Introduction to Railways
6.1 Classification of Railways

- As per Track Gauge
  - Narrow Gauge (<1000mm)
  - Meter Gauge (~1000mm)
  - Standard Gauge (~1435mm)
  - Broad Gauge (>1435mm in India 1676mm)
  - Multi Gauge (More than one gauge system)

- As per type of Track
  - Ballasted track
  - Ballastless track – Slab Track

Types of Railway

- As per Locomotive
  - Normal (Using Steam, diesel or other)
  - Electrified (Electricity as main source through catenary or track)
  - Mono rail
  - Meglay
Types of Railway

- **Intercity Railway**
  - High Speed Railway (For New line >250Km/hr and for Upgrade line >200 km/hr)
  - Normal Railway (<200Km/hr) [As per UIC – International Union of Railway]

(*It can be segregated by different measures*)

- **Urban Rail Transit**
  - Metro Rail
  - Light Rail
  - Tram
  - Mono Rail
  - AGT (Automated Guided Transport)
  - Meglav
1. components and functions

- Track is one of the major railway technology equipment's, and the foundation of driving, also known as the upper part of the building.
- Components: rail, sleepers, ballast bed, turnouts, linking parts and anti-climbing devices.
- **Rail**: main parts of track
  Functions: (1) guide vehicles running and transfer loads. (2) supply interface of least resistance.

- **Sleeper**: important parts of track structure
  Functions:
  (1) bear pressure from the rail and transfer it to ballast bed.
  (2) maintain the geometric position of the track.
  *Type: concrete sleepers and wooden sleepers.*

- **Linking parts**: Components that link rails (joint parts) or rails and sleepers (middle parts).
  Functions: (1) Ensure reliable links.
  (2) Prevent lateral movements.
  (3) Delay the accumulation of residual deformation.

- **Anti-climbing devices**: one of track equipments.
  Function: Prevent longitudinal relative movements.
Ballast bed: Foundation of rail sleepers. Arrange sleeper at predetermined intervals.
Functions: (1) increase the elasticity of track and the resistance to vertical, lateral movement.
(2) drainage and correct plan and profile of rails.
Category: gravel ballast bed bed and screening pebble ballast bed.

Turnout/Switches: Essential equipment when the rolling stocks transfer or cross from a track to another track.
Function: Ensure smooth transition or crossing.
Function and basic requirements

Guide and support

- flat-bottom rail: standard rail track
- construction rail: manufacturing of switch parts
- grooved rail: railway track in pavement
- block rail: railway track in concrete slab
- crane rail: heavy load hoisting cranes
Rail

- **basic requirements of rail**
  - **strength**
  - stiffness
  - hardness
  - toughness
  - weldability
  - economics

Rail type:
- Weight per meter
- Rail length
- Rail material
- etc.
Rail cross section

- Rail head
- Rail web
- Rail foot

Rail head: contact patch
  - High pressure
  - High wear
  - Adapt to wheel trend

Rail Web:
  - Bending —— height
  - Compression —— thickness
  - Connection —— Curve

Rail foot:
  - Stability —— width, thickness

Four parameters: H, B, b, t
Design requirements of rail section

I-shape consist of rail head, rail waist and rail bottom:

- Big head: large, thick, wide enough, matching shape, arcing central;
- Waist Length: high and thick, both sides of the curve, supporting wide
- Width: wide and thick, enough stiffness, strong anti-corrosion
- Four design parameters:
  (1) rail head width (b)
  (2) rail waist thickness (t)
  (3) rail height (H)
  (4) rail bottom width (B)
Stay stable. $H / B = 1.15 \sim 1.20$
• **Requirements:**

  - **Sufficient rigidity:** resist to the elastic deflection deformation caused by dynamic loads;
  - **Necessary flexibility:** reduce the impact of the rail wheels to prevent wheel-rail broken or damaged;
  - **Sufficient hardness:** prevent the wheels sag or wear too fast;
  - **Certain toughness:** prevent rail breakage under the impact of wheels;
  - **Roughness of the top surface:** achieve both adhesion traction and braking force of locomotive and reduce wheels rolling resistance;
  - **Economic rationality:** easy to manufacture, inexpensive, durable, light and heavy, self-made series.
Material and mechanical properties of rail

