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PUSAT KECEMERLANGAN KEJURUTERAAN DAN TEKNOLOGI JKR (CREaTE)

RAILWAY TRACK GEOMETRIC DESIGN

RAILWAY ENGINEERING INTERMEDIATE LEVEL COURSE

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RAILWAY TRACK GEOMETRIC DESIGN

CONTENTS:

- DESIGN FUNDAMENTAL
- HORIZONTAL CURVE DESIGN
- VERTICAL CURVE DESIGN

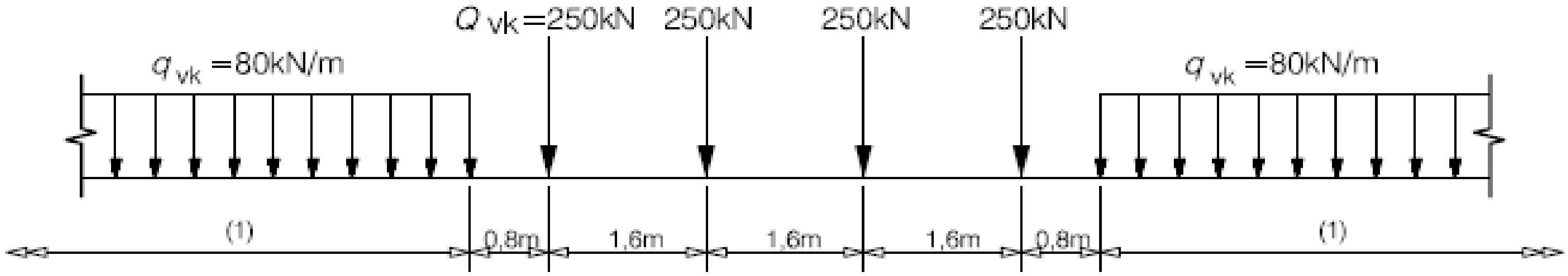
TRACK GEOMETRIC DESIGN FUNDAMENTAL

- ✓ **Safe to operate under all weather conditions**
- ✓ **Minimum costs for:**
  - Construction
  - Maintenance
  - Operation
- ✓ **Several critical design considerations**
  - Speed, type and volume of traffic
  - Space considerations (Right-of-Way)
  - Environmental concerns
  - Politics and land use issues
  - Other economic criteria

COMPARISON WITH HIGHWAY DESIGN

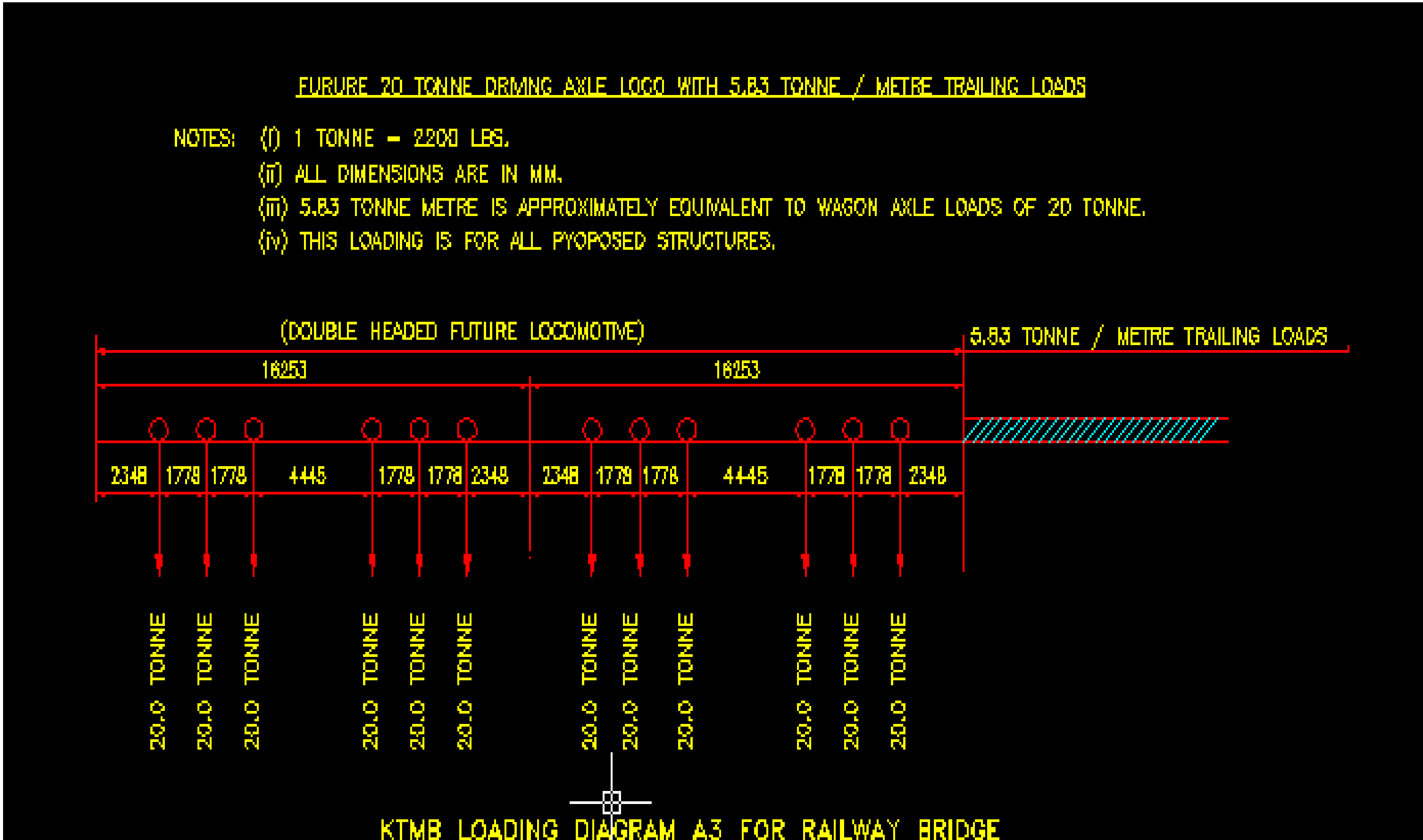
Highway	Railway
Operator has control over horizontal movement	**No control. Horizontal movement guided by rail**
Lower mass/power ratio	**Higher mass/power ratio – flatter grade required**
Gross weight Trucks/Lorries ~ Max 40 tonnes (5 axles) 8-9 tonnes/axle	**Gross weight locomotive 100-130tonnes. 20 tonnes/axle (M'sia) USA/Europe 30 tonnes/axle** **EMU 12- 14 tonnes/axle**
Less than 10m truck axles spacing	**~20m bogie centers – higher curve resistance**
Short stopping distance	**Long stopping distance** **-** Trains do not operate on mainline tracks by sight as road vehicles
Bigger tolerances and higher flexibility	**High speed trains require tighter tolerances in track alignment**
Usually single direction per lane	**Opposing trains may operate on same track**

DESIGN LOADING FOR RAILWAY BRIDGE

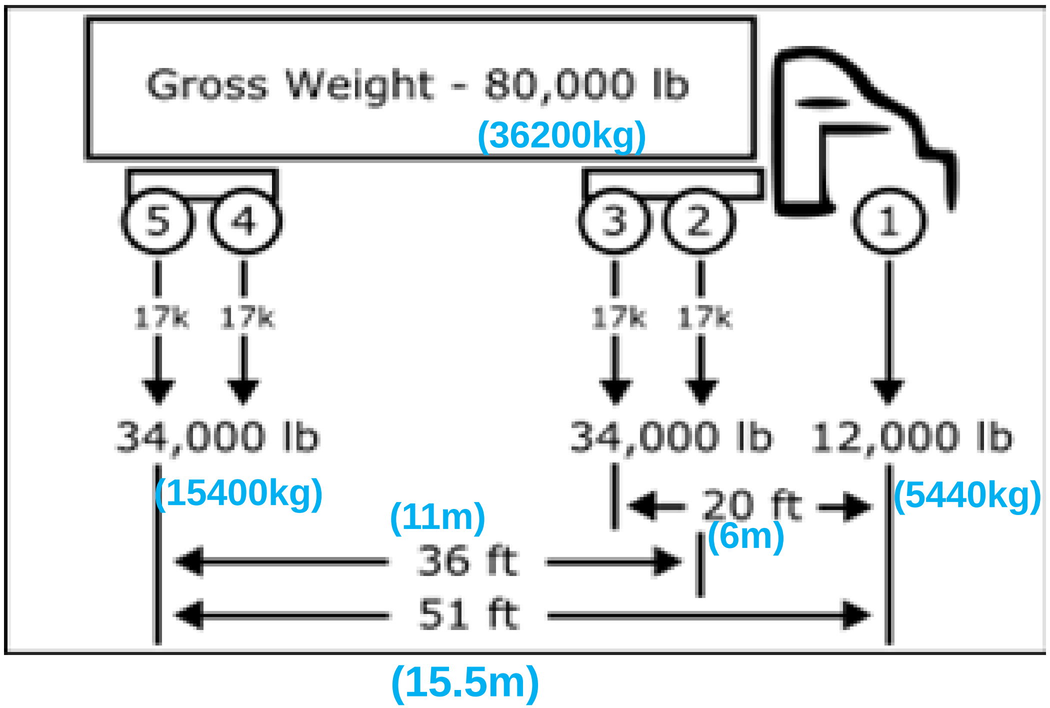


The characteristic values given in this figure of EN 1991-2 shall be multiplied by a factor *α* on lines carrying rail traffic which is heavier or lighter than normal rail traffic. When multiplied by the factor *α*, the loads are called "classified vertical loads". This factor *α* shall be one of the following: 0,75 - 0,83 - 0,91 - 1,00 - 1,10 - 1,21 - 1,33 – 1,46.
The value 1,33 is normally recommended on lines for freight traffic and international lines (UIC CODE 702, 2003). (for ULS)
The actions listed below shall be multiplied by the same factor *α* :
centrifugal forces
nosing force
traction and braking forces
load model SW/0 for continuous span bridges

KTMB DESIGN LOADING



COMPARED TO A TYPICAL TRUCK LOAD



- Lower axle load
- Closer axle spacing
- Smaller turning radius

➢ **For the railway, a bigger turning radius means a higher curve resistance**

TRACK GEOMETRIC DESIGN FUNDAMENTAL

- Horizontal curves shall consists of one or more circular curves of constant radius (having equal versines measured using chords of equal length)
- Each circular curve shall be connected to the adjacent curve or straight track with a transition curve (of a uniformly varying radius along its length)
- The length of the transition shall be calculated based on the required speed on the circular curve.

TRACK GEOMETRIC DESIGN FUNDAMENTAL

- **Horizontal alignments shall be designed to improve existing lateral structural passing clearances <u>wherever practicable</u> (with reference to kinematic envelope and loading gauge)**

- **Longitudinal rail levels shall be designed to improve existing vertical structural clearances and platform heights <u>wherever practicable</u> and shall not worsen them.**

TRACK GEOMETRIC DESIGN FUNDAMENTAL

- Each gradient shall be joined to the adjacent grade or level track by a vertical curve conforming to the operating railway requirements.

- The longitudinal levels of adjacent tracks shall be designed to ensure adequate ballast shoulders for stability

TRACK GEOMETRIC DESIGN FUNDAMENTAL

- Types of curves
- Curves Parameters
- Forces in curves

RAILWAY CURVES

Two Types of curves

Horizontal curves (curves in alignment)

Vertical curves (curves in the longitudinal profile)

NECESSITY OF CURVES

It is ideal to have a straight alignment. Straight alignment is always preferable. But curved alignment becomes inevitable when

- The stations to be connected may not lie on the same line.
- The line may have to avoid /need to go round built up areas, settlements, a lake or hillock or some such obstructions .
- In hilly country, a straight alignment would mean steep gradient, deep cuttings or costly tunnels. For eliminating these, curved are inevitable.

DISADVANTAGES

- Track on Curved alignment needs more maintenance effort .

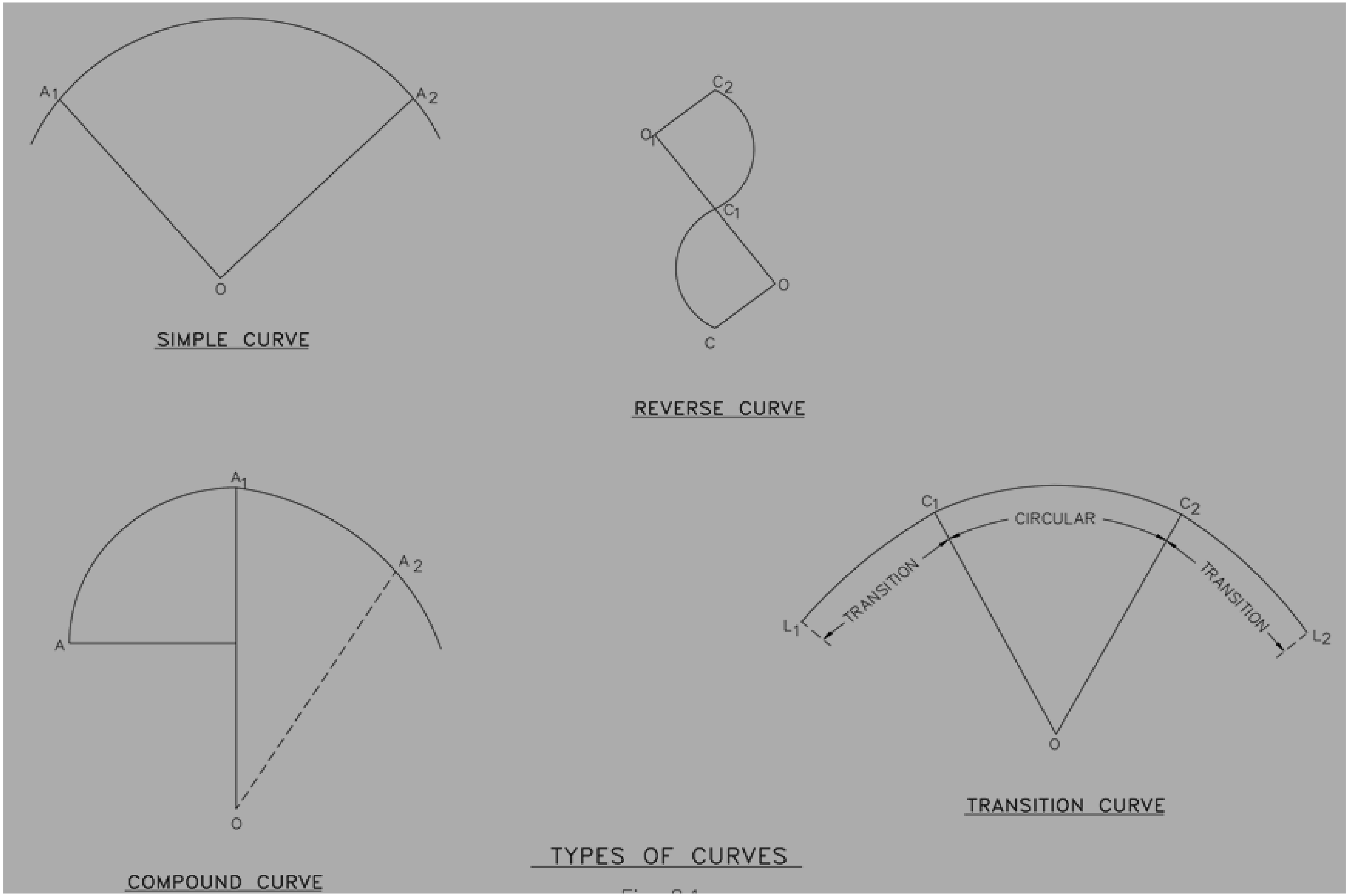
- Riding quality is affected along curved alignment unless the radius of the curve, the super elevation and the speed match.

