Transportation Engineering

Course Code –CE-422

Contact Hours -3+3

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What is a Curve

- A curve is defined either by its radius or by its degree.
- The degree of the curve is the angle subtended at its centre by a 100 ft chord or 30.5 m chord.
- The value of degree of curve can be determined by
  - Circumference of circle = $2 \pi r$

Curve (cont'd)

- Angle subtended at the centre by the circle with this circumference = 360 deg
- Angle subtended at the centre by a 30.5 m chord or degree of curve
- D = 360* 30.5/ 2* pi*r

  – D = 1750/R (R in meters)

  – D = 5730/R (R in feet)

Problem

- Find out the radius of the track laid on 4 ^{o} curve.
- Find out the degree of the curve if the radius is 1500 ft.
- Find out the degree of the curve if the radius is 500 m.
- Find out the radius of track in ft laid on 3 degree of the curve.

Why Curves are provided

- It is desirable to lay the track as straight and gentle as possible but it is not possible due to
  - Natural features of the country
  - Due to necessity of avoiding obstruction both natural and artificial
- As curves are unavoidable so it is desirable to lay track on the curves as flat as possible.

Why Curves should be avoided

- Curves produce resistance to haulage of trains
- Wear both in track and vehicle
- Reduce the safe speed limits
- Increase the maintenance cost

Compensation for Curvature

- Extra power is required to move the train along the curve.
- If speed of the train is not to be reduced then the effective pulling power is to be maintained.
- Extra power required is made available by the reducing the extra effort required to negotiate the gradient on the curve.

Compensation for Curvature

- When sharp curve is to laid, gradient is kept smaller than the ruling gradient and the amount by which it is reduced is compensation of curvature
- When sharp curves are provided there is speed reduction
  - Due to Curvature
  - Also extra power is required to overcome increased frictional resistance due to centrifugal force and sliding.
- Normally, compensation of 0.03 % to 0.05 % can be provided for every degree of curvature in curve.

Example

- If a 3 degree curve is located on a ruling gradient of 1 in 150. How much is the gradient on the curve

Solution

Gradient = 1/150*100 =0.67%

Assuming grade compensation = 0.05% for 1 degree.

Grade compensation for 3 deg = 0.05*3=0.15

Actual gradient on curve

0.67 – (3* 0.05) = 0.52% or 1 in 192.

Problem

- Find out the actual gradient of the track laid on 4 ^{o} curve. The track is Broad gauge track and ruling gradient is 1 in 200.
- Find out the actual gradient of the track laid on 5 ^{o} curve. The track is Standard gauge track and ruling gradient is 1 in 150.

Types of Curves

- Circular Curves
- Transition Curve
- Vertical Curves

Circular Curve

- Curve of constant radius and can be described by their radius or degree of curvature.
- Circular curves are classified as
  - Simple curve- curve of constant radius
  - Compound curve- circular curves of two different radii but curving in the same direction
  - Reverse curve- formed by two circular curves each curving in the opposite direction