- Depend mainly on chemical composition, physical and mechanical properties, microstructure and heat treatment process of rail.
- Physical and mechanical properties of rail steel includes strength limit $\sigma_b$, yield limit $\sigma_s$, fatigue limit $\sigma_f$, elongation $\delta_5$, section shrinkage $\psi$, impact toughness $\alpha_h$, and hardness.

The rail length and joints

- Standard length of rail:
  - 12.5m — 12.46m, 12.42m, 12.38m
  - 25m — corresponding length of shorten track: 24.96m, 24.92m, 24.84m

- Rail gaps: connect with plywood and bolts between rails.
  - Great dynamic action and conservation workload.
  - One of the weak links
Contact Fatigue
long rail
Sleeper/Tie

- The function of sleeper
  - Support: force bearing and transfer
  - **Maintain geometry:** esp. rail gauge and direction
Sleeper

Function:

- The sleeper is under anisotropic pressure from rail, and elastic spread on the track bed.
- The sleepers can effectively keep track geometry position, especially gauge and direction.

Requirement:

- The necessary solidity, elasticity and durability;
- Convenient for fixing rail;
- Has the ability to resist the longitudinal and transverse displacement;
- Convenient repair and low cost.
Sleeper types

- **by material**: wooden sleeper, concrete sleeper, steel sleeper, resin sleeper

- **by use purpose**: normal sleeper, switch sleeper, bridge sleeper

- **by structure**: monoblock; twin-block; half sleeper; broad tie

- **by laying method**: transverse sleeper, longitudinal sleeper and short tie
1. Wooden Sleeper

- Wooden sleepers is the railway's early adoption and still continue to be used.

- The main advantage:
  Good elasticity; easy to process; the rail link is relatively simple; good insulation performance etc..

- The main disadvantage:
  The price is more expensive; easy corrosion, abrasion and cracking, the service life is short; strength and elasticity is not completely consistent; Under dynamic loads, it will form irregularity, increasing the effect of wheel-rail power.

Wooden sleepers section is generally rectangular. The standard length of ordinary wooden pillow is 2.5m.
2. Concrete sleepers

The main advantage:
① The large weight, high resistance, uniform elasticity, strong stability;
② Rich source of material, save a lot of wood;
③ Fire-resistant, corrosion-resistant, not afraid moth, not affected by climate and fire, long service life;
④ Self important, large stiffness, the bottom of the rail deflection more smooth, the track dynamic slope is small, withstand voltage is good.

The main disadvantage:
① The self weight is large, poor flexibility;
② Handling and repair is not easy;
③ Poor insulation;
④ Coupling of complex parts.
Concrete sleeper

Concrete sleeper

Reinforce concrete

Pre-stressed concrete

Pre-tensioned

Post-tensioned

Type I

Type II

Type III
Concrete sleeper

- **Stress characteristic**
  - Short beam on elastic foundation

- **Stress distribution relate to support condition**
  - Unsupport  *type I*
  - Partial support  *type II*
  - Full support  *type III*
shape of concrete sleeper

- sleeper shape
  - Trapezoid: save concrete, lower self-weight, easy to demould
  - **Top width**: bending stiffness, bearing area of rail, fastener dimension, etc.
  - Rail inclination: 1:40, match to wheel tread inclination
  - **Bottom width**: reduce ballast stress, easy to tamp
  - sleeper length: stress distribution, 2.3-2.7m, mostly use 2.6m
  - sleeper height: under the rail > middle: stress distribution, pre-stressed rebar
Special concrete sleepers

Wide sleeper
Elastic sleeper
Other sleeper
The number and arrangement of laying sleepers

