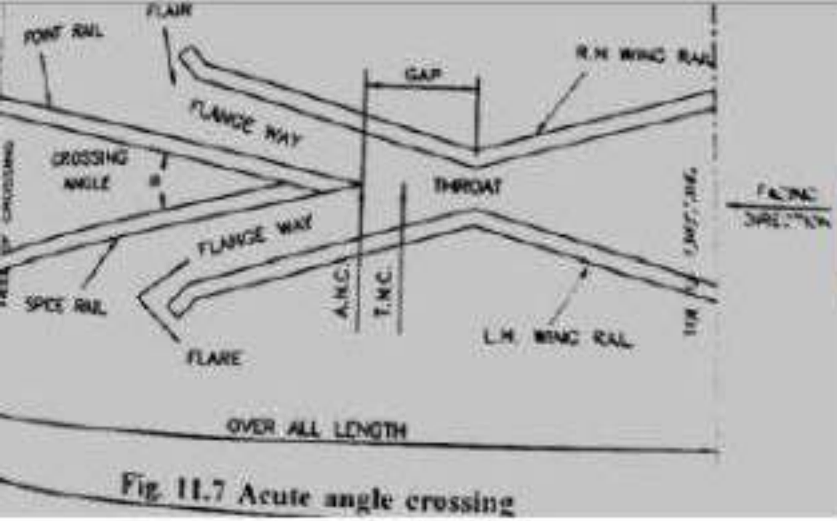
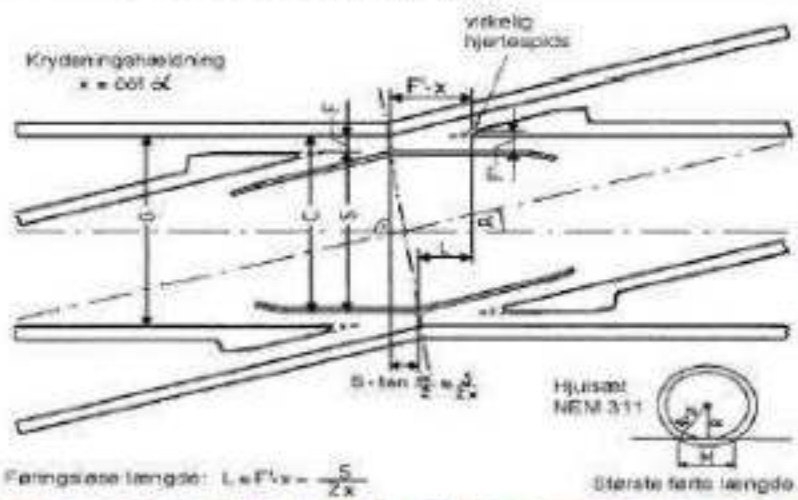


Fig. 11.7 Acute angle crossing

Actual angle crossing



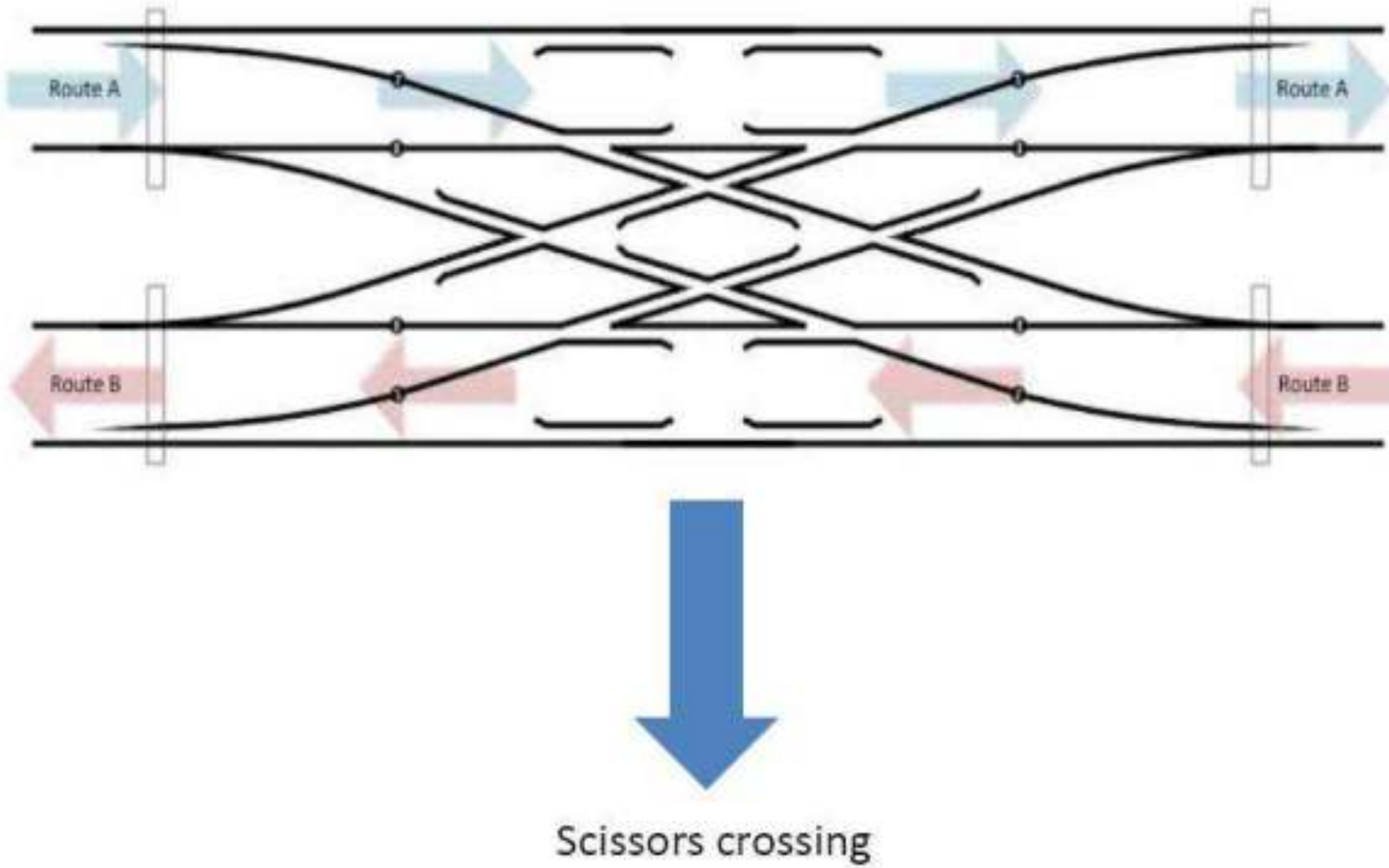
Obtuse angle crossing

Right angle crossing

Spring crossing

cross over

Diamond crossing



- use at goods yard.