- Wear and tear on the track and rolling stock increases due to additional forces on curved tracks

DISADVANTAGES

- Curved alignment has special features like cant (super elevation), transition, cant gradient etc which call for additional maintenance efforts .
- Wear of rail and Rail Contact Fatigue are more pronounced along curves.
- Unless the speed, the cant and the radius of curve matches, the running comfort are affected
- The margin of safety are comparatively less along curves

TYPES OF CURVES



DEGREE AND RADIUS OF A CURVE

- A circular is usually designated either by the length of its Radius or by its degree.
- Degree of curve is the angle subtended by an arc of 30.50 meters (100 feet) length, at the center of the curve
- Radius of the curve in meters =1750 /Degree of curve.
- Degree of curve = 1750 / Radius of the curve in meters.
- Radius of the curve in meters x Degree of curve = 1750.
- Degree of curve varies inversely as radius (the bigger the radius the less the degree of curve, the higher the degree the smaller the radius of the curve)

DEGREE AND RADIUS OF A CURVE

Examples :

I.**Conversion from Radius to Degree of curve.**

RADIUS IN METERS (GIVEN)		RADIUS	DEGREE OF THE CURVE
90	1750 /	90	19.40
200		200	8.75
450		450	3.89
810		810	2.16
875		875	2.00
1250		1250	1.40
1750		1750	1.00
2500		2500	0.70

II. **Conversion from Degree of curve to Radius of curve** :

DEGREE OF THE CURVE (GIVEN)		DEGREE	RADIUS OF THE CURVE IN METERS
0.70	**1750 /**	0.70	2500
1.00		1.00	1750
2.50		2.50	700
3.28		3.28	533
4.25		4.25	411.7
5.00		5.00	350
7.50		7.50	233
10.00		10.00	175
14.75		14.75	118.60
18.50		18.50	94.60
20.00		20.00	87.50

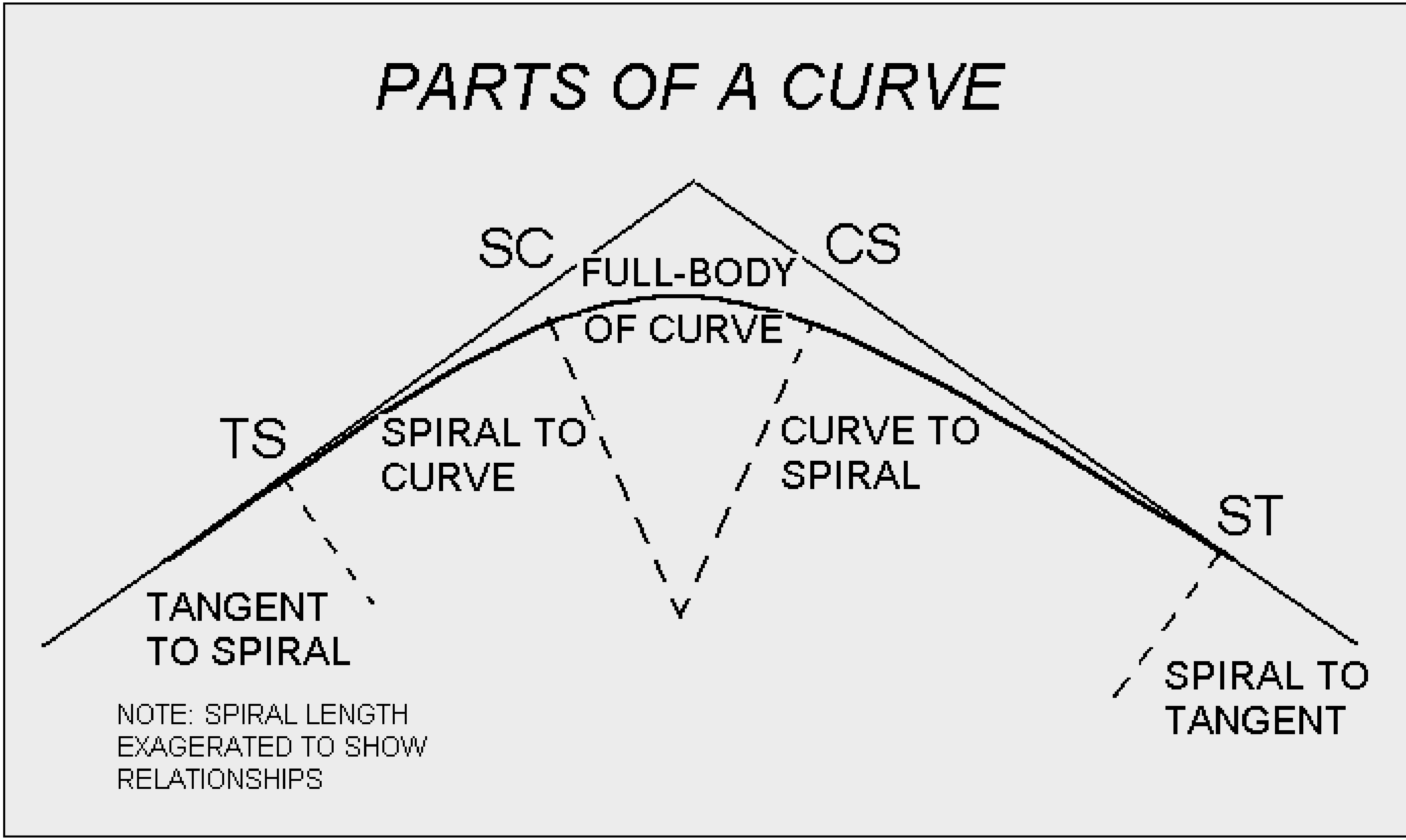
CURVE CHARACTERISTICS

- A constant radius (R) along the circular portion of the curves .

- Two transition curves one each on either end of the curve of radius from infinity to R.

- A constant superelevation (C_a) along the circular curve

- The superelevation changing from zero to the specified value (C_a) along the transition curve.

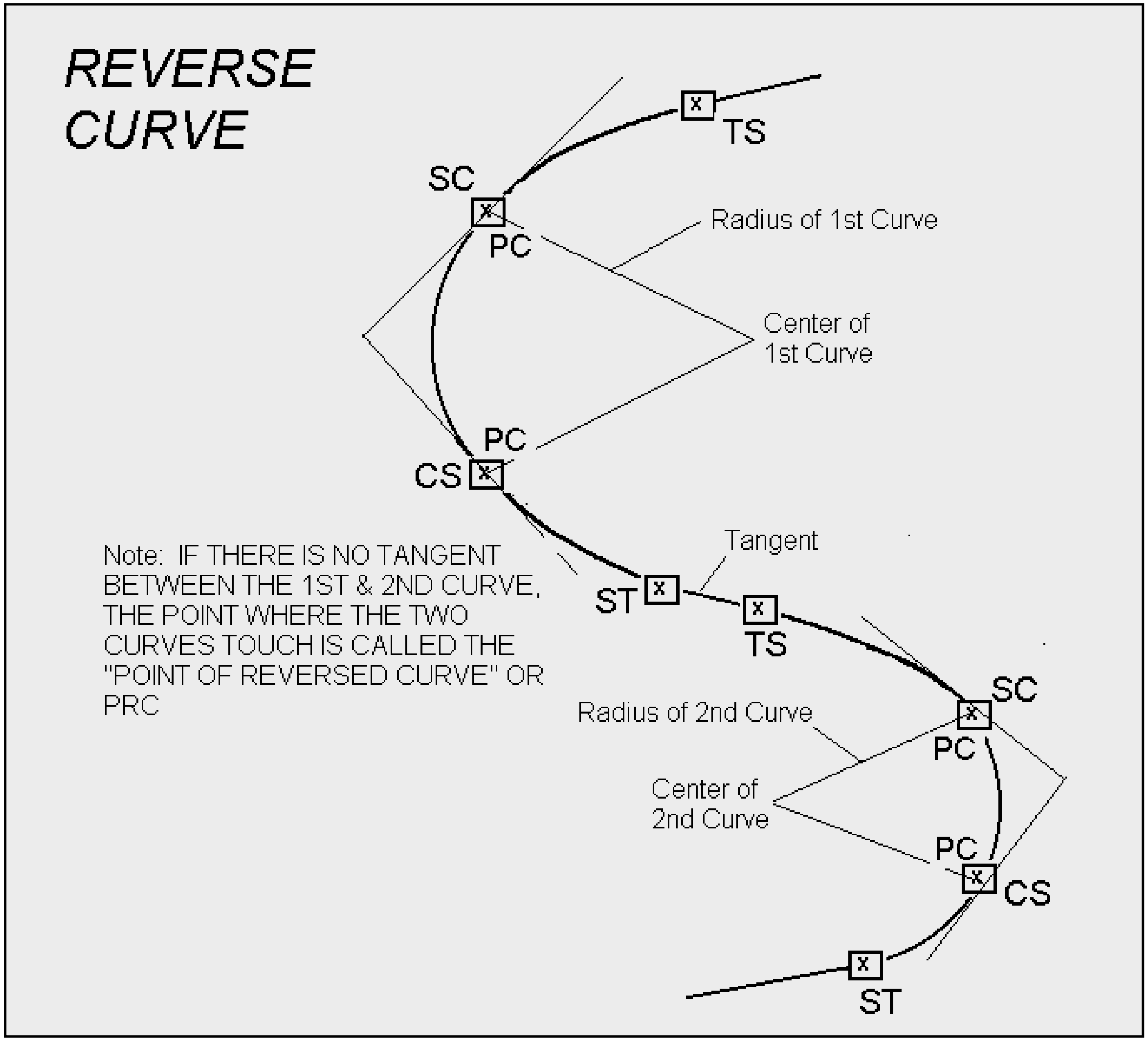


TS Tangent to Spiral

SC Spiral to Circular Curve

CS Circular Curve to Spiral

ST Spiral to Tangent



Note: Do not place a Point of Reverse Curve (PRC) on a track alignment – ensure a tangent (a straight track) is provided between reverse curves. The higher the speed of the track the longer this tangent needs to be.

REVERSE CURVE

- To be avoided
- Results in poor track-train dynamics
- Twist on track with reverse spiral requires high maintenance
  - Recommended 25-30m tangent to be provided
  - Greater than the length of longest rail vehicle that will traverse the curves
- The higher the speed of the track the longer this tangent needs to be.

SUPERELEVATION OR CANT

- **Superelevation or cant is the extent to which the outer rail on the curve is raised over the inner rail along the circular curve**
- **It is required along the curve to counteract or balance the effect of the lateral force on the train due to its movement along a circular path**
- **If superelevation is not provided, the lateral force is not balanced and causes discomfort to the passengers, besides resulting in unequal load on the inner and outer rails.** (To limit unbalanced lateral acceleration acting on passengers to 0.03 g per second) (**taken as $0.3 m/s^3$**)

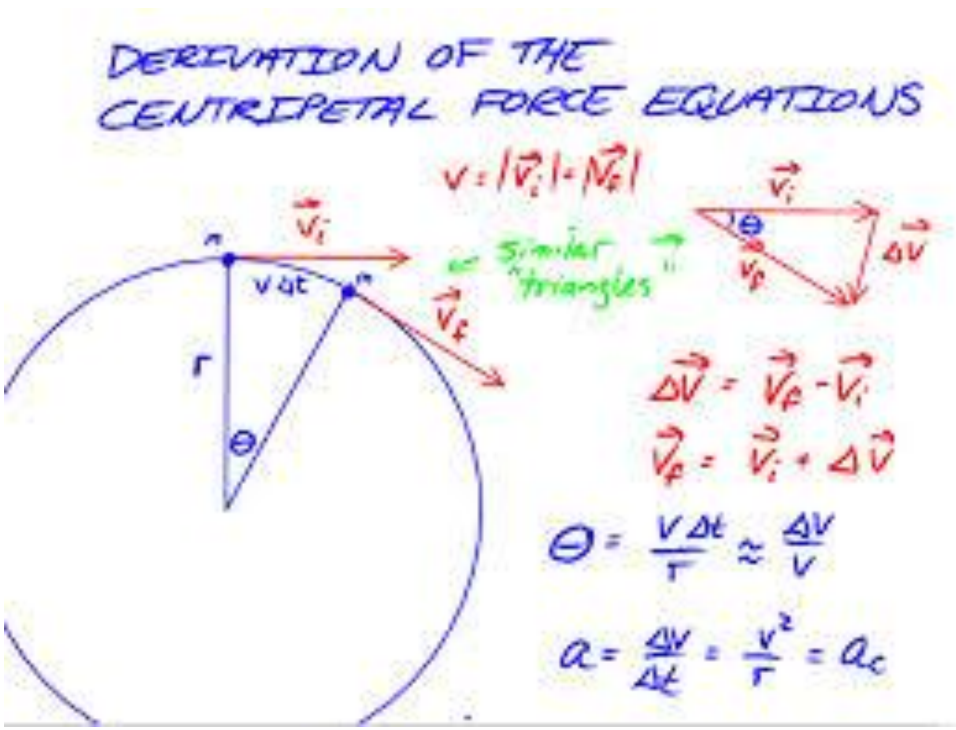
(How the cant balances the lateral force is explained in the forthcoming slides)

ACTUAL (APPLIED) CANT

Factors to consider in deciding actual cant

- Line speed limit
- Proximity of permanent speed restrictions, junctions and stopping places
- Track gradients
- Relative importance and types of traffic
- Limiting values of applied cant and cant deficiency
- Cant shall uniformly increase or decrease over the whole length of the transition curve between two circular curve or between a circular curve and a straight track (tangent track)
- It is good practice that cant be indicated on the track in steps of 5mm.