- Sleeper spacing relevant the configuration of the number per kilometer on sleeper
- Sleeper type and the number should be determined according to the traffic volume, speed and line equipment conditions, and take rail and ballast into account, with a reasonable matching, in order to in the economic conditions, guarantee that the track has enough strength and stability.
- Sleeper encryption, can reduce the track bed, roadbed surface, rail and sleeper itself by force, conducive to maintaining gauge, direction, ensure high-speed traffic safety.
- The sleeper is too close, which is not economic. Spacing is too small, which affect the quality of tamping.
- The standard of the number of laying sleeper per kilometre: III type pillow 1720, II type pillow 1840 occipital, wood 1920.
- Using of CWR track, can be arranged according to the 60cm spacing, that is, every kilometer 1667.
Connection components

- Connect rails, or rail and sleeper
  - rail joints
  - fastenings
Rail joints
Rail weld joint

- Flash contact welding
- Gas butt welding
- Thermite welding
Wooden sleeper fasteners

- Wooden sleeper fasteners: separate type (K type fastener) and the hybrid type
Concrete sleeper fasteners

- Enough Buckle pressure (approximately 10kN) - Longitudinal resistance requirements
- Appropriate flexibility (Rubber pad + elastic clip) - Track stability and low vibration requirements
- Larger adjustment amounts
- Insulation property
Track bed

Ballasted  ballastless
ballast bed

- Crushed stone

Cross section

Ballast gradation
6.3 Geometric Design of Railway Track

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.

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 super elevation on curves, etc.
3. **Alignment** of the track, including straight as well as curved alignment.
Features for Geometric Design

- Safe and smooth to operate under all weather conditions
- Minimum cost for
  - Construction
  - Maintenance
  - Operation
- Several critical design consideration
  - Speed, type, and volume of traffic
  - Space consideration (Right-of-way)
- Environmental concerns
- Politics and land-use issue
- Other economic criteria
Gradients are provided to negotiate the rise or fall in the level of the railway track.

A rising gradient is one in which the track rises in the direction of the movement of traffic and a down or falling gradient is one in which the track loses elevation in the direction of the movement of traffic.

Purpose of Gradient
- To provide uniform rate of rise or fall
- To reduce cost of earthwork
- To reach different stations, level crossing, bridges at different levels
Types of gradients

(a) 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 extra force $P$ required by a locomotive to pull a train of weight $W$ on a gradient with an angle of inclination $q$ is
  \[ P = W \sin q \]
  \[ = W \tan q \text{ (approximately, as $q$ is very small)} \]
  \[ = W \times \text{gradient} \]
  - In plain terrain: 1 in 150 to 1 in 250
  - In hilly terrain: 1 in 100 to 1 in 150

(b) Pusher or helper gradient

(c) Momentum gradient

(d) Gradients in station yards
Pusher or helper gradient

- In hilly areas, the rate of rise of the terrain becomes very important when trying to reduce the length of the railway line and, therefore, sometimes gradients steeper than the ruling gradient are provided to reduce the overall cost.
- In such situations, one locomotive is not adequate to pull the entire load, and an extra locomotive is required.
- When the gradient of the ensuing section is so steep as to necessitate the use of an extra engine for pushing the train, it is known as a pusher or helper gradient.
- Examples of pusher gradients are the Budni–Barkhera section of Central Railways and the Darjeeling Himalayan Railway section.

Momentum Gradient

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

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

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

It may be mentioned here that generally, yards are not leveled 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.
Curves provide extra resistance to the movement of trains. As a result, gradients are compensated to the following extent on curves:

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

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

(c) On NG tracks, 0.02% per degree of curve or 35/R, whichever is minimum. Where R is the radius of the curve in metres.
A curve is defined by its degree or radius. The degree of a curve is the angle subtended at the center by a chord of 100 feet or 30.48m.