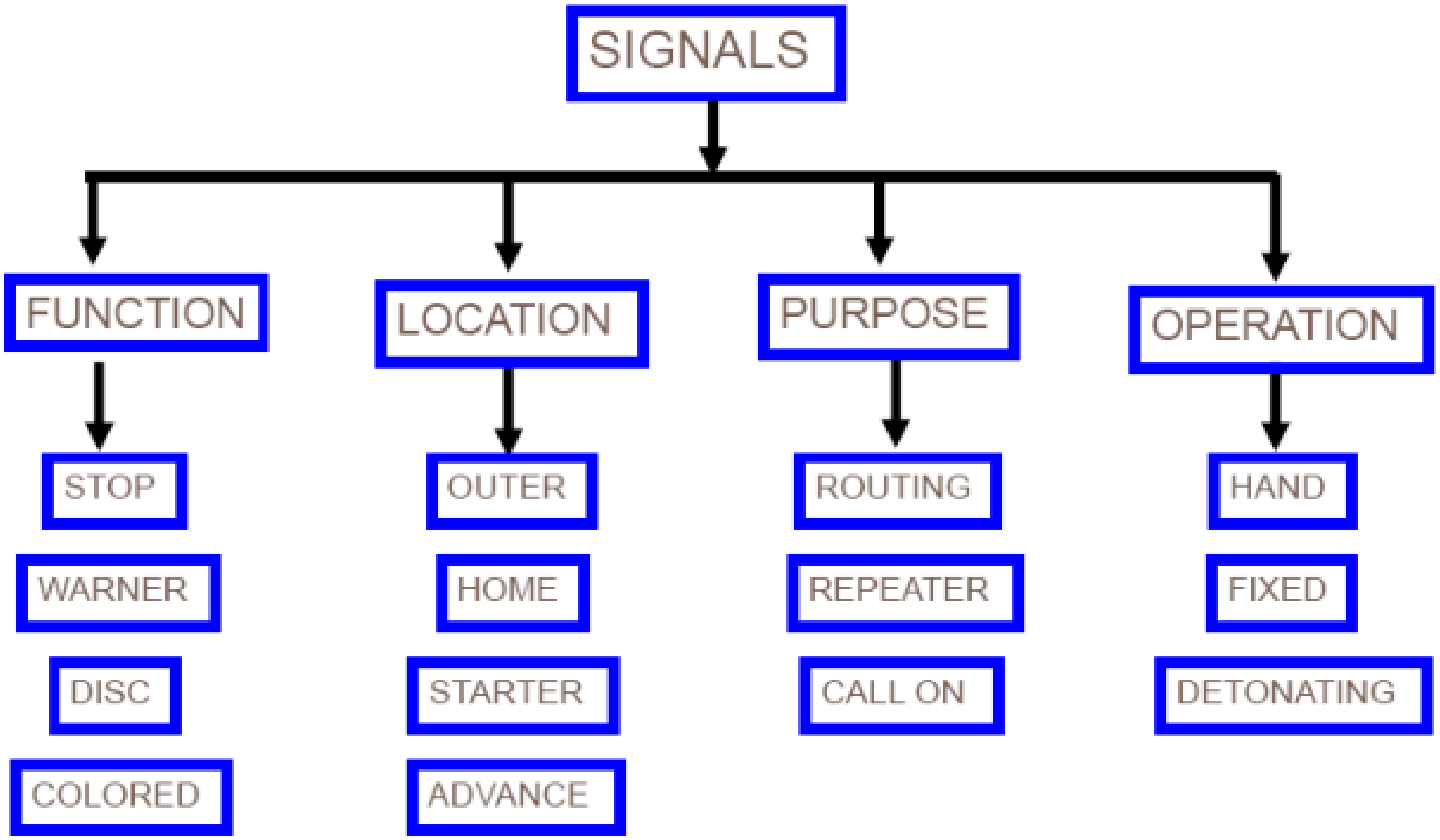
Signalling

- Signalling is the device by which the movement of trains is controlled
- Highly important in terms of safety
- Trains can be operated efficiently, utilization of tracks and tracks can be done at maximum levels
- Signalling includes signals, points, blocks and other equipment;

Objects of Signalling

- Maintain safe distance between trains running in the same direction on a single line.
- Safe distance between trains which are approaching or crossing a crossing.
- To run the trains at restricted speeds during repair works
- At junctions to prevent the trains from colliding

CLASSIFICATION OF SIGNALS



Classification of signals

- ❑ Depending on the functional characteristics
- Stop or semaphore type signals
- Warner signals
- Shunting signals
- Coloured light signals
- ❑ Depending on the location characteristics
- Outer receptional signals
- Home receptional signals
- Starter signals
- Advance starter signals

❑Depending on the operational characteristics

- Fog or audible or detonating signals
- Visual indication hand signals
- Visual indication fixed signals

❑Special / operation signals

- Routing signals
- Calling on signals
- Point indicators
- Repeater or co-acting signals
- Modified lower quadrant semaphore signals
- Miscellaneous signals

Controlling signals

Which are mandatory to observe for train movement

Indicating signals

Correspond to the traffic signs of highways. Also mandatory to observe.

Warning signals

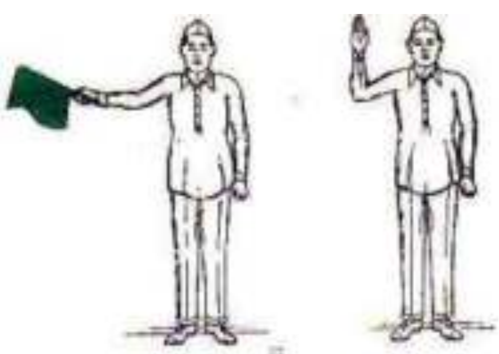
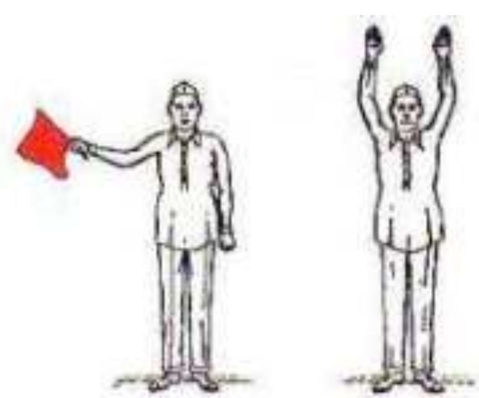
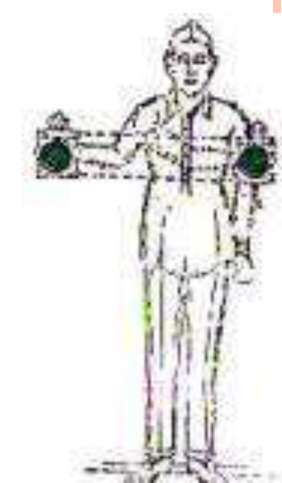
- They provide a pre-hand warning to the driver about the controlling signals ahead. These only enhance the efficiency and provide a further safety caution.

Detonating Signals

- Used when hand and fixed signals or not visible (foggy and cloudy conditions)
- Also used during emergencies (derailment, accidents etc.,)
- These are in the form of detonators fixed on the top of rails
- When engine passes over it explodes with big sound and alerts the driver to stop the train.
- 3 to 4 detonators are placed at an interval of about 10 to 15m at 400 to 500m ahead.

Hand Signals

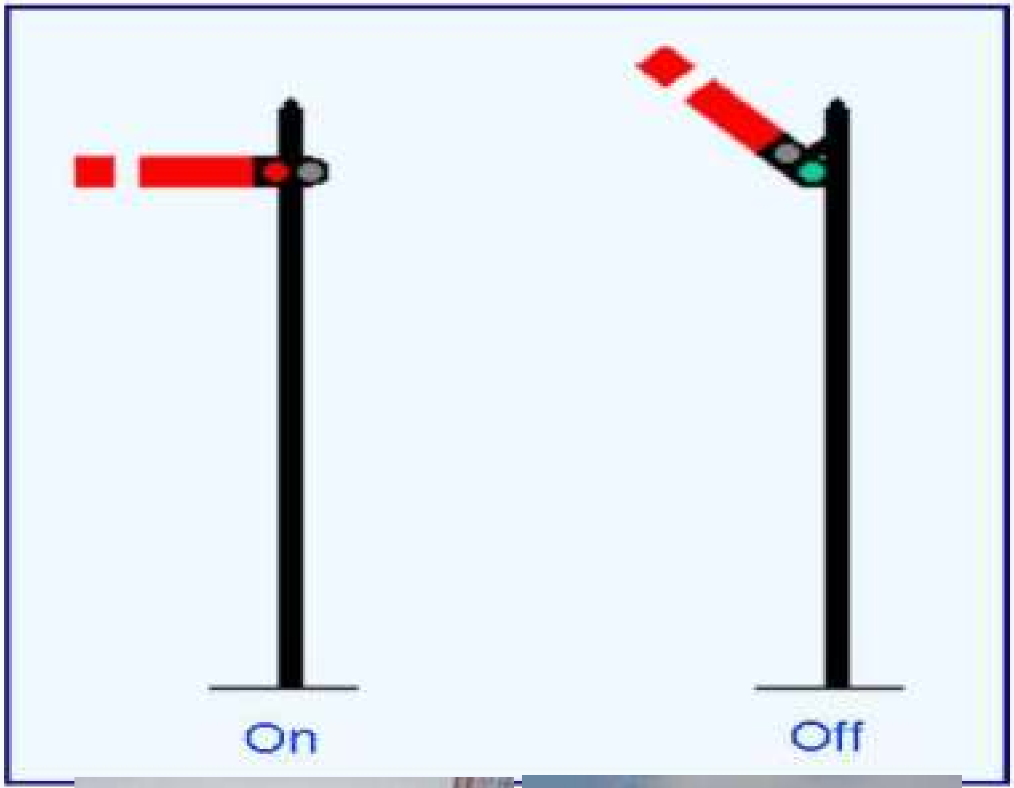
- Given by the guard using coloured flags or by bare arms
- During night times kerosene lamps fitted with movable green, red and yellow coloured glasses are used.
  - o Green - proceed
  - o Red - dead stop
  - o Yellow – proceed with caution

Semaphore Signals

- Consist of a vertical post on which a movable arm is pivoted at the top.
- Arm can be kept horizontal or it can be inclined at 45 degree to horizontal
- Outer end of arm is 2.45cm broader than that at post.
- Movable arm is controlled by means of levers and cables from the cabin.
- Spectacles of red and green or fixed in the arm
- These are fixed on the left hand side of track, with spectacles towards driver.