FORCES IN CURVES



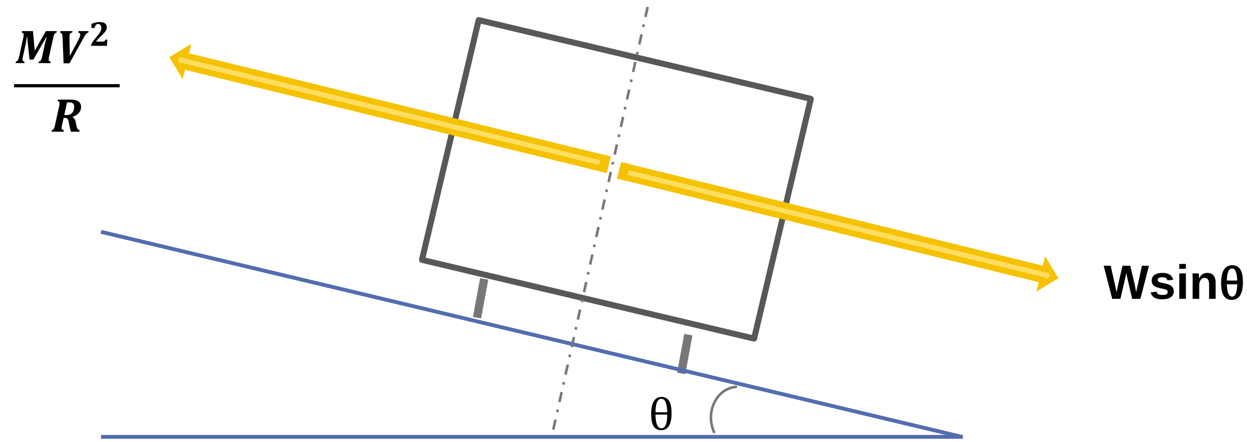
Centrifugal force experience by a vehicle in a curve = $\frac{MV^2}{R}$

<u>Equilibrium</u> is when centrifugal force
= centripetal force

= absence of lateral force, as if on a straight.

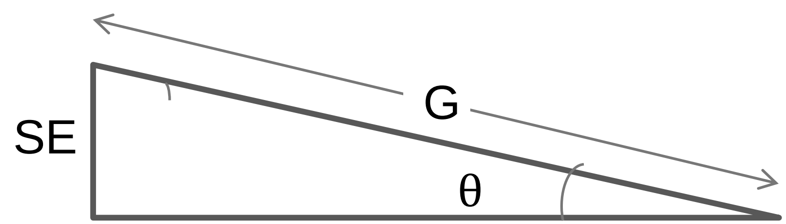
For small angle θ :
sin θ = θ
tan θ = θ
cos θ = 1

FORCES IN CURVES



$$W\sin\theta = \frac{MV^2}{R}$$

$$M * g\,\frac{SE}{G} = \frac{MV^2}{R}$$



Note: i) SE = Superelevation= Cant
ii) G = track dynamic gauge

Equilibrium Cant (C_{eq}) = SE $= \frac{GV^2}{gR}$

where G is in m, V in m/s and R in m. Cant and gauge in mm

EQUILIBRIUM CANT

Equilibrium Cant (C_{eq}) $= \dfrac{GV^2}{gR}$

If V is in km/hr, C_{eq} in mm and G in mm,

$$C_{eq} = \frac{(G)\,(V * (1000/3600))^2}{gR}$$

$$C_{eq} = \frac{GV^{\,2}}{127.14R}$$

SUPERELEVATION (CANT)

Difference in height between the inner and outer rail on a curve

- **Provided by gradually lifting the outer rail above the level of the inner rail**
- **Superelevation**

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

$G = gauge, V = velocity, R = radius\ of\ the\ curve$

- If V is in kmph and e is in cm,

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

EQUILIBRIUM CANT AND EQUILIBRIUM SPEED

- **Equilibrium cant = Cant at which there is equilibrium of the forces**
- **Equilibrium speed = The speed at which there is no unbalanced centrifugal force at the cant provided.**

SUPERELEVATION (CANT)

Superelevation for different gauges:

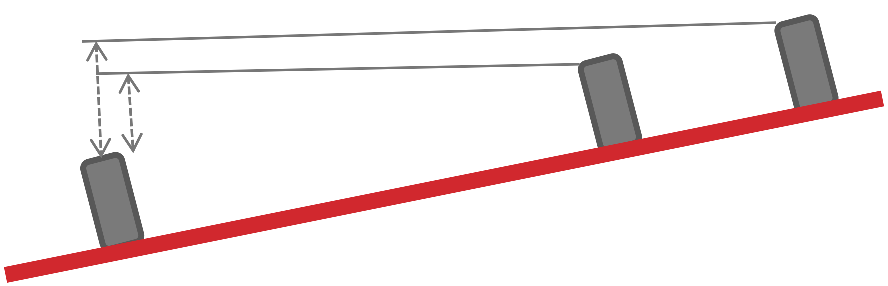
$$\text{For BG,}\quad SE\ (e) = \frac{v^2 \times 1.676}{1.27 \times R} = 1.315\frac{v^2}{R}$$

$$\text{For MG,}\quad SE\ (e) = \frac{v^2 \times 1.00}{1.27 \times R} = 0.80\frac{v^2}{R}$$

$$\text{For NG,}\quad SE\ (e) = \frac{v^2 \times 0.762}{1.27 \times R} = 0.60\frac{v^2}{R}$$

Maximum superelevation:

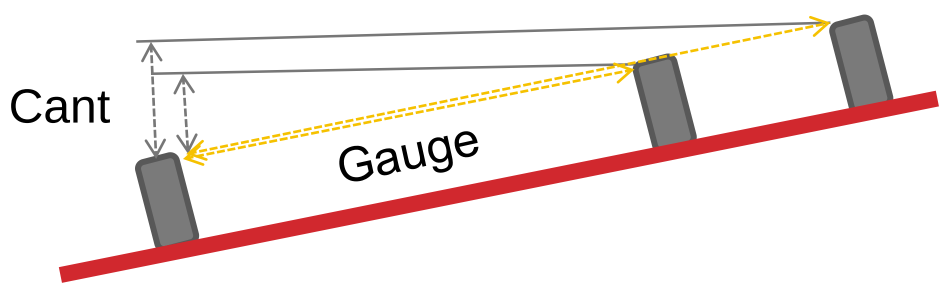
- **UK 190mm (SG)**
- **USA 150mm (SG)**
- **India/Bangladesh**
- **KTMB 100mm (MG)**



SUPERELEVATION (CANT)

Maximum superelevation:

- **UK 190mm (SG)**
- **USA 150mm (SG)**
- **India/Bangladesh 165mm (BG), 100mm (MG), 76mm (NG)**
- **KTMB was 90mm, now 100mm (MG)**



FACTORS TO CONSIDER

- Trains of various types and classes run at various speeds
- There may be lines where slow freight trains are predominant or vice versa, ie fast trains
- Track may have different speed limits
- There may be junctions and stopping places that affects speed
- Track gradient affect trains speed especially heavy freight trains

DETERMINATION OF ACTUAL CANT

The weighted average formula:

$$\text{Equilibrium Speed} = \frac{\sqrt{(F_1 N_1 S_1^2 + F_2 N_2 S_2^2 + F_3 N_3 S_3^2)}}{\sqrt{(F_1 N_1 + F_2 N_2 + F_3 N_3)}}$$

where,

F_1 = Factor of 4 for super fast trains with max. speed S1

F_2 = Factor of 3 for fast trains with max. speed S2

F_3 = Factor of 1 for goods trains with max. speed S3

N_1 = Number of super fast trains

N_2 = Number of fast trains

N_3 = Number of goods trains

DETERMINATION OF ACTUAL CANT

Optimum speed = Equilibrium speed

- Fast trains run smoothly without causing discomfort to the passengers,
- Slow trains run safely without derailment or overturning
- This equilibrium cant shall be adjusted if necessary so that the cant deficiency for the fastest train and the cant excess for slow trains are within limits (For KTMB, 70mm for cant deficiency and 65 mm for cant excess).

TERMINOLOGY

Equilibrium cant

- **Value of superelevation derived from the equation using equilibrium speed**

Cant deficiency (Cd)

- **Occurs when a train travels around a curve at a speed higher than the equilibrium speed**
- **Difference between cant required at travel speed and actual cant**
- **Maximum permissible Cd:**
  - IR 100mm high speed routes, 75mm (BG), 50mmm (MG), 40mm (NG)
  - BR 76mm (BG), 51mmm (MG), 38mm (NG)
  - KTMB 70mm (MG)
  - UK Jointed Track : 90mm; CWR : 110mm. (SG)

Cant excess (Ce)

- **Occurs when a train travels around a curve at a speed lower than the equilibrium speed**
- **Difference between actual cant and cant required at travel speed**

C (Theoretical Cant), C_a (Actual Cant), C_d (Cant Deficiency) and C_e (Cant Excess)

As trains travel at different speeds and also due the practical problems and limitations in providing and maintaining the calculated cant for the maximum speed, the actual cant (Ca) applied will be less than the cant (C) theoretically calculated for maximum speed. The difference between C and Ca is called cant deficiency (Cd).

The difference between the actual cant provided (Ca) and the theoretical cant required for a particular speed is called Cant excess (Ce). Ce is relevant for freight trains which usually run at lesser speeds.

Permanent Way Manual/Railway Operating Standards prescribes the maximum values for actual Cant (Ca) and cant deficiency (Cd) and cant excess (Ce). The designed maximum permissible speed has to satisfy these limitations .

MAXIMUM CANT DEFICIENCY

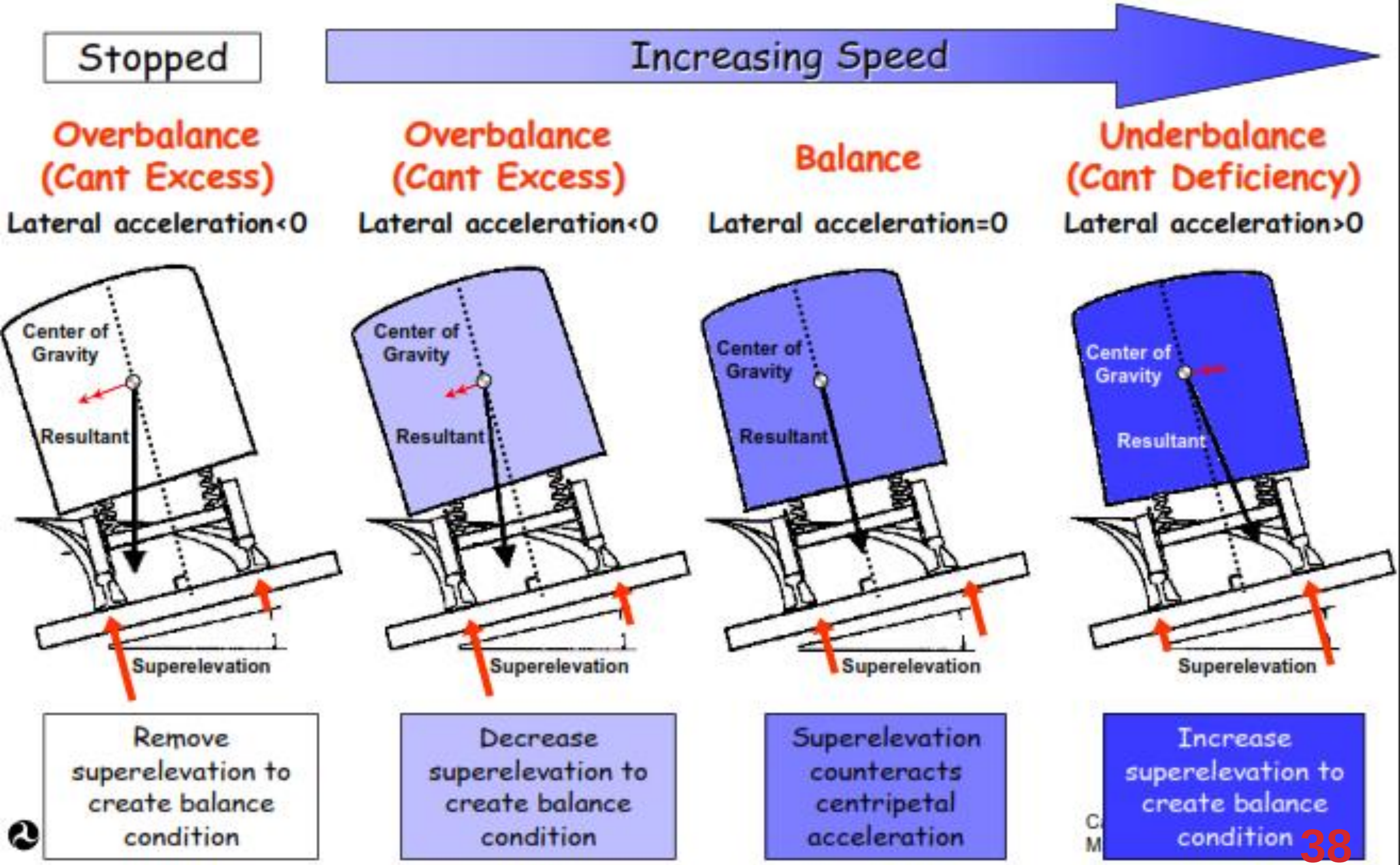
	Maximum Cant	Max. Cant Deficiency
France	160 / 180 * mm ~ 6 ¼ / 7 * inches	150 / 100 * mm ~ 6 / 4 * inches
Germany	180 mm ~ 7 inches	150 mm ~ 6 inches
Japan **	200 mm ~ 8 inches	unknown

* Paris-Lyon High-Speed Line ** Tokaido Shinkansen

For the calculation of maximum speed for KTMB Class 1 lines, maximum cant (C_a) of 100mm and the maximum permitted cant deficiency (C_d) of 70mm is used.

CANT EXCESS & CANT DEFICIENCY

SOURCE: US DOT VOLPE CENTER



What is the significance of Cant Excess, C_e ?