If \( R \) is the radius of curve,

- Circumference of the curve = \( 2 \pi R \)
- Angle subtended at the center by the circle = 360 degree
- Angle subtended by the arc of 30.48m = \( 1750/R \)

Thus, a 1 degree curve has a radius of 1750 m.
Superelevation on Curves (Cant)

- Cant is defined as the difference in height between the inner and outer rails on the curve. It is provided by gradually raising the outer rail above the inner rail level. The inner rail is considered as the reference rail and normally is maintained at its original level. The inner rail is known as the gradient rail.

- **Function of super elevation:**
  - Neutralizes the effect of lateral force.
  - It provides better load distribution on the two rails.
  - It reduces wear and tear of rails and rolling stock.
  - It provides smooth running of trains and comforts to the passengers.
**Speeds**

- **Equilibrium speed:** It is the speed at which the effect of centrifugal force is exactly balanced by the superelevation provided. It can also be said that when the speed of a vehicle running on a curved track is such that the resultant weight of the vehicle and the effect of radical acceleration is perpendicular to the plane of rails and the vehicle is not subjected to an unbalanced radical acceleration, is in equilibrium then its particular speed is called equilibrium speed.

- **Maximum permissible speed:** This is the highest speed which may be allowed or permitted on a curved track taking into consideration of the radius of curvature, actual cant, cant deficiency, cant excess and the length of the transition curve. When, the maximum permissible speed on the curve is less than the maximum sanctioned speed of the section of a line, permanent speed restriction become necessary on such curves.
**Cant deficiency**
Cant deficiency is the difference between the equilibrium cant (theoretical) necessary for the maximum permissible speed on a curve and the actual cant provided there. As per Indian Railways, Cant deficiency is recommended as follow:
- **BG Track:** 75 mm
- **MG track:** 50 mm
- **NG track:** 40 mm

**Cant Excess**
When a train travels on a curved rack at a speed lower than the equilibrium speed, then the cant excess occurs. It is the difference between the actual cant provided and the theoretical cant required for such lower speeds. Maximum value for cant excess is
- **BG track:** 75 mm
- **MG Track:** 65 mm
Centrifugal Force

When a body moves on a circular curve, it has a tendency to move in a straight direction tangential to the curve. This tendency of the body is due to the fact that the body is subjected to a constant radial acceleration.

Radial acceleration = \( v^2 / R \)

This radial acceleration produces a force known as centrifugal force whose value is given as

\[ F = \frac{(Wv^2)}{gR} \]

Where,

- \( F \) is the centrifugal force
- \( W \) is the weight of the body
- \( V \) is the speed of the body m/sec
- \( R \) is the radius of the curve in m
Let,
- $\theta$ be angle which the inclined plane makes with the horizontal
- e superelevation
- G gauge
- P centrifugal force
- W weight of vehicle

\[
\tan \theta = \frac{\text{Superelevation (e)}}{\text{Gauge length (G)}}
\]

Also, \( \tan \theta = \frac{P}{W} \)

From above both equation
- \( \frac{P}{W} = \frac{e}{G} \)
- \( e = \frac{[PG]}{W} \)
- \( e = \frac{[Gv^2]}{[gR]} \)
Mostly decided on the basis of experiments and research. The maximum value of super-elevation is generally adopted as $1/10^{th}$ to $1/12^{th}$ of the gauge. As per Indian railways BG track 165mm(normal condition) 185mm(special permission)

### Maximum degree of curve

It depends on various factors as gauge, wheel base of vehicle, maximum super-elevation etc.

<table>
<thead>
<tr>
<th>Gauge</th>
<th>On plain track</th>
<th>On turnout</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. degree</td>
<td>Min. radius, m</td>
</tr>
<tr>
<td>BG</td>
<td>10</td>
<td>175</td>
</tr>
<tr>
<td>MG</td>
<td>16</td>
<td>109</td>
</tr>
<tr>
<td>NG</td>
<td>40</td>
<td>44</td>
</tr>
</tbody>
</table>
Empirical formulas

For BG and MG
- On transition curve  \( V=4.4\sqrt{(R-70)} \)
- For non-transition curve (80% of the speed on the transition curve)
  - \( V=0.8*4.4\sqrt{(R-70)} \)