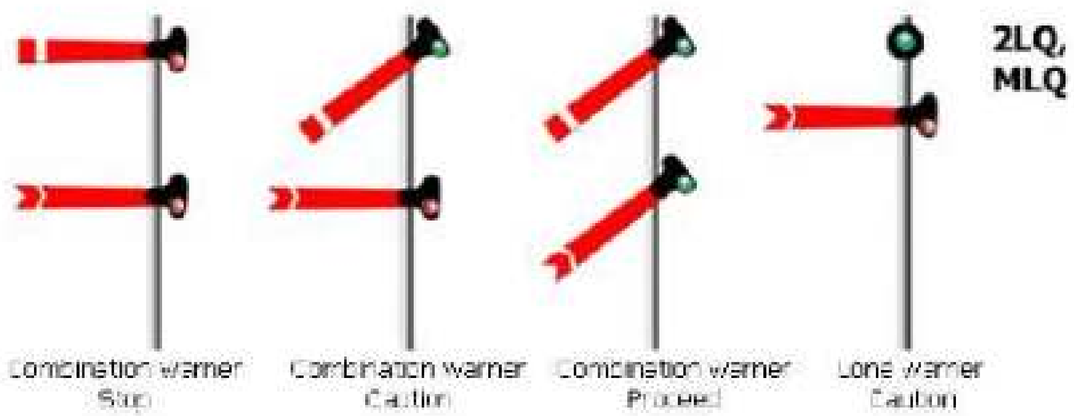
- Horizontal arm indicates " DANGER –STOP "
- and the inclined arm indicates " CLEAR – PROCEED".
- In the day time position of arm indicates the signal.
- During the night time light of lamp passing through spectacle gives the signal.



Warner Signal

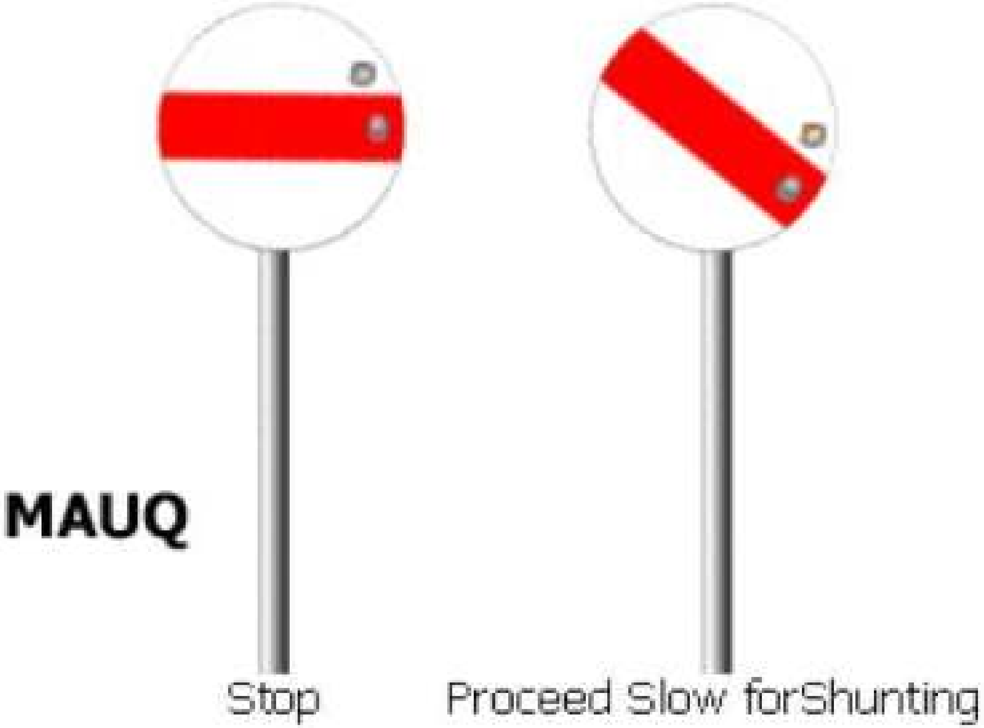
- This is similar to semaphore signal
- Difference is it contains a fish tailed arm
- These signals are placed ahead the semaphore
- signals to warn the driver before entering the railway station.
- When the arm is horizontal – indicates signal ahead is stop
- Warner signals are placed 540m away from the first stop signal.
- Some times warner signals are provided with yellow lights instead of red to distinguish them from semaphore signals during nights.
- Some times both warner and semaphore signals are placed on the same pole

- Both horizontal – stop line not clear
- Semaphore lower, warner horizontal – proceed with caution
- Both lowered – proceed on with confidence (this section and next section both are clear)



Shunting Signals

- Also called as disc or ground signals or miniature semaphore signals
- Used during shunting operations
- Consist of a circular disc painted white with a red band along its diameter.
- Red band is horizontal – stop
- Red band is inclined – proceed
- Similar to semaphore these are also provided with lamp and colored glasses


MAUQ
Stop
Proceed Slow forShunting

Coloured light signals

Used for automatic signalling these days

No moving arm is present

Give indication by electric light both during day and night

o Red – Stop

o Green – Proceed

o Yellow – Proceed with caution

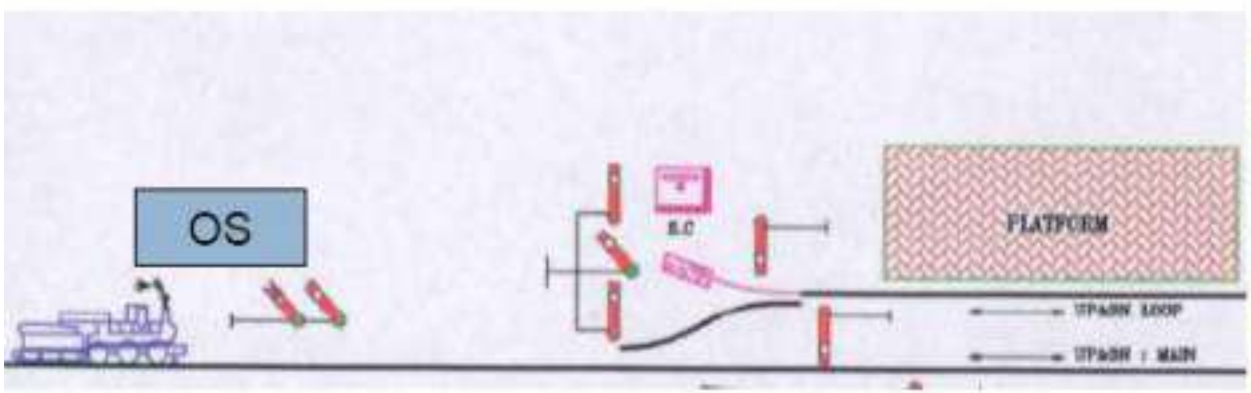
Outer Signal

This is the warner signal first seen by the driver

- Trains moving at high speed require certain distance for stopping
- Hence driver informed about the position in advance that platform is clear or not.
- This signal gives the position of stop signal ahead.
- As it is provided at some distance away from station it is also called as distant or outer or warner signal.

In horizontal or stop position it indicates that the driver must bring his train to halt within 90 m before outer signal and than proceed to the home signal with caution

In the inclined or proceed position it indicates that track and platform is clear and proceed normally without any danger.