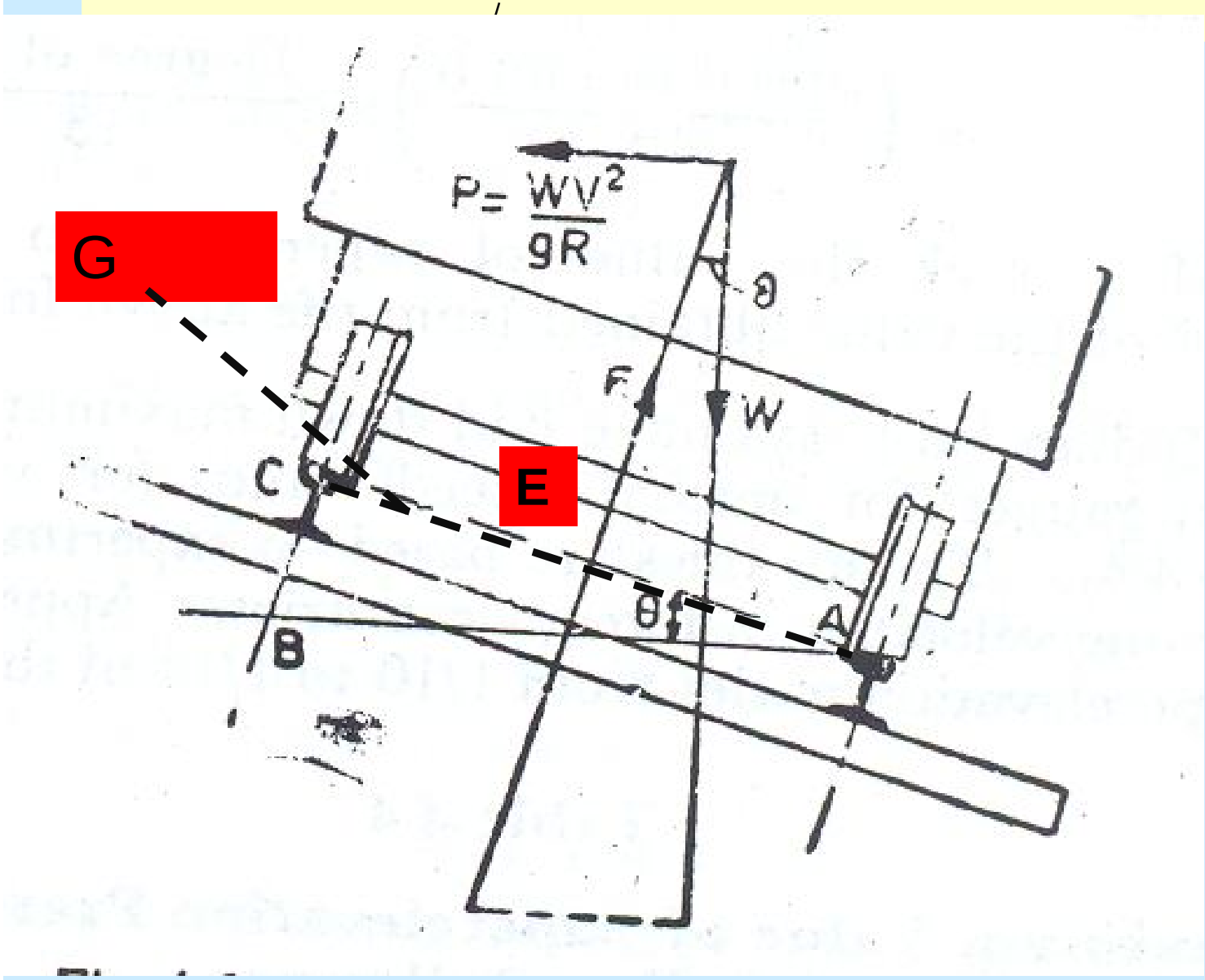
Curves Types (cont'd)

- Transition Curves
  - Curve of variable radius and provided between straight and circular curve. Also provided between two circular curves of different radii. They are also called easement curves
  - Cubic parabola is used for transition curves
- Vertical Curves
  - Provided at intersection of two gradient lines

Variable affecting Speed on Curves

- When the train moves over the curve centrifugal force is exerted on the outer rail.
- Magnitude of the force depends upon speed of train and radius of curve
- Other factors are
  - Super elevation of track
  - Rate of change of super elevation
  - Super elevation gradient
  - Super elevation deficiency and excess cant

Super elevation or Cant



Super elevation or Cant

BC - is the super elevation

W- axle load

P- centrifugal force

G- gauge of the track

F- Resultant of the two forces to pass through centre E of the track to load the two tracks equally

$$W \sin \theta = P \cos \theta$$

$$\tan \theta = \frac{P}{W}$$

Super elevation or Cant

Let v = speed of train in miles per hour/ km per hour
R = radius of the curve in ft or in meters
g = acceleration due to gravity
P = centrifugal force acting on the vehicle through its centre of gravity