For Narrow gauge
- with transition curve
  - \( V=3.65\sqrt{(R-6)} \) Subjected to maximum speed of 50kmph
- Non transition curve
  - \( V=2.92\sqrt{(R-6)} \) Subjected to maximum of 40kmph

For High speed
- \( V=4.58\sqrt{R} \)

Rational formula considering suerelevation
- BG track  \( V=0.27\sqrt{[(Ca+Cd)R]} \)
- MG track  \( V=0.347\sqrt{[Ca+Cd)R]} \)
- NG track  \( V=3.65\sqrt{[R-6]} \)
  - Ca actual cant
  - Cd Cant deficiency
Transition curve

- **Objectives**
  - To attain gradual rise of the outer rail
  - To decrease the radius of curve gradually
  - To introduce super-elevation (Cant) at constant rate.
  - To provide smooth running of vehicles and provide comfort to the passengers.
  - To reduce the chance of derailment.

- **Types of Transition curve**
  - Spiral curve
  - Lemniscates curve
  - Cubic parabola
  - Sine Curve
Length of Transition Curve

- The distance along the center line of the track between the starting point on the straight portion of the track and the meeting point on the junction with the circular curve.

As per Indian Railway

- Length of transition curve is greatest among these
  - Based on the arbitrary gradient (1 in 720): \( L = 7.2e \)
  - Based on the change of cant deficiency: \( L = 0.073D \cdot V_{\text{max}} \)
  - Based on the change of superelevation: \( L = 0.073e \cdot V_{\text{max}} \)
    - \( D \) is cant deficiency, \( V_{\text{max}} \) is maximum speed and \( e \) is actual cant

Generally, Length of transition curve is maximum of among these

- As per Railway code: \( L = 4.4 \sqrt{R} \)
- At the rate of change of cant of 1 in 360 i.e. 1cm for every 3.6m length of track
- Based on the rate of change of Radial acceleration as 0.35m/sec\(^2\): \( L = (0.066V^2)/R \)
- Based on the maximum permissible speed: \( L = (CaV_m)/125 \)

Length of Vertical Curve

- \( L = R \theta \)
  - \( L \) is length of Vertical curve, \( R \) radius of vertical curve and \( \theta \) difference in percentage of gradients expressed in radians
Negative Super Elevation

- When the main line lies on a curve and has a turnout of contrary flexure leading to a branch line, the super-elevation necessary for the average speed of trains running over the main line curve cannot be provided.
- AB, which is the outer rail of the main line curve, must be higher than CD.
- For the branch line, however, CF should be higher than AE or point C should be higher than point A. These two contradictory conditions cannot be met within one layout.
- In such cases, the branch line curve has a negative super-elevation and, therefore, speeds on both tracks must be restricted, particularly on the branch line.
The provision of negative superelevation for the branch line and the reduction in speed over the main line can be calculated as follows.

(i) The equilibrium superelevation for the branch line curve is first calculated using the formula

\[ e = \frac{GV^2}{127R} \]

(ii) The equilibrium superelevation \( e \) is reduced by the permissible cant deficiency \( C_d \) and the resultant superelevation to be provided is

\[ x = e - C_d \]

where, \( x \) is the superelevation, \( e \) is the equilibrium superelevation, and \( C_d \) is 75 mm for BG and 50 mm for MG. The value of \( C_d \) is generally higher than that of \( e \), and, therefore, \( x \) is normally negative. The branch line thus has a negative superelevation of \( x \).

(iii) The maximum permissible speed on the main line, which has a superelevation of \( x \), is then calculated by adding the allowable cant deficiency \( (x + C_d) \). The safe speed is also calculated and smaller of the two values is taken as the maximum permissible speed on the main line curve.
Switches are of special component for railways, for the branching and joining of tracks. The productivity and line speed of a railway is essentially influenced by the number and type of its switches.

The structure of a switch is far more complicated and expensive and require large scale maintenance.