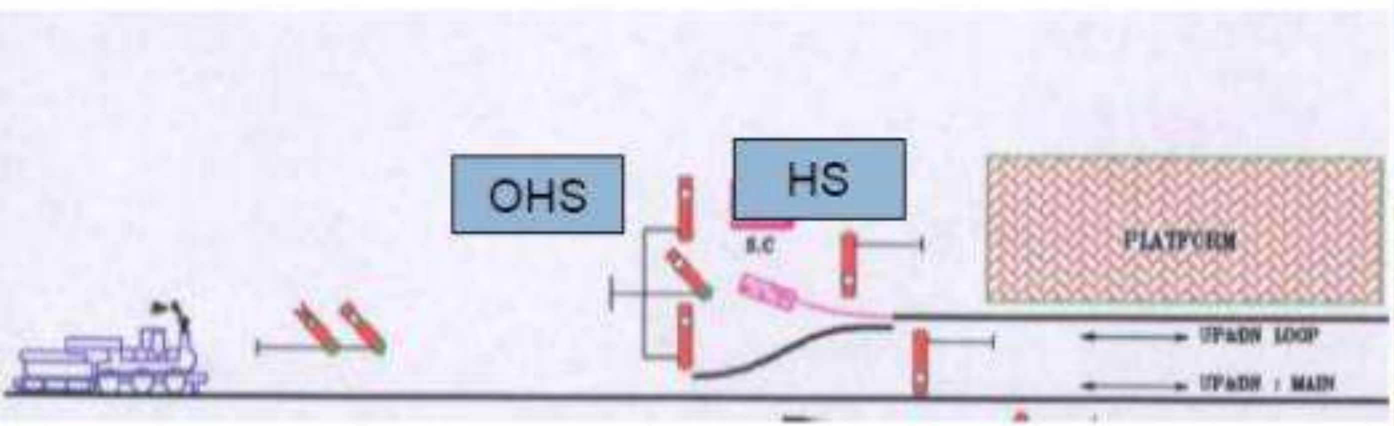


Home signal

- It is next signal after outer signal towards station
- It is a simple semaphore signal and indicates whether platform is clear or not

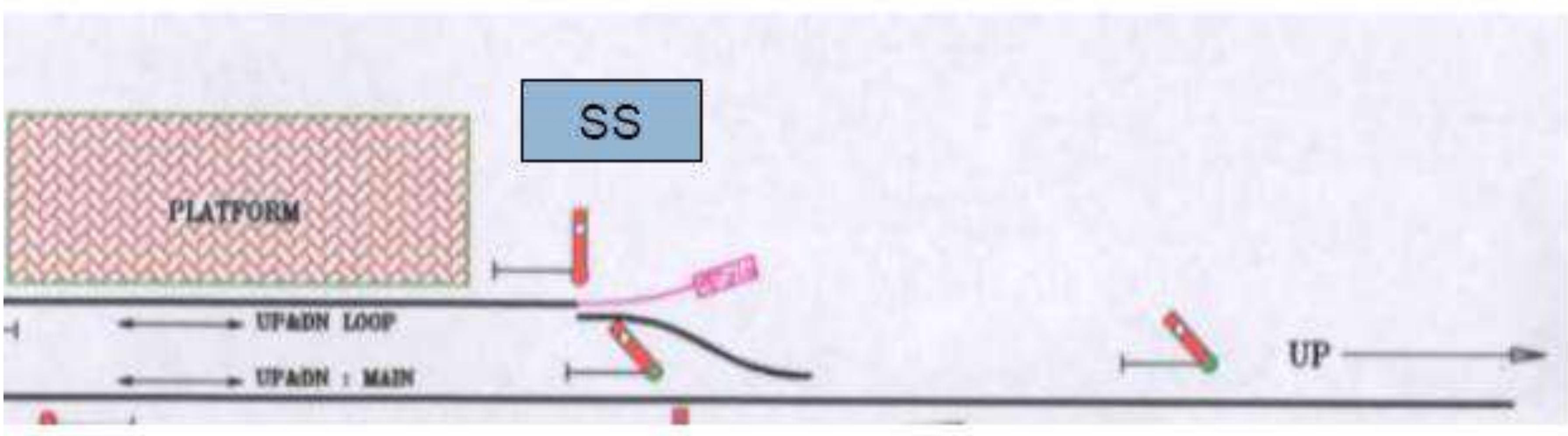
HOME SIGNAL

After the outer signal towards station is a stop signal and exactly placed at the station limit is called home or stop signal. Its main function is to protect the stations. The permission to enter the platform is given by the operation of this signal. The maximum unprotected distance between the signal and the point, it is intended to protect is specified as 180 m due to its location at the door of station, it is called home signal.



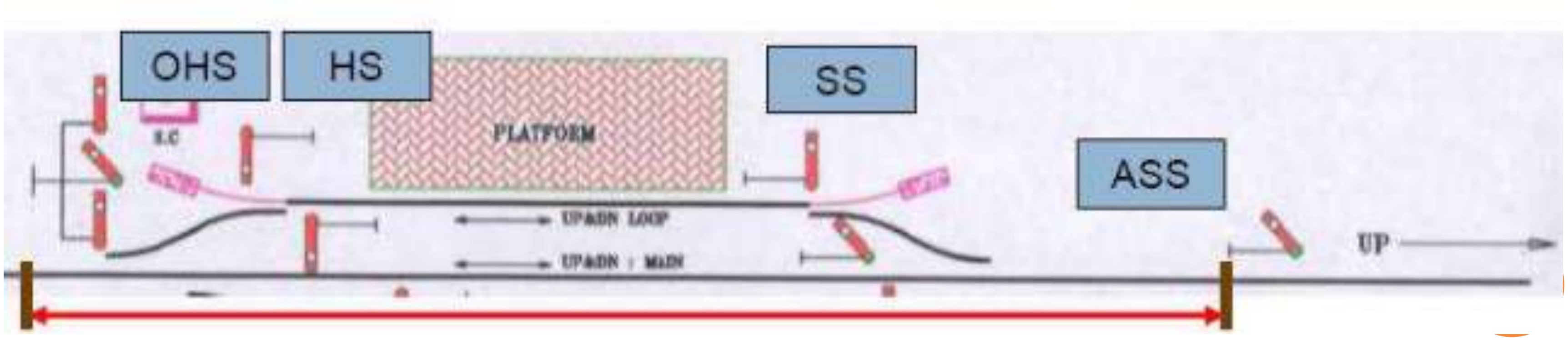
STARTER SIGNAL

- This signal is provided at the forward end of platform and controls the movement of the train as they leave the station. It gives permission to the train to leave the platform for next station. No train can leave the platform unless this signal is lowered, that is why it is called starter signal. A separate signal is provided for each line.



ADVANCE STARTER SIGNAL

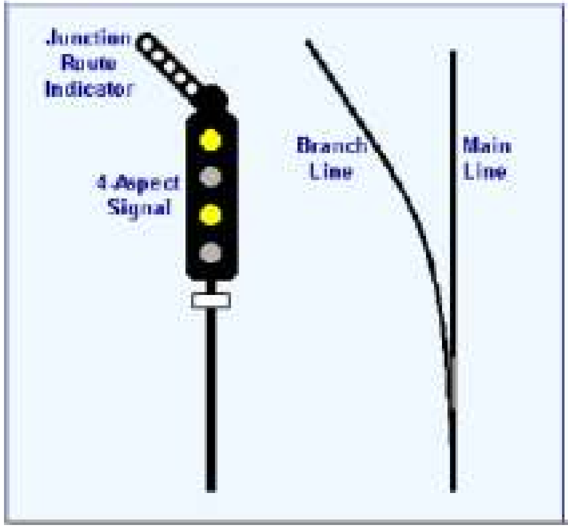
- The limit of a station section lies between the home signal and the advance starter signal. The signal which allows the train to enter in block section is called advance starter signal. It is always placed beyond the outer most set of the point connections. These signals are placed about 180m beyond the last point or switches.