- When the cant actually provided (C_a) is more than theoretically required for that speed, the excess value is called Cant excess.
- Cant excess will also reduce comfort, like Cant deficiency .
- Cant excess will increase the load on the inner wheel and reduce the load carried by outer wheel. This condition will lead to greater wear of the inner rail .
- This unequal distribution of load between the inner and outer wheels will reduce the margin of safety ,as the outer wheel with lesser load tends to mount the rail, in combination with unfavorable features like surface unevenness on the outer rail.
- In order to prevent cant excess situation, the train speed shall not be less than the minimum designed speed .

EFFECT OF CANT DEFICIENCY ON TRAIN PERFORMANCE

Increase in lateral force exerted on track during curving

- Increased deterioration of track, lower safety margin for curving, and may result in unsafe wheel force conditions

Decrease in load on wheels on inside rail

- Increased risk of vehicle overturn, especially if high winds present

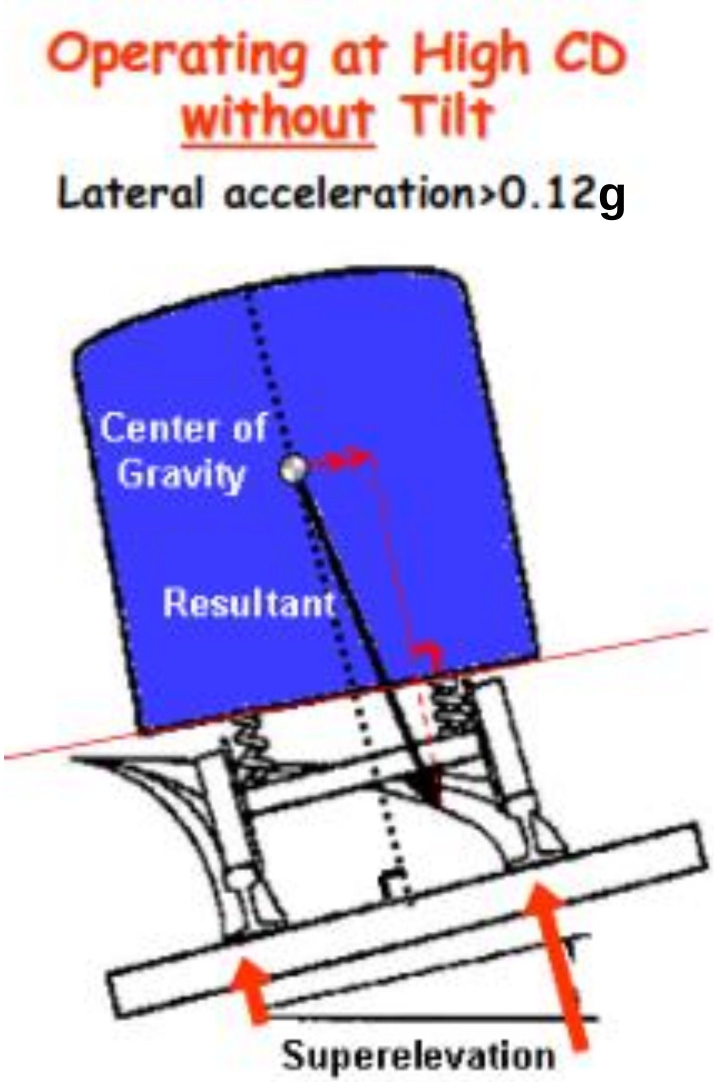
Reduction in margin of safety associated with vehicle response to track geometry variations

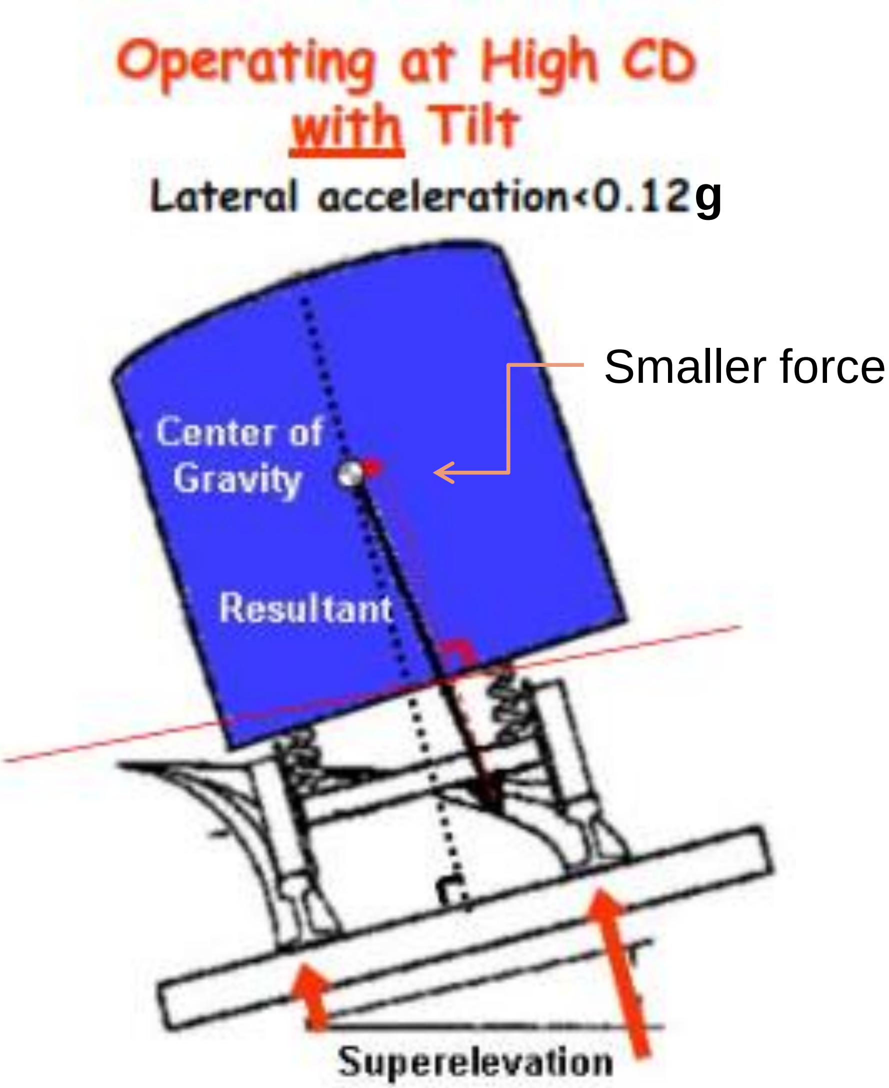
- Suspension elements operating at performance limits

Increase in resultant carbody lateral acceleration

- Decreased passenger ride comfort
- *Tilt can be used at high cant deficiency to reduce the net lateral acceleration experienced by the passengers*

TILTING TRAIN





SPEED AND RADIUS

Curve radius	≤ 33 m/s = 120 km/h	≤ 56 m/s = 200 km/h	≤ 69 m/s = 250 km/h	≤ 83 m/s = 300 km/h	≤ 97 m/s = 350 km/h	≤ 111 m/s = 400 km/h
Cant 160 mm, cant deficiency 100 mm, no tilting trains	630 m	1800 m	2800 m	4000 m	5400 m	7000 m
Cant 160 mm, cant deficiency 200 mm, with tilting trains	450 m	1300 m	2000 m	No tilting trains planned for these speeds		

AMERICAN GUIDELINE FOR MAXIMUM CURVATURE

➢ High Speed Passenger	1° Curve
➢ Main Lines – flat terrain	2° Curve
➢ Main Lines – hilly terrain	4° Curve (if possible)
➢ Branch Lines – 25 mph	8° Curve
➢ Yard Tracks	12° Curve (varies)

Over 13º curves may cause operational difficulties

Radius of the curve in meters =1750 /Degree of curve

DETERMINATION OF MAXIMUM SPEED

Based on the formula

$$C_{eq} = \frac{GV^2}{127.14R}$$

BS 80 A rail track (G = 1063.5 mm) C = 8.37x V^2/R ***(see next slide)***

UIC 54 kg track (G = 1070 mm) C = 8.42x V^2/R

For the calculation of maximum speed for KTMB Class 1 lines, maximum cant (C_a) of 100mm and the maximum permitted cant deficiency (C_d) of 70mm is used.

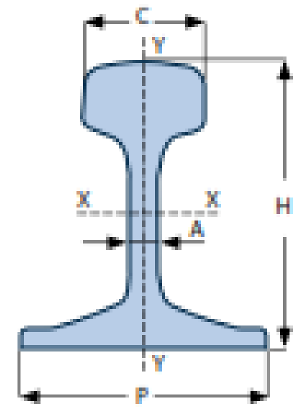
For 80 A rails:

$$V = [R\ (C_a+C_d)/8.37]^{0.5}$$

For 54kg rails and 60kg rails

$$V = [R\ (C_a+C_d)/8.42]^{0.5}$$

TECHNICAL DATA



EN13674-1 2011 Flat bottom rails >46kg/m

Rail profile	Equivalent profile name	Section weight kg/m	Rail height mm (H)	Head width mm (C)	Web thickness mm (A)	Foot width mm (P)	Moment of inertia, Ixx cm⁴	Moment of inertia, Iyy cm⁴
46E1	SBB I	46.17	145.00	65.00	14.00	125.00	1641.10	298.20
46E2	U33	46.27	145.00	62.00	15.00	134.00	1642.70	329.30
46E3	NP 46	46.66	142.00	73.72	14.00	120.00	1605.90	307.50
49E1	DIN S49	49.39	149.00	67.00	14.00	125.00	1816.00	319.10
50E1	U50E	50.37	153.00	65.00	15.50	134.00	1987.80	365.00
50E2	50EB-T	49.97	151.00	72.00	15.00	140.00	1988.80	408.40
50E3	BV 50	50.02	155.00	70.00	14.00	133.00	2057.80	351.30
50E5	50 UNI	49.90	148.00	67.00	14.00	135.00	1844.00	362.40
50E6	U 50	50.90	153.00	65.00	15.50	140.00	2017.80	396.80
52E1	52 RATP	52.15	150.00	65.00	15.00	150.00	1970.90	434.20
54E1	UIC 54	54.77	159.00	70.00	16.00	140.00	2337.90	419.20
54E2	UIC [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	341.50
54E3	DI[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	354.80
54E4	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	352.70
54E5	54[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	416.30
55E1	U3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	418.40
56E1	BS[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	421.60
60E1	UI[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	512.30
60E2	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	510.50

EN 13674-4:2006+A1:2009 (E) – Flat bottom rails 27kg/m to 46kg/m

Rail profile	Equivalent profile name	Section weight kg/m	Rail height mm (H)	Head width mm (C)	Web thickness mm (A)	Foot width mm (P)	Moment of inertia, Ixx cm⁴	Moment of inertia, Iyy cm⁴
35E1	Xa	35.76	125.00	58.00	12.00	110.00	936.30	174.50
36E2	36kg (S-40)	36.59	128.00	58.27	13.00	115.00	1020.10	202.70
39E1	BS 80A	39.77	133.35	63.50	13.10	117.47	1204.90	219.60
40E1	S41 R14	40.95	138.00	67.00	12.00	125.00	1366.90	262.10
41E1	S41 R10	41.24	138.00	67.00	12.00	125.00	1382.10	265.30
45E1	BS 90A	45.11	142.88	66.67	13.89	127.00	1564.10	284.70
45E2	DSB 45	45.51	141.00	69.30	13.76	126.00	1535.90	297.00

DETERMINATION OF CANT ACTUAL/CANT APPLIED

Given Data **: Radius = 790 meters , speed = 120 kph, Track with is MG with 54 Kg UIC rail, ,Max.Cd =70mm, Calculate Ca .**

V = 120 kph= 120000/3600 meters/sec = 33.33 m/sec

R = 790 m,G= dynamic gauge= 1070 mm, g= 9.81 m/sec^2

Substituting, C= Ca+Cd = G x V^2/ g.R

= 1070x 33.33x33.33 / 9.81 x790 = 153.4 mm

Ca = 153.4 -- 70 = 83.4 mm rounded off to 85 mm

Given Data **: Radius = 1140 meters , speed = 140 kph, Track with is MG with 54 Kg UIC rail, ,Max.Cd =70mm, Calculate Ca .**

CALCULATE THE MAXIMUM PERMISSIBLE SPEEDS ON THE FOLLOWING CURVES BASED ON THE DATA GIVEN:

Given Data : Radius = 340meters ,, Track with is MG with 54 Kg UIC rail, ,Max.Cd =70mm, Ca = 90 mm.= dynamic gauge= 1070 mm, g= 9.81 m/sec^2 .

Speed V is to be calculated

Substituting, C= Ca+Cd = 90+70= 160mm = G x V^2/ g.R .

hence V^2 = 160 x g.R / G = 160 x 9.81 x 340 /1070 = 498.75

V = (498.75)$^{1/2}$ = 22.333 meters/sec = 80.397 kph

Hence the maximum permissible speed or the speed potential of the curve

= 80.0 kph

Given Data : Radius = 1100meters ,Track with is MG with 54 Kg UIC rail, ,Max.Cd =70mm, Ca = 90 mm. G= dynamic gauge= 1070 mm,

g= 9.81 m/sec^2 .

Speed V is to be calculated

LINE SPEED

- **Line speed** is the maximum speed allowed on a particular route
- **Maximum permissible speed** is the speed permissible on a curve after considering the curve properties , ie cant, degree, cant deficiency etc. Where the maximum permissible speed is less than the line speed, then a Permanent Speed Restriction need to be imposed.

BREAK TIME....