The purchase costs for one effective meter of a switch—depending on the type of switch—are up to four times higher than for one meter of track.
Function of switches

- Switches enable vehicles to pass from one track to another without interrupting their run.

- Crossing are the intersection of two tracks, diamond crossings with slips make it possible for vehicles to pass from one track to another without interrupting their run at the point of intersection.

- The service life of a switch on wooden sleepers is nowadays 20 years, on concrete sleepers about 30 years.
Main types of switches

- The main types of switches, crossings and diamond crossings with slips
  - switches: split/single switches, symmetrical switches, three way switches
Mains types of switches

- Crossings
Mains types of switches

- Diamond crossings with slip / Slip switches

Schematic representation of a double diamond crossing with slip, with blades arranged within the diamond crossing.
Mains types of switches

- **Diamond crossings**
  - Cross-overs
    - Cross-over, double cross-over
d. two turnouts and two double slips with central diamond crossing
Components of a single switch

- Switch proper, frog and check/guard rails, intermediate rails

Diagram of simple turnout showing the names of the principal parts
Components of a single switch

- A set of stock rail
- A pair of tongue rail
- A pair of heel block
- A number of slide chair to support the tongue rail
- Two or more stretcher bars to connect tongue rail
- A gauge tie plate to fix and ensure correct gauge at points
- Guard or check rail

Diagram of simple turnout showing the names of the principal parts
Switch blade and stock rail

Cross-sectional drawing of T-rail switch blade
The locking system is integrated in a hydraulic setting cylinder. The principle of an integrated locking and switching machine enables the blades to move sequentially so less power is needed at the same time.
Type of a single switch

- **Rail type**: 50, 60, 75kg/m
- **Frog angle**: $N = \cot a$
- **Sleeper type**: wooden sleeper, concrete sleeper
- **Frog type**: movable frog, rigid frog
Cast manganese frog-Austenitic Manganese Steel (AMS)
Rail Yards
A rail yard is a complex series of railroad tracks for storing, sorting, or loading and unloading, railroad cars and locomotives. Railroad yards have many tracks in parallel for keeping rolling stock stored off the mainline, so that they do not obstruct the flow of traffic. Large yards may have a tower to control operations. Many railway yards are located at strategic points on a main line. Main-line yards are often composed of an up yard and a down yard, linked to the associated railroad direction. There are different types of yards, and different parts within a yard, depending on how they are built.

Types:
Freight Yard
Switching Yard/Shunting yard
Coach Yard
A train station, railway station, or depot is an area where trains regularly stop to load or unload passengers or freight.

It generally consists of at least one track-side platform and a station building (depot) providing such ancillary services as ticket sales and waiting rooms. If a station is on a single-track line, it often has a passing loop to facilitate traffic movements.

Stations may be at ground level, underground, or elevated. Connections may be available to intersecting rail lines or other transport modes such as buses, trams or other rapid transit systems.

Types of station
1. Terminal Station
2. Junction Station
3. Signal Station

Passenger Station
Mixed passenger and Freight station
Freight Station
A **passing loop** (UK usage) or **passing siding** (North America) (also called a **crossing loop**, **crossing place** or, colloquially, a **hole**) is a place on a single line railway, often located at a station, where trains or trams travelling in opposite directions can pass each other.

Trains/trams going in the same direction can also overtake, provided that the signaling arrangement allows it.

A passing loop is double-ended and connected to the main track at both ends, though a dead end siding known as a refuge siding, which is much less convenient, can be used.

Ideally, the loop should be longer than all trains needing to cross at that point. If one train is too long for the loop it must wait for the opposing train to enter the loop before proceeding, taking a few minutes. Ideally, the shorter train should arrive first and leave second. If both trains are too long for the loop, time-consuming "see-sawing" (or "double saw-by") operations are required for the trains to cross.

On railway systems that use platforms, especially high-level platforms, for passengers to board and disembark from trains, the platforms may be provided on both the main and loop tracks or possibly on only one of them.