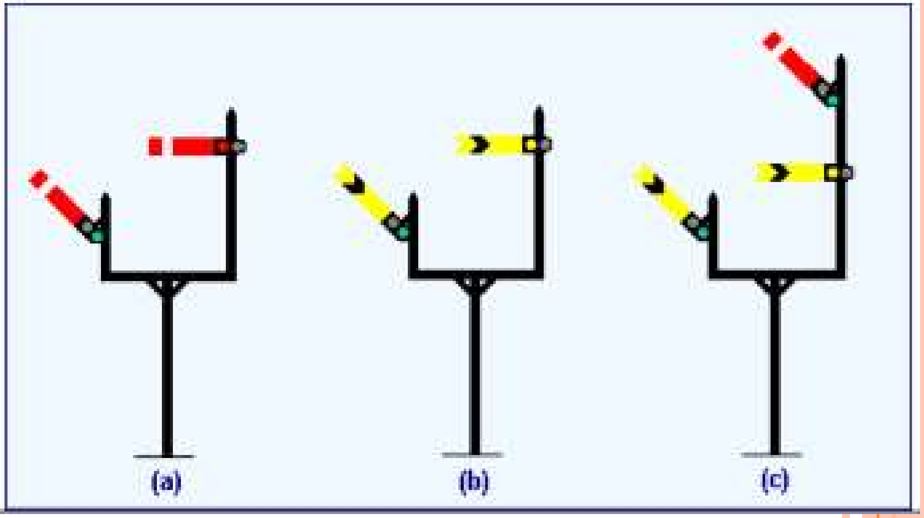


ROUTING SIGNAL

When many branch lines diverge in different directions from the main line, it is very difficult to provide individual signal for each line at the divergent point.

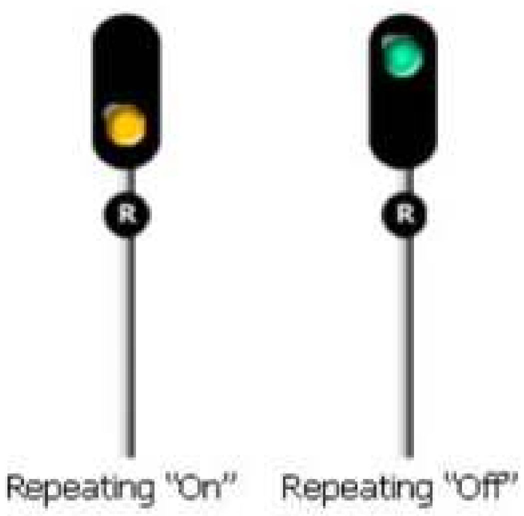
In such situations various signals for main line and branch lines are fixed on the same vertical post. These signals are called routing signal. Generally signal for main line is kept higher than those for branch lines





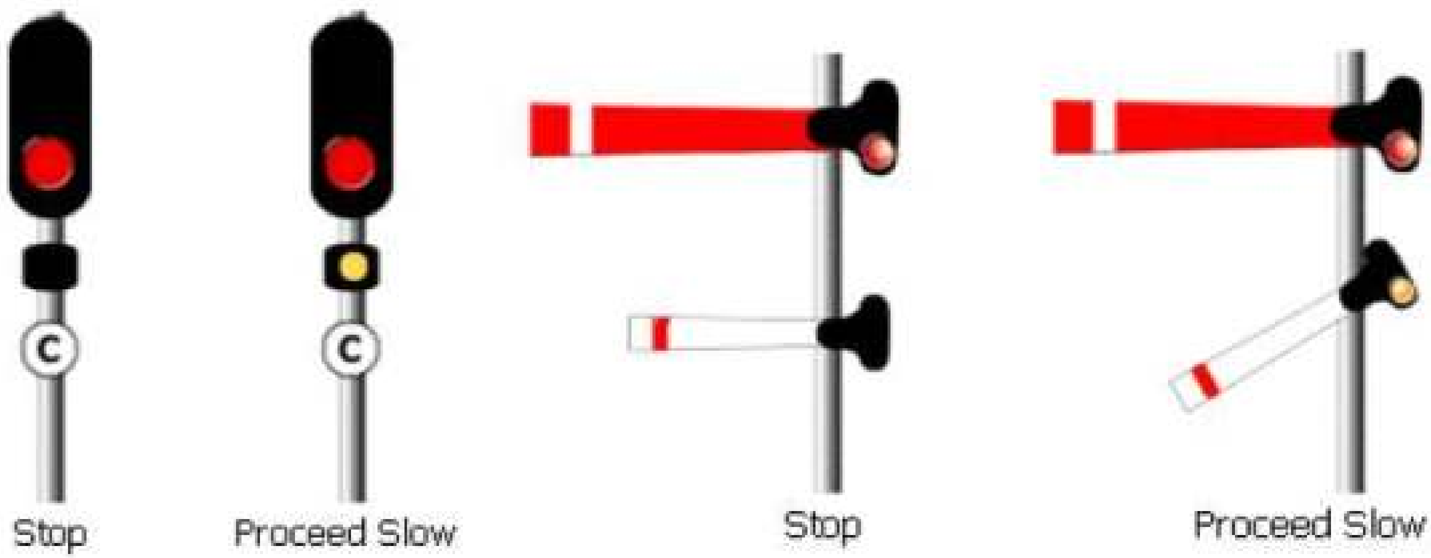
REPEATING SIGNAL

When the view of the main signal is obstructed due to some structures or on curves etc. some signals are used to repeat the information of the main signal. Such signal are know as repeating signal.



CALLING ON SIGNAL

These signal are similar to semaphore signal, but they are smaller in size and are fixed on the same post below the main signals. A calling on signal permits a train to proceed with caution after the train has been brought to a halt by the main signal. These are helpful when repair works are going on.



Signalling Systems

- Absolute block system
- Space interval system
- Time interval system
- Pilot guard system

Absolute Block System

- This system involves dividing the entire length of the track into sections called *block sections.*
- A block section lies between two stations that are provided with block instruments
- The block instruments of adjoining stations are connected through railway lines.
- A token can be taken from the block instrument of a particular station with the consent of both the station masters.

- In the absolute block system, the departure of a train from one station to another is not permitted until and unless the previous train has completely arrived at the next station.
- i.e., trains are not permitted to enter the section between two stations at the same time.
- Each station has two block instruments; one for the station ahead and the other for the previous station
- These are electrically interconnected

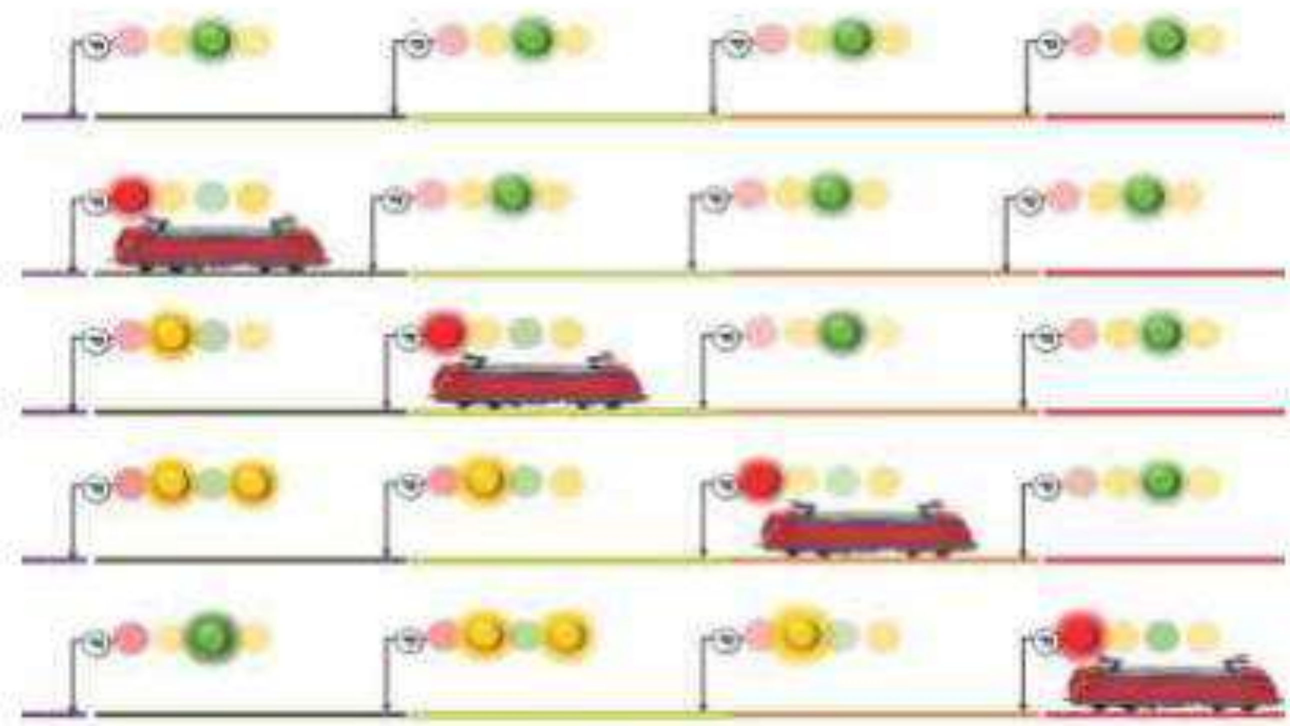


Fig. - 5.3

Absolute Block System

Time interval method

- Trains are Spaced Over an length of a track in such a way that, if the first train stops, the following train driver should be able to stop the train in sufficient distance without colliding with the first one.
- This type is used where traffic is less and weight of the trains are less, e.g: Trams
- This Type of System cannot be used in Passenger rails since weight and traffic is High

Space interval method

- In this method of "Control Over Movement", the length of the track is divided in to sections called Blocks.
- The Entry of a train in to the 'Block' is controlled in such a way that only when it is free, a train can be allowed to enter it.
- This means that between two consecutive trains , there is definite space interval.