THE NEED FOR TRANSITION CURVES

- **‘Transition’ means gradual changeover. A transition curve enables a gradual changeover from the straight (infinite radius) to a curve of definite radius (R).**
- **A transition curve differs from a circular curve in that its radius is always changing.**
- **If the transition curve is not provided the sudden change in the Radius of the alignment and consequent lateral acceleration will affect riding quality and cause discomfort to passengers apart from the additional forces on the track**

TRANSITION CURVES

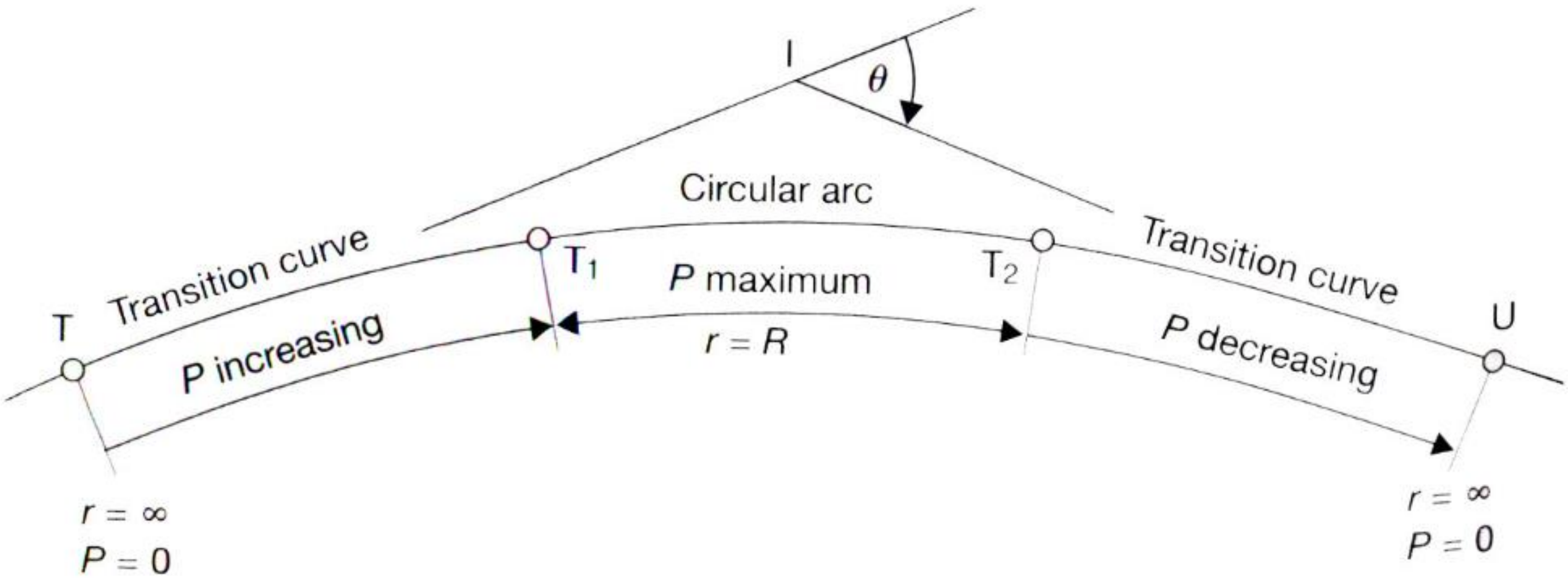
- Lateral acceleration depends on the radius and we do not want sudden change in lateral acceleration. Transition curve enables gradual change of radius from infinity along the straight to the definite value on the circular curve thereby ensuring smooth change of lateral acceleration.

- If transition is not provided ,the lateral acceleration from zero to the maximum value on the curve is deemed to take place over a length called 'virtual transition' which can go up to 13-15 meter for Meter gauge. Based on the length of virtual transition and the speed, the rate of change of lateral acceleration has to be checked

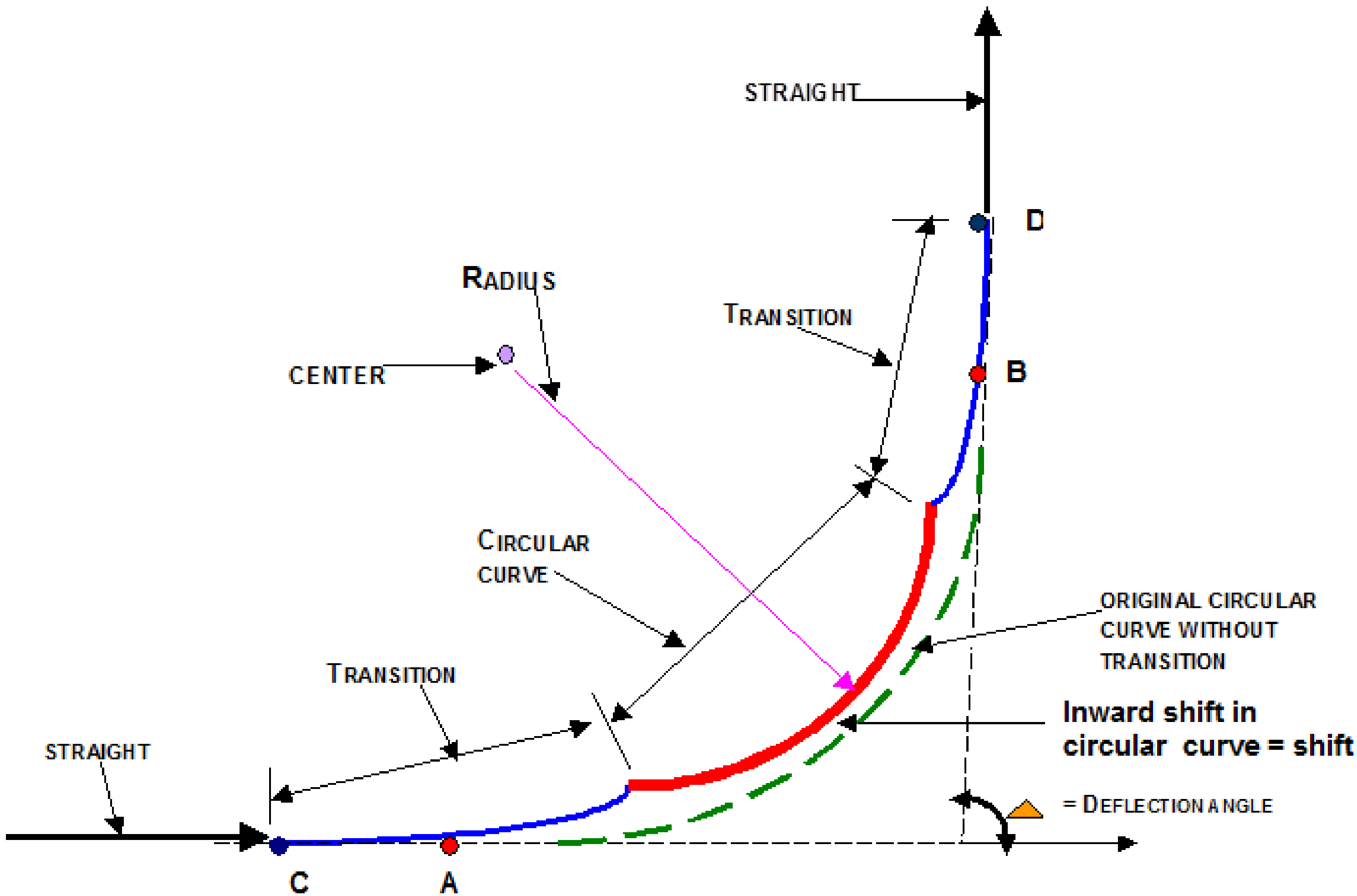
TRANSITION CURVES

- Transitions enables gradual increase of superelevation from zero mm on the straight to the specified value (C_a mm) along the circular curve .
- The above factors gain importance when the speed is high. Accordingly if the transition is not provided the speed may have to be suitably reduced.
- Transition curve is also necessary in a compound curve where a curve of smaller radius joins a curve of larger radius .
- The shape usually adopted for a a circular curve is a clothoidal spiral or a cubic parabola. For small angles of deflection both these curves are more or less the same. It is easier to calculate the offsets by adopting the cubic parabola.

TRANSITION CURVES



TYPICAL SHAPE OF A TRANSITIONED CIRCULAR CURVE CURVE
(not to scale)



Note that the simple circular curve AB becomes longer as CD, with transitioning at either end.

CIRCULAR CURVE SHIFT

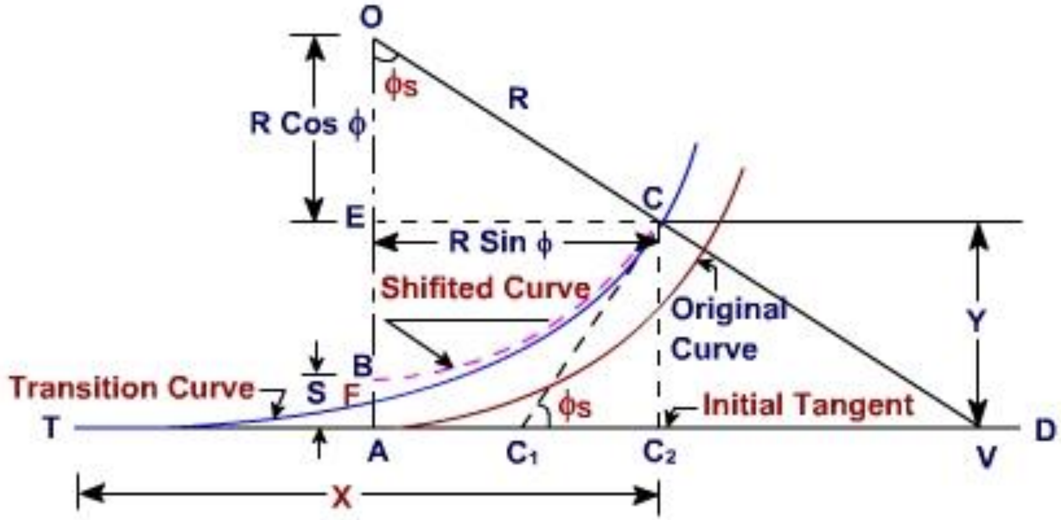


Figure 39.3 Details of a transition curve

TRANSITION CURVES

- **The mass of a vehicle is assumed constant and consequently:**

$$F \propto \frac{1}{R}$$

- **The smaller the radius of a curve the greater the radial force acting on the vehicle.**
- **Any vehicle leaving a straight section of track and entering a circular curve of radius R will immediately experience the full radial for F. If the radius is too small, or the speed too high, the force F will become too large, the vehicle will go off the track or overturn.** *(Recall the Spain train derailment 2013)*

SANTIAGO DE COMPOSTELA DERAILMENT
24 JULY 2013

- 79 died, 140 injured (Total 218 passengers and 4 crew)
- 250 m before the start of the curve the train (Hybrid) was travelling at 195 km/h and in spite of the emergency brakes being applied was still travelling at 179 km/h when it derailed 4 seconds later.
- Train was overspeeding, at about twice the posted speed limit of 80 km/hr
- The increased centre of gravity of the diesel units resulted in the overturn, showing clearly in the video clip. The radius of the curve was 350–400 m. On good mainline standards of 6 deg cant, it is good for 100 km/h service speed. With a centre of gravity 1000 mm above the railhead, the overturning speed is 200 km/h. With a centre of gravity 2000 mm above the railhead (quite likely for a diesel prime mover), the overturning speed moves down to 150 km/h.
- Older ASFA signalling system, which will warn drivers if they are exceeding speed limits, but will not automatically slow or stop a speeding train.
- The Spanish rail authority Adif subsequently installed three ASFA ("Automatic Braking and Announcement of Signals") balises on 1.9 km of the approach track
- Class Videos\Spanish Train Crash 3D Google Earth Animation.mp4

STEPS FOR CURVE DESIGN

1. **Determine the equilibrium speed for the section**
2. **Workout the equilibrium cant corresponding to the equilibrium speed**
3. **After finding out the equilibrium cant, the actual cant to be provided is fixed to satisfy the following conditions :**
   1. Maximum actual (or applied) cant is 90mm (100 mm for Rawang - Ipoh). Note that other railways have different norms.
   2. Cant deficiency (Maximum) - 70 mm
   3. Cant excess (Maximum) - 65 mm

STEPS FOR CURVE DESIGN

4. If the above limits cannot be fulfilled then the maximum speed on the curve has to be reviewed .
5. After knowing Ca, Cd and the maximum permissible speed on the curve, find out the transition length using the standard formula. (Explained in next slide)

Remember

$$F = MV^2/R$$

CALCULATING LENGTH OF TRANSITION (L)

The length of transition curve L depends on:

- **Actual cant, Ca mm**
- **Cant deficiency, Cd mm**
- **Max. cant gradient permitted, and**
- **Maximum permissible speed V in km/hr on the curve..**

These have to be first computed before calculating L .

CALCULATING LENGTH OF TRANSITION (L)

If L= length of transition curve in meters, adopt the maximum of the lengths obtained by applying the three formulae as under:

i. **L= 0.72Ca, (L=Ca in Rawang -Ipoh)**
ii. **L = 0.008 xCa xV , (0.005 xCa x V)in Rawang -Ipoh) ,**
iii. **L = 0.008 x Cd xV .**

The above formulae are based on the following criteria:

- Cant gradient shall not exceed 1 in 720 (preferably 1 in 1000)
- The rate of change of actual cant or cant deficiency shall not exceed 35 mm / sec (55 mm /sec for Ca in Rawang –Ipoh)

Note: If these criteria changes, the formula will change accordingly

SHIFT OF CIRCULAR CURVE

- If a transition curve has to be introduced the entire circular curve has to be shifted laterally towards the center of the curve by a small distance known as SHIFT. Shift value = L2 / 24 R, where L= length of transition curve , R= Radius of the circular curve
- Because of this shift of track, the formation of track has to be widened as necessary towards the centre of the circular curve .