Centrifugal Force is given by

$$P = \frac{WV^2}{gR}$$

Super elevation or Cant

Substituting the value of P in Eq. 1

$$\tan\theta = \frac{WV^2}{gR} \times \frac{1}{W} \qquad (2)$$

$$\tan\theta = \frac{BC}{AB} \qquad (3)$$

Substituting the value of $\tan\theta$ in Eq. 2

$$BC = \frac{V^2}{gR} \times (AB)$$

$AB \cong G$ (gauge of track)

BC= superelevation

$$e = \frac{GV^2}{gR}$$

Railway Super elevations with f=0

- Railway super elevation is normally designed so that f=0, if the curve is traversed at the design speed. The reason for this is that nonzero side forces may lead to binding of the flanges of the wheels against the rails.
- Moreover, lateral forces tend to force the track out of its alignment and gauge over the time.
- Consequently, the usual practice is to design for zero side friction.

Super elevations in terms of R and V

- Calculate the expressions for BG, MG, Standard gauge and narrow gauge track when speed is in miles per hour and R is in ft and super elevation is in inches

- 1 mile = 5280 ft
- g= 32.2 ft/sec^2
- Speed in ft/sce = 1.47 x speed in mph

Expression for BG, SG and NG

- e = 4.4 V^2/ R for BG
- e = 3.8 V^2/ R for SG
- e = 2.62 V^2/ R for MG
- e = 2.0 V^2/ R for NG
- R is in ft and speed in miles / hr and e in inches

Super elevations in terms of R and V

- Calculate the expressions for BG, MG, Standard gauge and narrow gauge track when speed is in km per hour and R is in m and super elevation is in cm.

Problem

- Find SE of a 3^o curve for a BG, MG, NG and SG track. The permitted speed is 50 mph.
- Find SE of a 4^o curve for a BG, MG, NG and SG track. The permitted speed is 60 km/hr.

Definition of Various Terms

- Cant/ Super elevation
  - Amount by which one gauge rail is raised above the level of the other for neutralizing the effect of centrifugal force. It is also called super elevation
  - It is positive when outer rail is above the inner rail and negative when inner rail is above the outer rail
- Equilibrium Speed
  - is the speed at which the vehicle is not subjected to any unbalanced centrifugal force.
  - Curve has a definite superelevation

Definition of Various Terms

- Super elevation Gradient
  - They indicate increase or decrease in super elevation.
- Rate of change of super elevation
  - The rate at which super elevation is decreased or increased relative to the maximum speed of the vehicle passing over transition curve.

Definition of Various Terms

- Super elevation Deficiency
  - When cant is provided for low speed and the train is moving at a high speed, the existing cant is not sufficient
  - Amount by which existing cant is less than the required to attain equilibrium (that is cant deficiency)
  - Outer rail will be stressed
- Super elevation Excess
  - When the super elevation is provided for high speed and there is excess for slow moving train
  - Heavy wear for inner rails

Disadvantages of Avoiding Super elevation

- Rapid wear of rails
- Forces the track out of alignment
- Possibilities of derailment