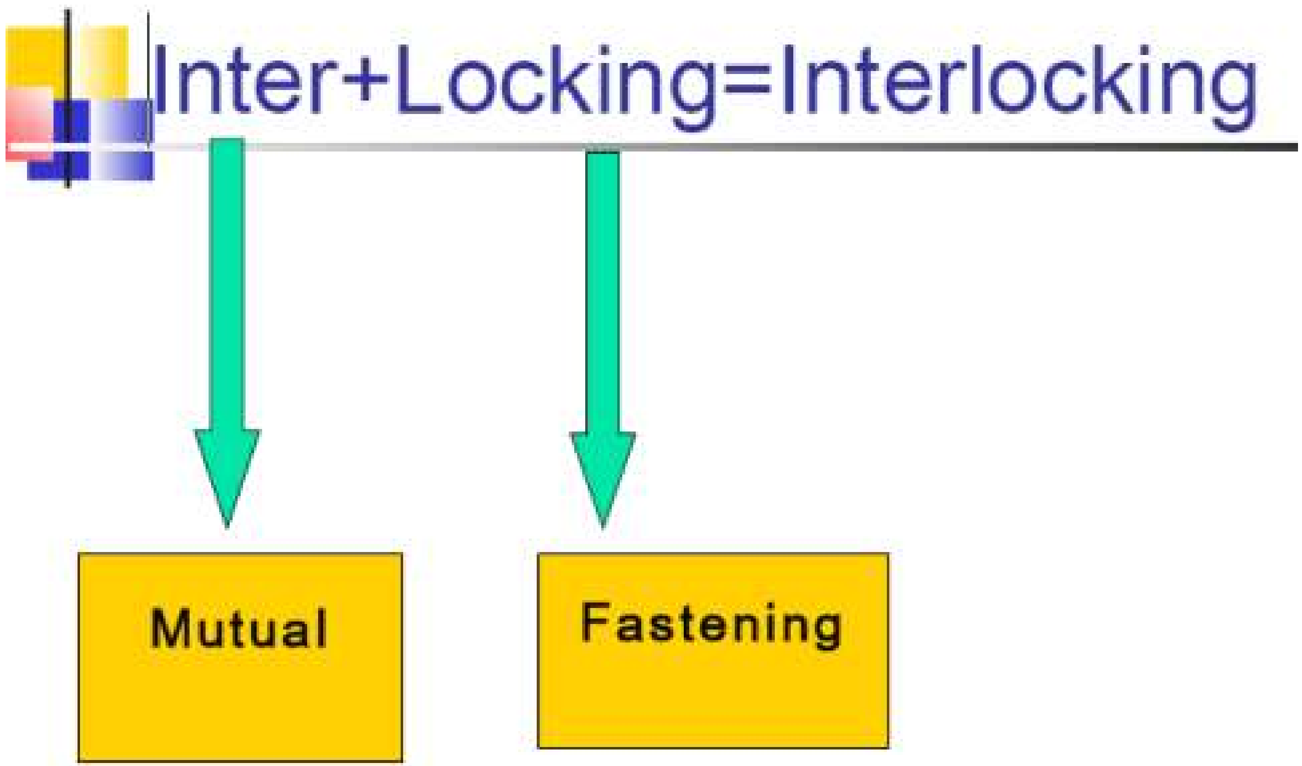
Interlocking system

- Arrangement of of signals, points and other appliances, so interconnected by mechanical or electrical locking that their operation takes place in a predetermined sequence to ensure that conflicting movement of signals and points do not take place and train runs safely.

Necessity

- increase in the number of points and signals
- Increase in speeds
- Points and signals arranged in fool proof manner. Conflicting movements are avoided
- Helps in proper and safe working of the system

- An arrangement of signals, points and appliances, operated from a panel or lever frame or VDU, so interconnected by Mechanical locking or electrical locking or both that their operation must take place in proper sequence to ensure safety



Standards

- **1st standard** : makes use of key interlocking
  - Running speed for trains restricted to 50kmph
- **2nd standard:**
  - used on non trunk main routes
  - Operated mechanically or electrically
  - Speed less than 75kmph
- **3rd standard;**
  - Makes used of mechanically or electrically interconnected
  - Uses latest interlocking techniques also.

Key Interlocking

- Simplest method of interlocking
- Involves the manipulation of keys in one form or other
- This type of interlocking is normally provided with standard 1 interlocking
- Arrangement of key interlocking is done as below when a main line and branch line exist on a single track.

Key Interlocking

Key interlocking

- Point can be set either for main line or branch line
- A, B are the keys for main and branch lines. At any point only one of the keys can be taken out.
- Lever frame operating the signals is provided with 2 signals and will be operated by keys A and B only.
- If the train is to be received on main line, the key is locked for point on main line, and A is taken out and inserted in the lever for signal of main line.
- Thus lowering the signal of main line.
- This type of signal is called indirect interlocking.
- If there are multiple lines succession interlocking will be used.

Mechanical Interlocking

- Improved form of interlocking compared to key interlocking
- Greater safety and
- less manpower
- Done using plungers and tie bars
- Plungers are of size 30cm x 1.6cm and have notches in them
- Tie bars are placed at right angles to plungers
- and are provided with suitable shaped riveted cast iron pieces (tappets) that exactly fit in notches.

- Main components are
    - Locking frame
    - Point frame
    - Signal fittings
    - And connecting devices
- Levers are arranged in a row in the frame
- Pulling a point lever operates the point to which it is connected through a steel rod.
- Pulling a signal lever changes the signal by pulling the wire connecting the lever and signal.
- This entire arrangement is provided in a locking trough where tappets are provided, which move at right angles to the plungers.
- When lever is pulled, it causes the plunger which it is connected to move.
- Due to wedge action, the tappet accommodated in the notch of the plunger is pushed out at right angles to the movement of plunger.

Mechanical interlocking

- The motion gets transferred to the other tappets which are connected to the other tappets by means of tie rod.
- Some tappets gets pushed in, some pushed out as a result.
- In case a tappet is free and pushed into the notch, it locks the lever connected to that plunger.
- Else if it is already locked, it will come out of notch, and the lever becomes free to be operated.