SHIFT OF CIRCULAR CURVE

A39.3 Transition curve.swf

Class Videos\Curve shift\A39.3 Transition curve.swf

SHIFT OF CIRCULAR CURVE

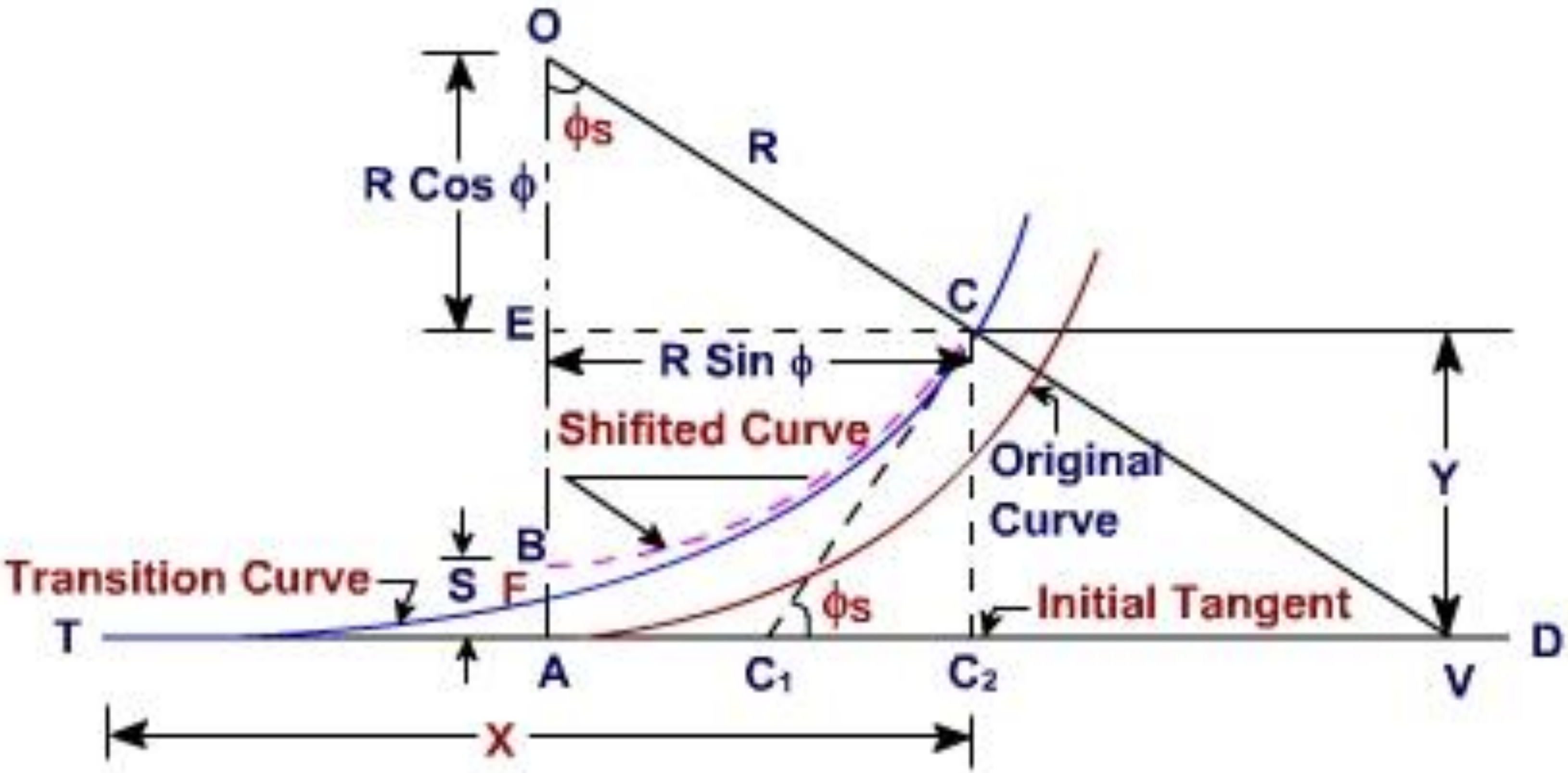


Figure 39.3 Details of a transition curve

TRANSITION CURVES

Cubic parabola is usually adopted for transition curve.

Formula $Y = X^3 / 6RL$

where

Y= offset from the straight, X= distance measured along the straight from the start of the transition,

R= radius of the circular curve and

L= length of the transition curve.

WORKED OUT EXAMPLES

RAWANG - IPOH project

Data given:

Dynamic gauge = G= 1070 mm

Maximum permissible speed = 160 kph

Actual Cant = super-elevation (Max) = Ca = 100mm

Cant deficiency (Max)= Cd = 70 mm

Cant Excess (Max) = Ce = 65 mm

Slow train (Freight train) minimum speed for computing cant excess taken as 80 kph

Equilibrium speed =V kph= 105 kph (based on the adopted formula)

Radius of the circular curve = R = 670 meters

Length of the circular curve = 545 meters

Rawang -Ipoh Project

To find out actual cant to be provided .

i) Calculate equilibrium cant :
Equilibrium cant = 8.42 x V^2 / R = 8.42 x 105 x105 / 670= 138.55 say 139mm>100mm
Hence provide a cant of 100 mm, as that is the maximum cant permitted

ii) Check for cant excess :
speed of slow train = 80 kph
Cant needed for 80 kph = 8.42 x 80 x 80 / 670 = 80 mm
Cant provided = 100 mm
Hence, cant excess = 100 – 80 = 20 mm less than 65 mm **which is OK**

iii) Check for Cant deficiency:
Cant needed for the design speed of 160 kph = 8.42 x 160x160 / 670= 322 mm
Cant deficiency (max) = 70 mm
Hence cant to be provided = 322-- 70 mm = 252 mm which is >100 mm.
Therefore **160 kph speed is not feasible on this curve**
iv) To Find out the maximum permitted speed :
Actual cant = 100 mm = Ca
Max.Cant deficiency allowed = 70 mm= Cd
Max. permitted speed = V max kph . Formula Ca +Cd = 8.42 x $V\ max^2$ / R
100 +70 = 8.42 x $V\ max^2$ / 670
$V\ max^2$ = (100 +70) x 670 / 8.42 = 13527 **V max = $(13\ 527)^{1/2}$ = 116 kph**
Therefore speed on this curve has to be restricted to 116 kph in order not to exceed the maximum permitted cant deficiency of 70 mm.

SOLUTION :
Provide an actual cant of 100 mm and restrict the speed to 116 kph so that
Cant deficiency does not exceed 70 mm
Cant Excess (Max) is within 65 mm

Rawang- Ipoh Project

Calculation for transition curve.

i) Length of transition curve in meters is the maximum of

L = Ca, L =(0.005 xCa xVmax) , L = 0.008 xCd x Vmax
Ca = 100mm , Cd = 70 mm L is max. of 100 or 0.005 x 100 x116 or 0.008 x70 x 116
L in meters is maximum of 100 meters , 58 meters , 65 meters ie **100 meters**
Cant gradient provided is 100mm in 100,000 mm = **1 in 1000**

ii) Inward Shift of the transition curve :

Shift = L^2 / 24R = 100 x 100 / 24 x 670 = **0.622 meter**

Rawang - Ipoh Project- worked example

iii) Offsets for setting out the transition curve:

Formula $Y = X^3 / 6RL$ = $x^3 / 6x670x100$ where

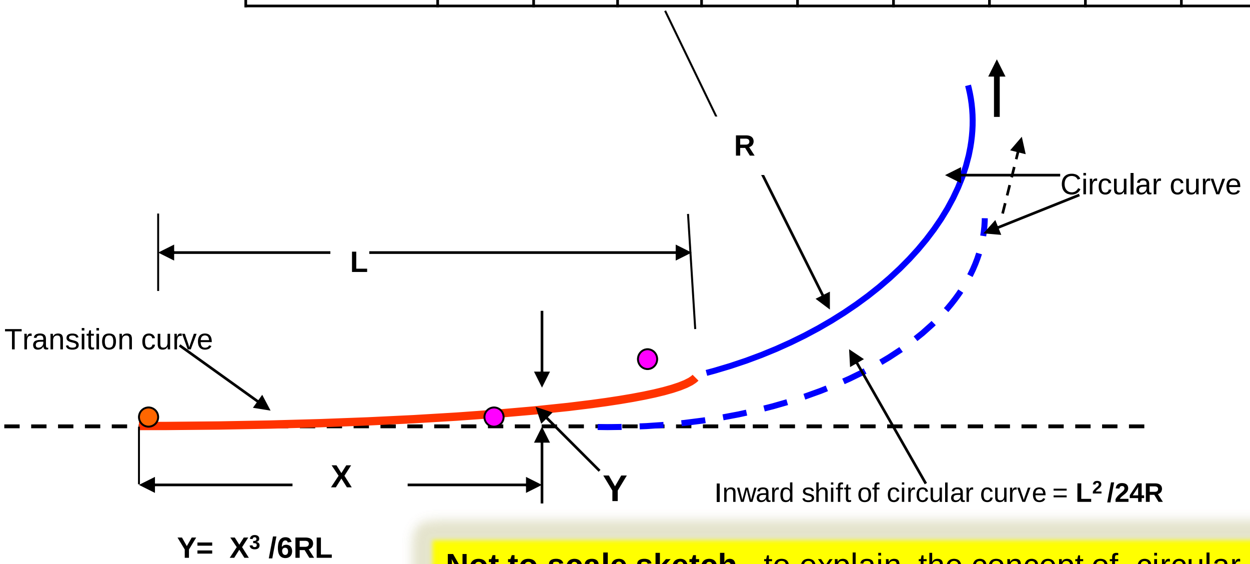
Y = offset , X = distance measured from the start of the transition curve

R= radius of circular curve = 670 meters , L= length of transition curve = 100 meter.

If all units are in meters, the offset will be in meters .

(In the table below, the figures obtained has been multiplied by 1000 to get the value in mm)

Length along trans. curve in meters	10	20	30	40	50	60	70	80	90	100
Offset in mm	2.5	20	67	160	311	537	853	127 4	181 3	2488



Not to scale sketch, to explain the concept of circular and transition curve. Please note that introduction of transition curve

a)shifts the circular curve inwards.

b)reduces the original length of circular curve.

c)reduces the length of the straight alignment also.

Rawang -Ipoh Project

To achieve 160 kph speed, what should be the minimum radius of circular curve?

Data given:

Dynamic gauge + 1070 mm
Maximum permissible speed = 160 kph
Actual Cant = super-elevation (Max) = Ca = 100mm
Cant deficiency (Max)= Cd = 70 mm
Cant Excess (Max) = Ce = 65 mm
Slow train (Freight train) minimum speed for computing cant excess taken as 80 kph
Equilibrium speed =**V kph** = 105 kph (based on the adopted formula)
Radius of the circular curve = **R** = **to be calculated**

Provide a cant of 100 mm, as that is the maximum cant permitted
Cant provided = Ca= 100 mm
Cant deficiency (max) = Cd = 70 mm
Hence cant for working out minimum radius = 100 +70 = 170 mm
Apply f **Formula Ca +Cd = 8.42 x V max^2 / R**
100 +70 = 170 mm = **8.42 x 160x160 / R**
minimum radius R= 8.42 x 160x160/ 170 = <u>1268 meter</u>
On circular curve with radius less than <u>1268 meter</u> we cannot permit speed of 160 kph

ii) Check for cant excess :
speed of slow train = 80 kph
Cant needed for 80 kph = 8.42 x 80 x 80 / 670 = 80 mm
Cant provided is 100 mm
Hence, cant excess = 100 – 80 = 20 mm less than 65 mm **which is <u>OK</u>**

Cant excess condition is also satisfied.

Calculations of maximum and minimum speed

Conditions to be satisfied:
Cant deficiency of max.70 mm and the
Cant excess of max. 65 mm, are not to be exceeded.

Basic Formula
Theoretical cant in mm = 8.42 x V^2 / R (for 54 kg rail with G= 1070 mm)
R = Radius in meters , V= speed in kph

Data given :
Applied cant = 100 mm which is also the actual cant
Cant deficiency = Cd (max) = 70 mm
Cant excess (max) = 65 mm

For calculating maximum speed, the max cant deficiency is the governing factor.
Hence theoretical cant in mm = (actual cant +70)= 100 +70= 170.

For calculating the minimum speed, the cant excess is the governing factor.
Hence theoretical cant in mm = (actual cant -- 65) = 100-- 65 = 35

The following table shows the speeds worked out accordingly:

Radius of curve meters	Maximum speed of train in kph so as not to exceed the Cd (Cant deficiency) of 70 mm	*Minimum speed of train in kph ,so as not to exceed the Cant excess of 65 mm	Remarks
1200 meters	155.60	70.60	We have to operate in this speed range.
800 meters	127.00	57.60	
600 meters	110.00	49.90	
400 meters	89.83	40.76	
200 meters	63.50	28.82	

If the actual or applied cant is different, the above speeds will be different.

NEGATIVE CANT

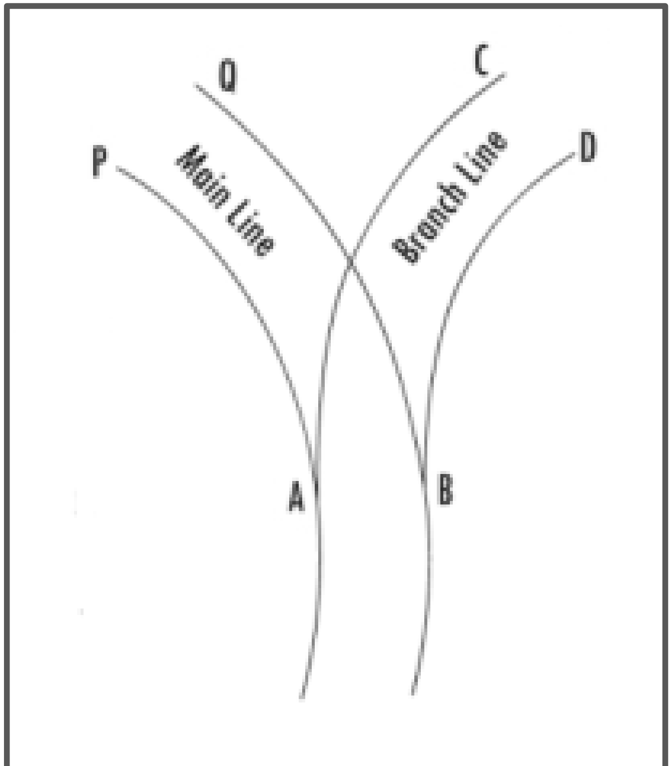
Which rail is higher?

Outer rail Main Line or Outer rail Branch Line?

How do you calculate the maximum speed for both line?

Note:

The maximum negative cant shall be 20 mm with a maximum speed of 25 km/hr. Above 25 km/hr, no negative cant is to be used.