Negative Super elevation

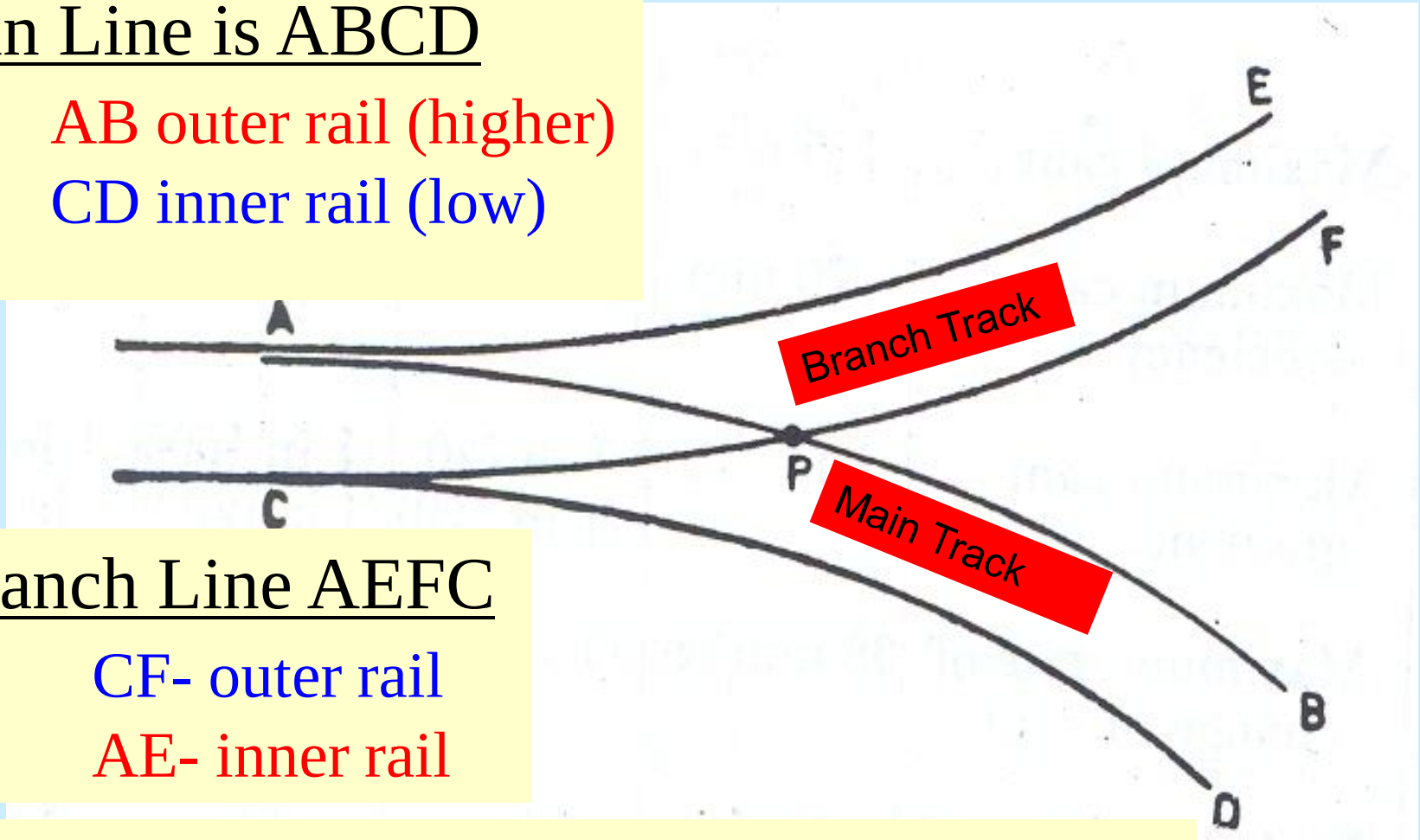
- When a branch line on the curve joins the main line
  - It is not possible to provide super elevation on the main line required for the design speed.
  - Thus negative super elevation is provided on the branch line
  - Reduction in super elevation on the main line

Negative Super Elevation

Main Line is ABCD

AB outer rail (higher)

CD inner rail (low)



Branch Line AEFC

CF- outer rail

AE- inner rail

Point C should be higher than A for Branch track but it is lower than A

Deficiency in Super Elevation and Negative Super Elevation

- When diverging track, curves in the direction opposite to that of the main curve, the superelevation necessary for average speed of the trains running over the main curve cannot be given.
- The speed of trains over the diverging track has to be considerably reduced, and the speed on the main track may also have to be reduced.
- The reason for these reductions is that, on the diverging track, the inner rail becomes higher than the outer rail.

Maximum SE permitted

For Pakistan

- BG – 6.5 inches
- MG- 4 inches
- NG- 3 inches

Max. Deficiency in SE without reduction in speed

BG- 3 inches

MG- 2 inches

NG – 2 inches

Problem

- A 6^o curve branches off a 3^o main curve in opposite direction in the layout of a BG track. If the speed on the branch track is restricted to 22 mph. Determine speed restriction on main line. Assume deficiency in super elevation is 3 inches.