Different cases of mechanical interlocking

- **Normal interlocking**:
  - Pulling one lever locks other lever in normal position
- **Back locking or release locking**:
  - Lever in normal position locks the other lever in normal position.
  - When pulled other lever released and is free to operate
  - When other pulled, first one gets locked in pulled position.
- **Both wall locking:**
  - Once the lever is locked other lever locked in current position.
- **Conditional locking**:
  - Pulling one lever locks other lever only when certain

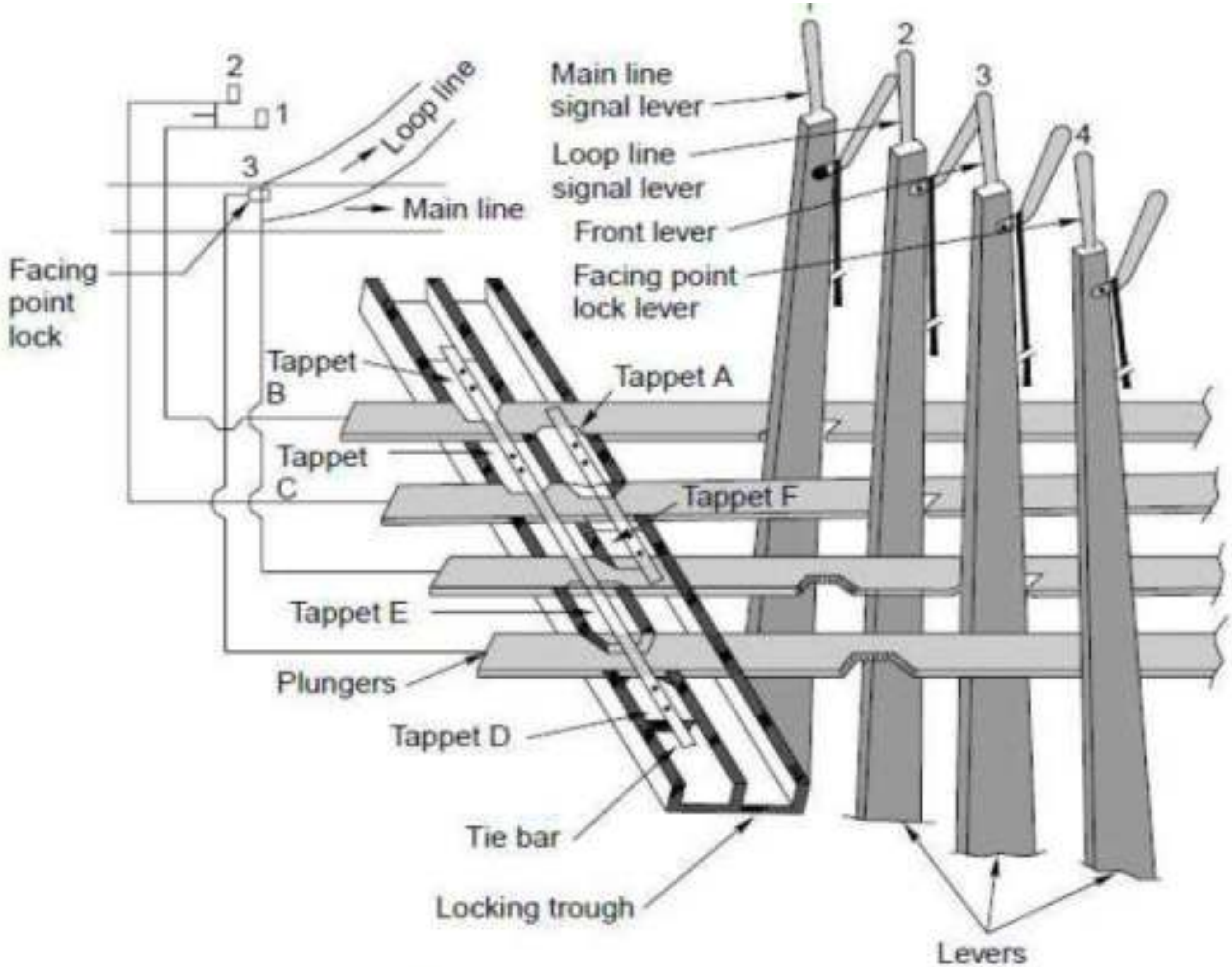


Fig. 31.21 Interlocking of points and signals of a two-line railway station

Electrical interlocking

- Achieved through electrical switches known as relays
- Manipulation of relays achieves interlocking
- In the place of plungers or in addition to plungers, lever locks are attached with levers.
- These work by making use of the principle of
- electromagnetism.
- Soft iron core wrapped inside a iron core turns into magnet when current passes through it.
- An arrangement named armature is attached to this magnet.
- Depending on whether the armature is attached or not interlocking works here.
- This entire system is housed in a glass or metal box known as relay.

Panel interlocking

- All points and signals are operated electrically from a central location
- The switches for operating these points and signals are mounted on a panel, which also bears the diagram of the yard layout
- Electrical interlocking is achieved by means of relays
- Centralized controlling of greater area is great advantage
- With elimination of inter cabin controlling greater number of trains can be run with less

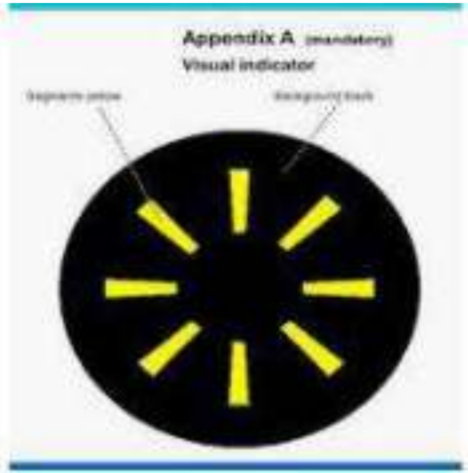
Route Relay Interlocking

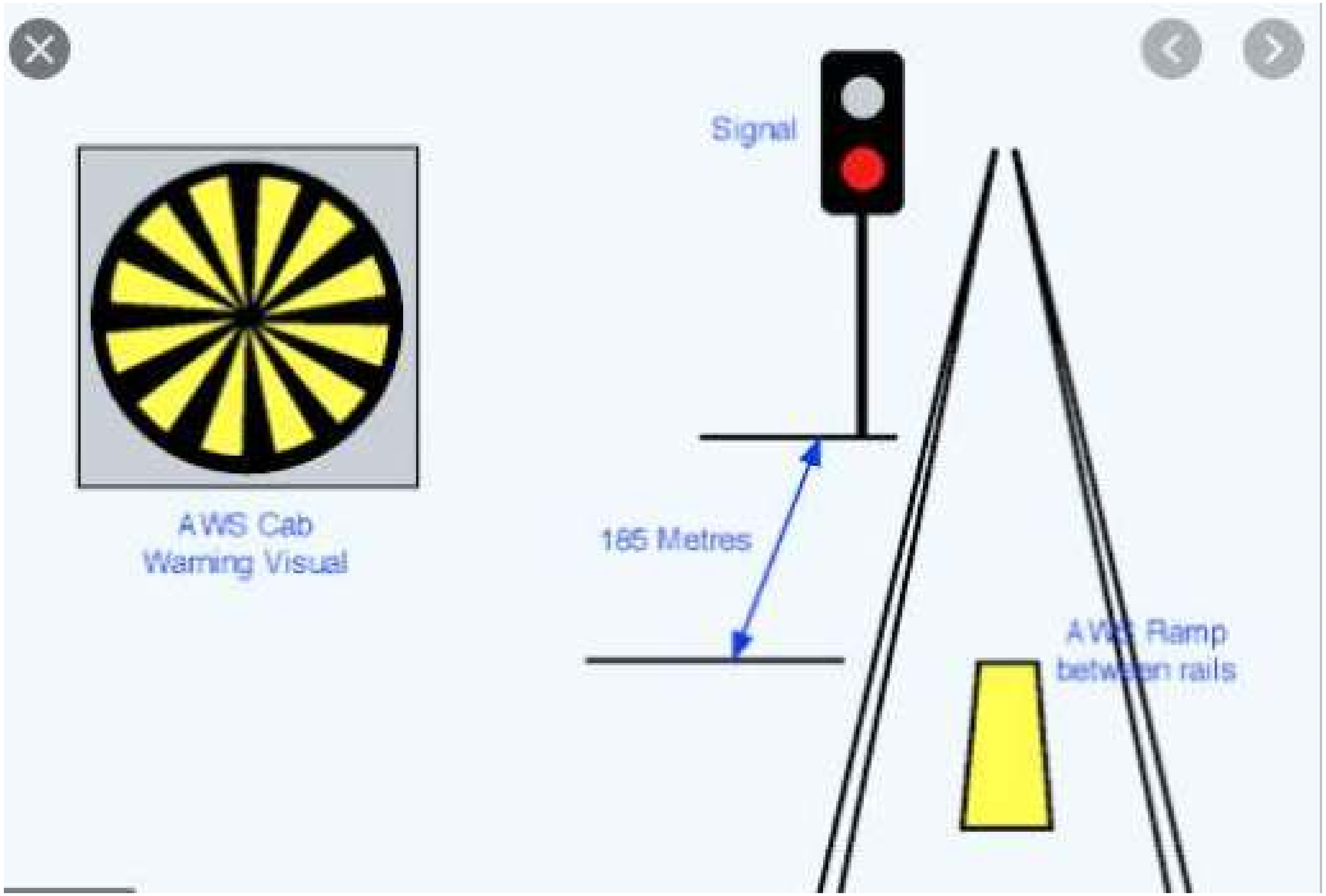
- Improvement over panel interlocking
- In panel interlocking each point in the line has to be individually setup with a switch and clearance of signal is obtained by operating the switch.
- In R.R.I only a pair of switches are used for doing all these operations automatically.
- Signal is also cleared in the similar automated manner
- The main requirement for this type of interlocking is entire track needs to be track circuited.
- The conditions of track circuit and various indications of all signal are mirrored on the panel that carries the diagram of the yard.