Contra-Flexure Turnout
Contra-Flexure Curves

CONTRA FLEXURE & NEGATIVE CANT

Procedure for finding respective speeds on main and branch lines will be as follows:

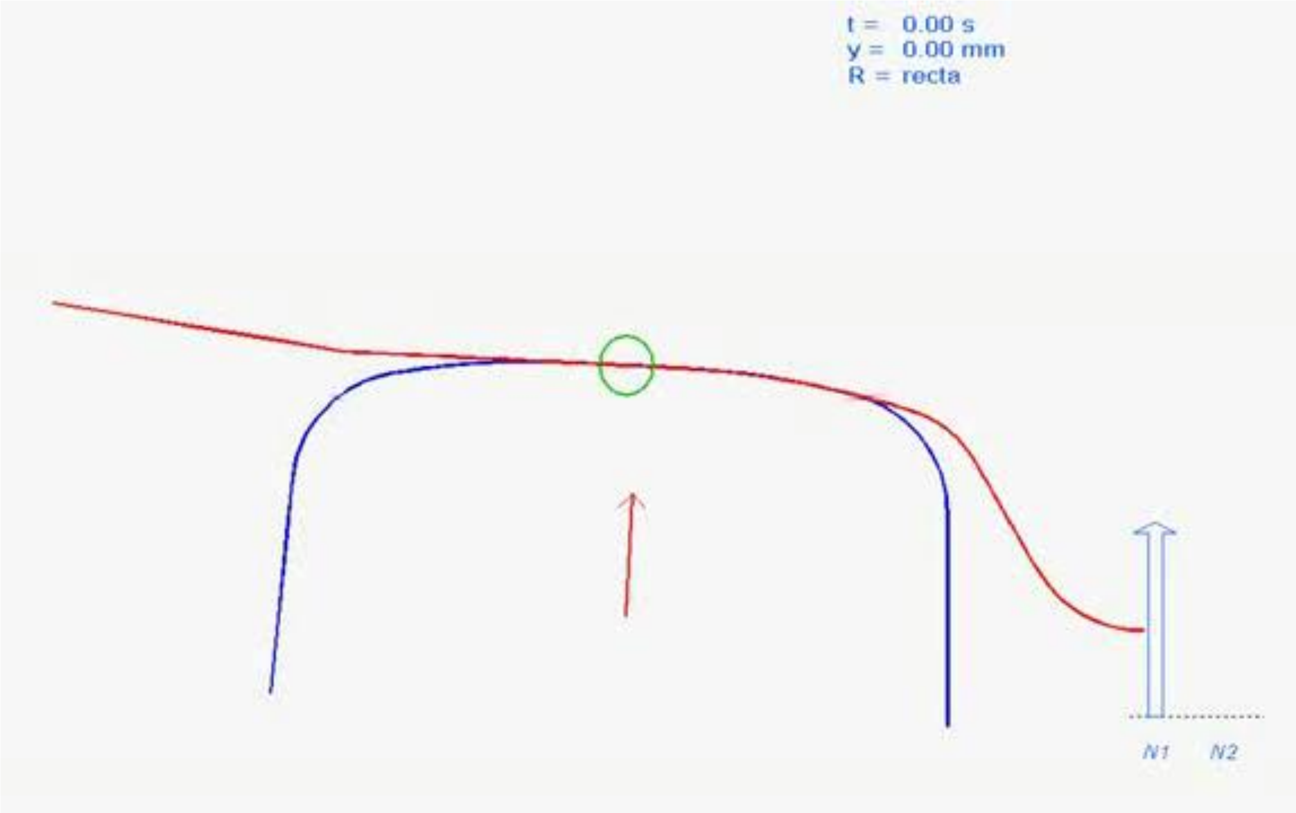
- The equilibrium cant on branch line is calculated by usual formula by assuming suitable speed on branch line.
- The permissible cant deficiency is deducted from the equilibrium cant.
- The result thus obtained will represent the negative super-elevation to be given on the branch line.
- Evidently, the negative cant on branch line will be equal to the maximum cant permitted on the main line.
- Permissible cant deficiency is added to the maximum cant permitted on the main line and correspondingly, the restricted speed on main line is worked out.

EXERCISE
CONTRA FLEXURE & NEGATIVE CANT

Refer to Handout (Calculation of speed and Cant)

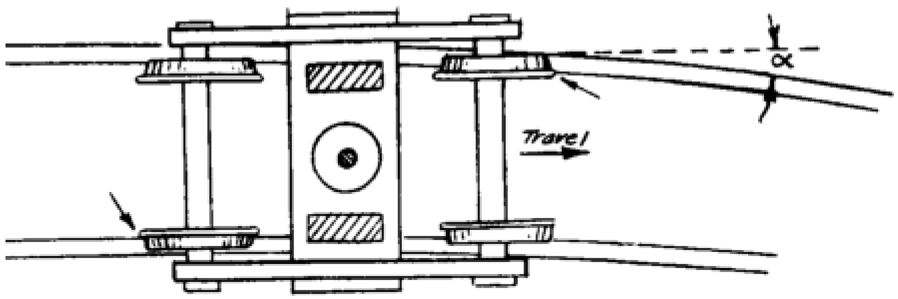
WHEEL/RAIL CONTACT

WHEEL-RAIL ELASTIC CONTACT SIMULATION IN CURVE



WHEEL RAIL CONTACT IN REVERSE CURVE

As the rail vehicle leaves the first curve, the guiding effect of the track is acting to counter the centrifugal force until such time that the first wagon exits the curve. The rotational momentum about the vertical axis of the vehicle will generally force the restraining effect from the outside rail to the inside rail immediately after exiting the curve.



Angle of Attack

The reversing curve will cause a sudden and abrupt force acting to change the rotation of the vehicle in the other direction. This sudden reversing of direction causes excessive horizontal forces across the rail at the wheel/rail interface, which can be a derailment hazard.

REVERSE CURVE

AREMA Manual for Railway Engineering strongly recommends at least one car length worth of distance between reversing curves.

For passenger traffic, the generally accepted criteria is a tangent in length representing two seconds of travel time (some railways prefer three seconds).

The Transportation Research Board (TRB) Track Design Handbook for Light Rail Transit recommends a desired tangent length between curves of 300 feet, with an absolute minimum of 100 feet. For lead tracks and industrial spurs, a minimum tangent distance of 50 feet should be provided between curve points. All turnouts should be located on tangents.

VERTICAL CURVES

VERTICAL CURVES

In a vertical curve, the force a train exerts on the track changes. Too tight a 'crest' curve could result in the train leaving the track as it drops away beneath it; too tight a 'trough' and the train will plough downwards into the rails and damage them. More precisely, the support force *R* exerted by the track on a train as a function of the curve radius *r* is given by

$$R = mg \pm \frac{mv^2}{r}$$

positive for troughs, negative for crests, where *m* is the mass of the train and *v* is the speed in m/s. For passenger comfort the ratio of the gravitational acceleration *g* to the centripetal acceleration v^2/r needs to be kept as small as possible, else passengers will feel large 'changes' in their weight.

VERTICAL CURVES

- **Vertical curves enables smooth changeover of the direction of train in the vertical plane at the vertical intersection points (VIP) i.e. at the junction of the grades.**
- **Vertical curves can be circular or parabolic in shape.**
- **Vertical curve is necessary at the locations where the change in gradient (algebraic difference between the adjoining gradients) exceeds 0.40 % (as per the KTMB Permanent Way Manual)**

VERTICAL CURVES

Vertical curve becomes necessary at the change of Gradients (both sags and summits) when the gradient difference exceeds 0.4 % (1 in 250).

Consideration:

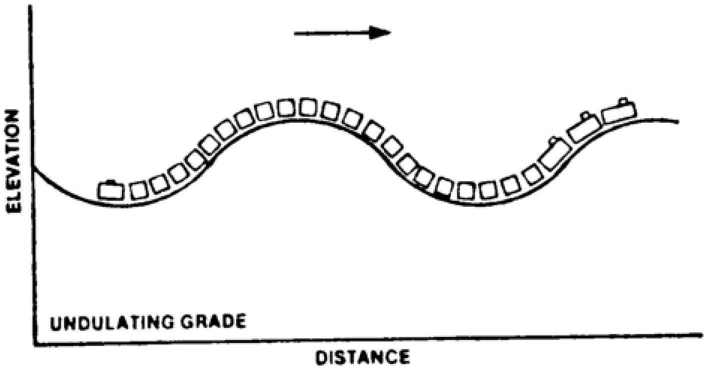
- **The change in grade must ensure smooth running of the train.**
- **The vertical acceleration experienced by passengers must be limited to a comfortable level. The upper limit is 0.03g where g = acceleration due to gravity**
- **Avoid bunching of wagons in a sag or variation in the tension of couplings on a summit.**

VERTICAL CURVES

- KTMB specify minimum vertical curve radius of 5000m

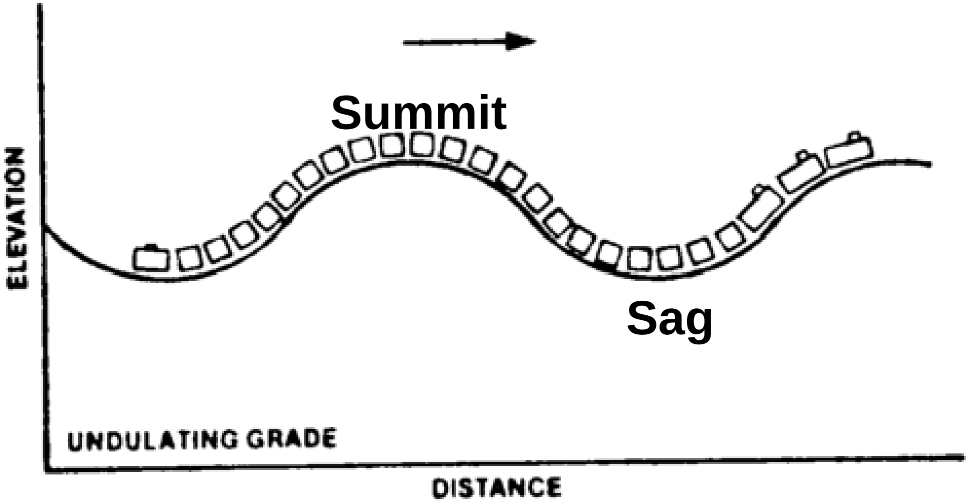
- High Speed 1 in the UK has a minimum vertical curve radius of 10000m. High Speed 2, with the higher speed of 400 km/h, stipulates much larger 56000m radii. In both these cases the experienced change in 'weight' is less than 7%.

- Australia:
  - Sags 24,900m Max 2,660m
  - Summits 12,450m Max 1670m



VERTICAL CURVES

Reversing curves should be avoided at all costs. With reverse curves, there are two dynamic components acting on a single car or rail vehicle causing a yawing effect, which is of concern. (bunching effect, pull-apart, train buckling, coupler facing)



RULING GRADIENT

- Ruling gradient is the steepest gradient in the section for which the line was designed.
- Ruling gradient determines the maximum load of the train which a locomotive can haul in the section.
- Where a highway in mountainous areas may have grades of 6% to 8 %, a railway grade may only be 1.5% or up to around two percent.

EFFECT OF GRADIENT

The effect of grades on train operations is significant. For each percent of ascending grade, there is an additional resistance to constant-speed movement of 20 lbs. per ton of train. This compares with a resistance on level, straight track of about 5 lbs. per ton of train. A given locomotive, then, can haul only half the tonnage up a .25-percent grade that it can on the level. Descending grades carry their own penalties in the form of equipment wear and tear and increased fuel consumption.

EXPRESSING GRADIENT

Gradient is expressed as a fraction or ratio, or percentage.

Example:

0.25 % = 0.25 /100 = 1 in 400

1 % = 1 /100 = 1 in 100

2.5 % = 2.5 /100 = 1 in 40

1:200 = 1/200 = 0.5 %

GRADE COMPENSATION

- The load the locomotive can haul depends on the gradient .
- On a curve, the force needed to overcome curve resistance, is equated with additional load on the train.
- Hence if there is a curve on a gradient, while designing and constructing the line, the actual gradient is reduced to compensate for the curve resistance.
- Alternatively, the equivalent gradient is obtained by adding the curve resistance component to the actual gradient
- On KTMB meter gauge the grade compensation to be provided on curves is <u>0.03 % per degree of curve</u>

GRADE COMPENSATION

- **On KTMB meter gauge the grade compensation to be provided on curves is <u>0.03 % per degree of curve</u>**
- **In Indian Railways:**
  - BG 0.04 %
  - MG 0.03 %
  - NG 0.02 %
- **See worked example in Handout (Geometric Design of Track)** *(See in Technical reference folder) (Also see Track Geometry Section 5 ARTC)*
- **ARTC : Curve compensation can be calculated empirically by:**
  - n = 1.65R

    Where R is the curve radius in metres and n is the equivalent gradient 1 in "n“
- **Grade should be calculated over the length of the train. Characteristics of the traffic should be considered when selecting grading.**

GRADE COMPENSATION

3.7.1 PROPOSED AREMA STANDARDS FOR COMPENSATED GRADIENTS (1999)

a. Compensation of gradients due to horizontal curvature is recommended on all gradients, but is essential on ruling gradients.

b. The purpose of the compensated gradient is to equate the total resistance of a train on a horizontal curve on a gradient to that of the total resistance of a train on tangent track on a gradient.

c. The amount of gradient compensation is determined by the compensation factor and the degree of curve.

d. The recommended compensation factor to be used is 0.04 percent per degree of curve. This corresponds to the resistance created by standard three piece trucks on non-lubricated curves.

e. The recommended compensated gradient due to curvature shall be calculated as follows:

$$G_c = G - 0.04D$$

Where:

$G =$ gradient before compensation, expressed in percent

$D =$ degree of curve expressed in decimals of degrees

$G_c =$ compensated gradient expressed in percent

GRADE COMPENSATION FOR A 1% GRADE

	Uncompensated Grade		Compensated Grade	
Degree of Curve	Actual	Effective	Actual	Effective
1	1.00	1.04	0.96	1.00
2	1.00	1.08	0.92	1.00
3	1.00	1.12	0.88	1.00
4	1.00	1.16	0.84	1.00
5	1.00	1.20	0.80	1.00
6	1.00	1.24	0.76	1.00

WORKED EXAMPLE:

GRADE COMPENSATION FOR CURVE RESISTANCE

Data given :

Curve radius = 480 meters,

Ruling gradient of the section = 1 in 100 = 1 %

Degree of curve = 1750/Rad. of curve in meters

= 1750/480 = 3.89 degrees

Curve resistance (formula) compensation

= <u>0.03 % per degree of curve</u>

Actual compensation needed = 0.03 x 3.89° = 0.1167 %

Gradient to be provided = 1 % - 0.1167 % = 0.8833 %

= 0.8833 /100 = <u>1 in 113.2</u>

WORKED EXAMPLE:
GRADE COMPENSATION FOR CURVE RESISTANCE

Data given : Curve radius = 295 meters

Gradient actually provided = 1 in 350 = 0.286 %

Find out the equivalent gradient taking into account the curve resistance .

Degree of curve = ………?………

Curve resistance compensation = <u>? % per degree of curve</u>

Compensation for curve resistance = ……… %

Hence equivalent gradient = actual gradient + compensation

= ………?………. % = 1 in …?…...