- By looking at these indications a panel operator can a panel operator can easily know whether a track is free or not.
- Once the route is set to allow, the portion gets illuminated with white light.
- If the route is occupied, it will show in red colour.
- If the train has cleared the track, the lights will off.

The Automatic Warning System (AWS)

- It is a device that triggers the automatic application of brakes if the signal is indicating danger and the driver has not taken any action.
- The system consists of a track device located at a desirable braking distance at the rear end of the first stop signal.
- The track device is activated when the signal indicates danger and is ineffective when the signal is ‘clear’.
- Alarm will sound if driver don’t take action during a stop signal.
- Then emergency brakes are applied automatically.




Signal
AWS Cab
Warning Visual
185 Metres
AWS Ramp
between rails

Different components.

Points:

- Points are set mechanically and are kept in locks and stretcher bars.
- The mechanical arrangement for operating them includes a solid rod and cranks.
- Point locks, detectors and lock bars used for controlling and directing the points.

Point locks

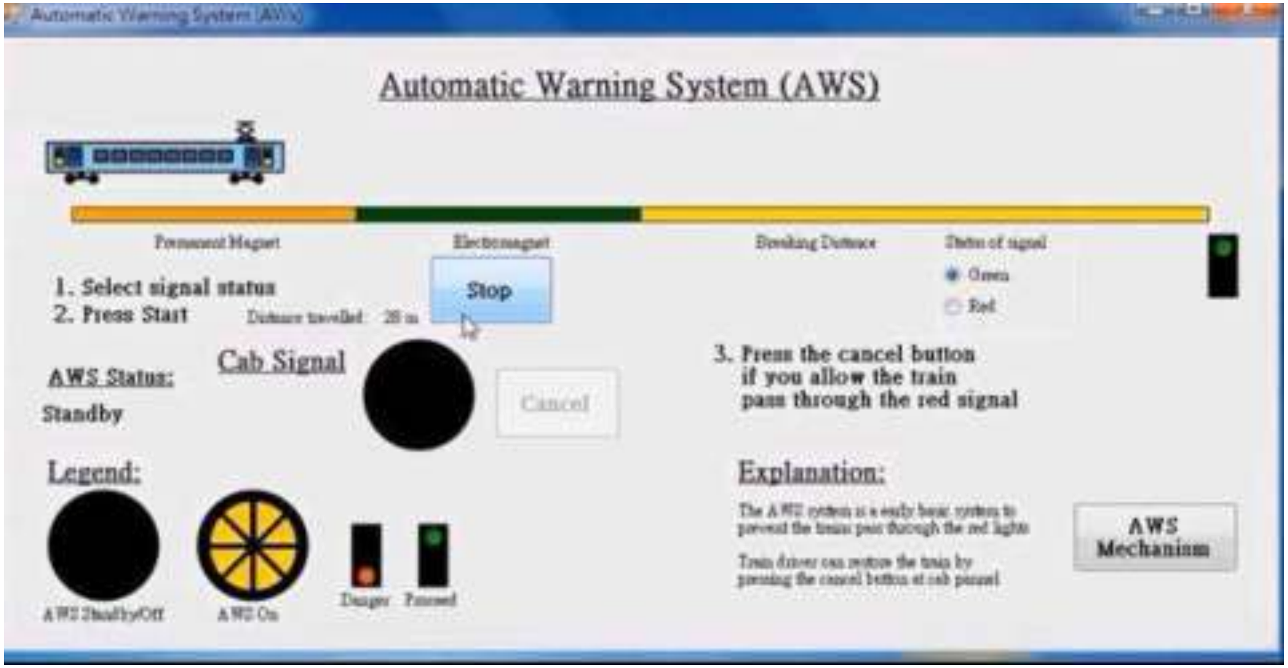
- A point lock is provided to ensure that each point is set correctly.
- It is provided between two tongue rails and near the toe of the switch assembly.
- The point lock consists of a plunger, which moves in a plunger casing.
- The plunger is worked by means of a plunger rod, which is connected to the signal cabin through a lock bar.

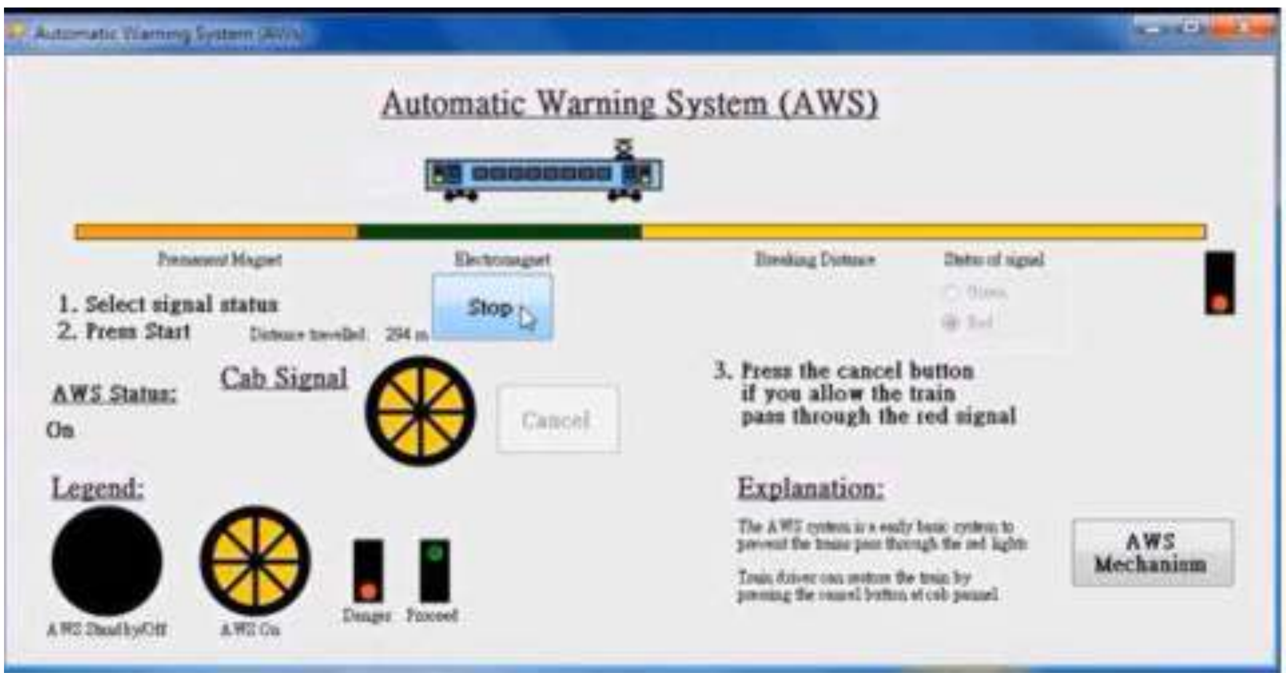
Detectors:

- Provided at all points
- To detect any defect or failure in the connection between points and levers
- To ensure the correct signal is lowered
- It can be mechanical or electrical

Lock bar

- A lock bar is provided to make it impossible to change the point when a train is passing over it.


Automatic Warning System (AWS)
Permanent Magnet
Electromagnet
Status of signal
Green
Red
1. Select signal status
2. Press Start
Stop
AWS Status:
Standby
Cab Signal
Cancel
3. Press the cancel button
if you allow the train
pass through the red signal
Legend:
Explanation:
AWS Mechanism
Danger
Proceed
AWS On


Automatic Warning System (AWS)
Permanent Magnet
Electromagnet
Status of signal
1. Select signal status
2. Press Start
Stop
AWS Status:
On
Cab Signal
Cancel
3. Press the cancel button
if you allow the train
pass through the red signal
Legend:
Explanation:
AWS Mechanism
Danger
Proceed
AWS On