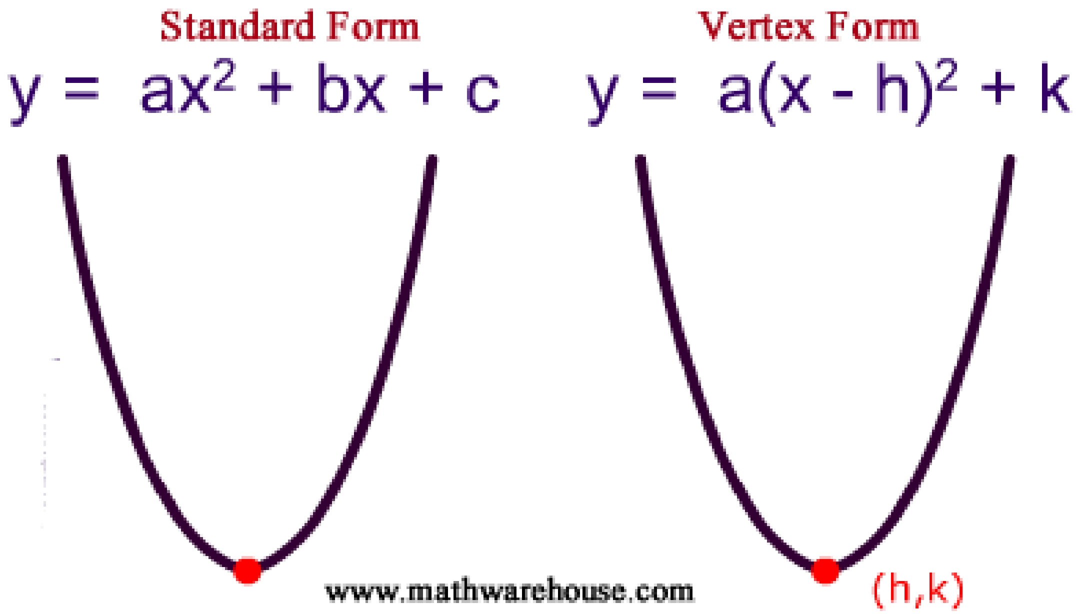
WORKED EXAMPLE:
GRADE COMPENSATION FOR CURVE RESISTANCE

Data given : Curve radius = 295 meters

Gradient actually provided = 1 in 350 = 0.286 %

Find out the equivalent gradient taking into account the curve resistance .

EQUATION OF A PARABOLA



WHAT IS THE SHAPE OF VERTICAL CURVE AND THE FORMULA FOR FIXING THE RADIUS?

Parabolic shape is preferred . But when radius is large there is not much difference between the two.

Formula for vertical curve:

$R = v^2 / f$ where R = Minimum Radius of the Vertical curve in meters

v = Speed of the train in meters /second

f = Permissible vertical acceleration in meter/ sec^2

The permissible vertical acceleration is taken as

0.3 meter / sec^2

KTMB lays down the minimum radius as 5000 meters

CALCULATION TO FIND OUT THE VERTICAL ACCELERATION

Assume speed v= 120 kph (max. design speed) = 33.33 meters /sec

Radius of vertical curve R = 5000 meters

Vertical acceleration = v^2/ R

= $(33.33)^2$ / 5000 = <u>0.22 meter /sec</u>^{2} much less than the prescribed 0.30 meter / sec^2

hence Ok

CALCULATION FOR LENGTH OF VERTICAL CURVE

The length of vertical curve = L in meters

= Radius x total deflection angle in radians

Example：A rising grade of 1 in 250 (0.4 %)is meeting a falling grade of 1 in 125 (0.8 %).

Radius adopted = 5000 meters

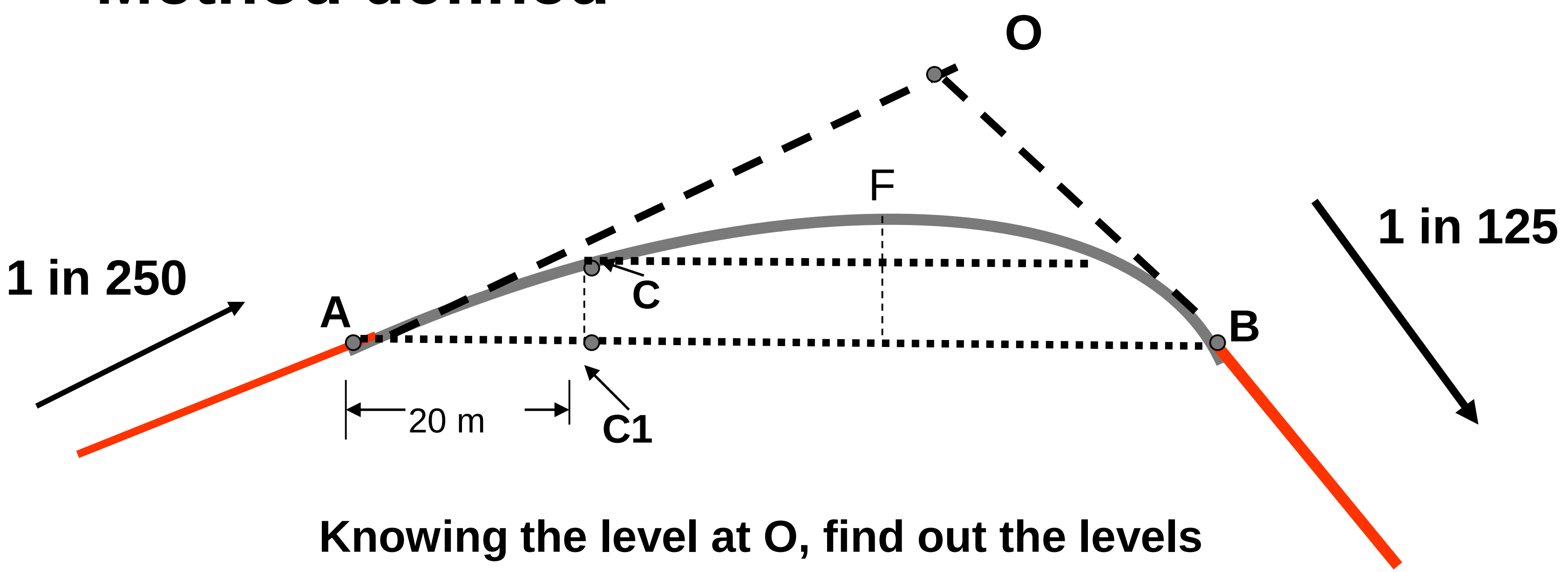
Difference in grade = 0.40 -(-0.80)= 1.20%. > 0.40% hence vertical curve is needed.

Length L of vertical curve = R x (1.20%.)= 5000x1.2/ 100

= 60 meters

CALCULATION FOR THE OFFSETS FOR A VERTICAL CURVE

Method defined

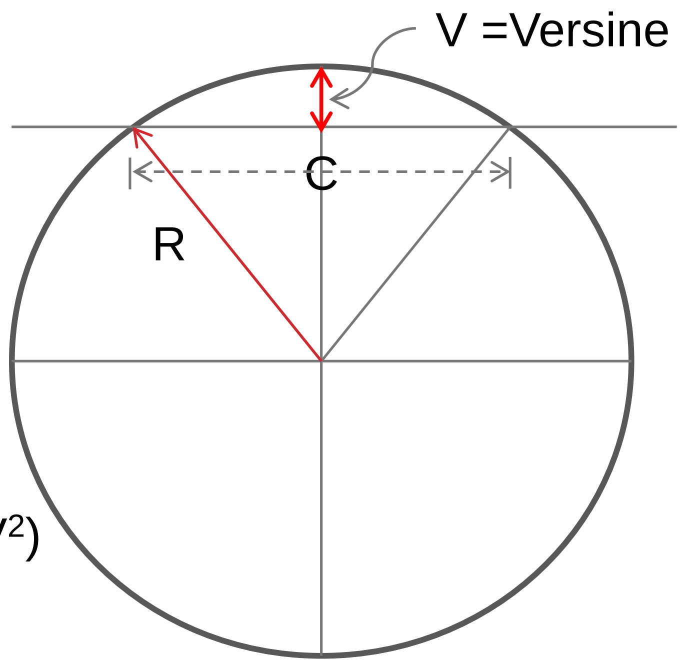


Knowing the level at O, find out the levels at A and B. Find out the level at C1 and add the calculated offset value C1-C

But before we proceed, let's recap about curve versine/curve geometry (next slide)

CURVE GEOMETRY

***Versine V*= $^{C^2}/_{8R}$**



R ^{2} = $(C/2)^2 + (R-V)^2$

R ^{2} = $(C^2/4) + (R^2-2RV-V^2)$

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

V^2 is considered very small compared to R and is considered as zero.

Thus,
$2RV = C^2/4$
$V = C^2/8R$

CURVE GEOMETRY

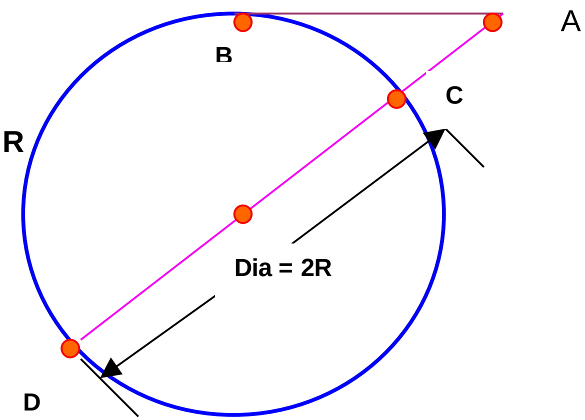
In the design of horizontal curve (Alignment) or vertical curve (Longitudinal Profile) we use certain basic properties of circular curve .These are

For large values of Radius R

$AB^2 = AC \, X CD$

$= AC \, X 2R$

$AC = AB^2 / 2R$

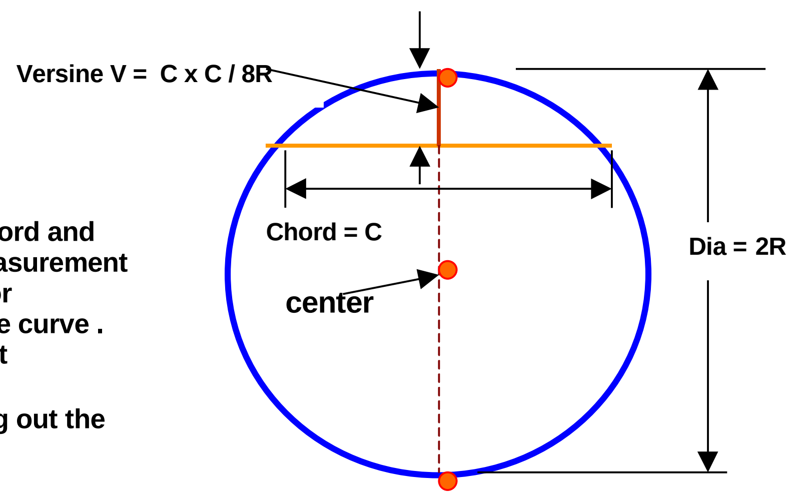


For large values of Radius R

Versine $V = C \times C / 8R = C^2 / 8R$

This relation between Versine, chord and Radius is used for periodical measurement of curvature, to check the need for adjustment and realignment of the curve . Curve realignment is an important maintenance requirement.

This property also enables finding out the offsets for vertical curves

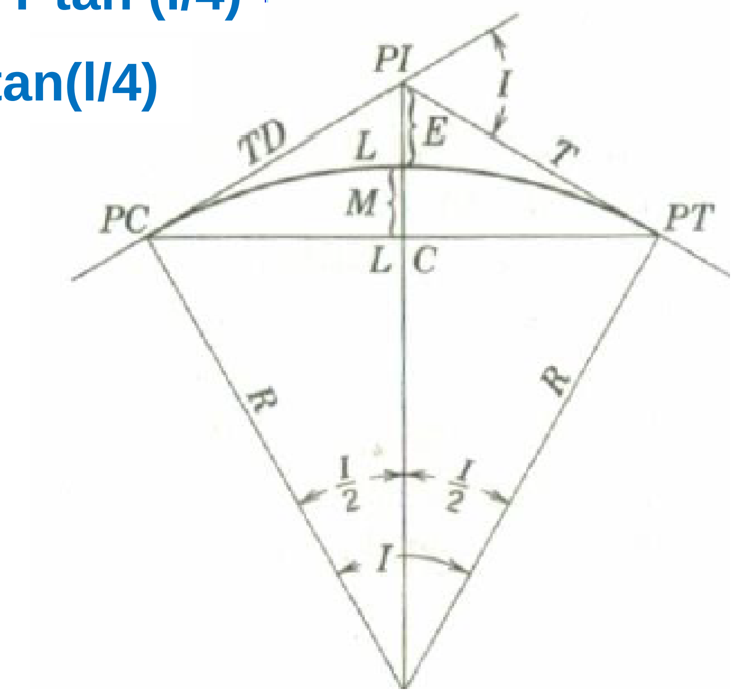


CURVE GEOMETRY

Functions of Simple Curves

- Tangent Distance = TD = R tan I/2
- Long Chord = LC = 2R sin I/2
- Mid-Ordinate = **M = E cos (I/2)**
- External Distance = **E = T tan (I/4)**

Also E = R tan (I/2) tan(I/4)



CALCULATION FOR OFFSETS

Level at O 100.00 meters

Level at A = 100.00 -(0.4x 30 /100) = 99.88

Level at B = 100.00 -(0.8x 30 /100) = 99.76

Reduced level at vertex F = (RL at A +RL at B) /2 +versine over 60 meter chord

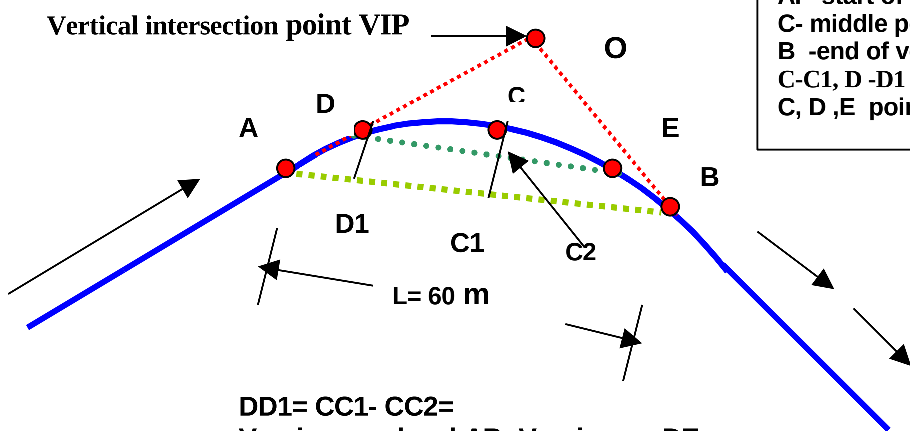
= 99.82 + 60x60/8x 5000= 99.82+ 0.09= 99.91

Reduced level at Point C= level at C1 + CC1=

99.88+ (99.88 -99.76)x 20/60+ CC1= 99.92+CC1

CC1= versine over 60 meter chord-versine over 20 meter chord = 60x 60

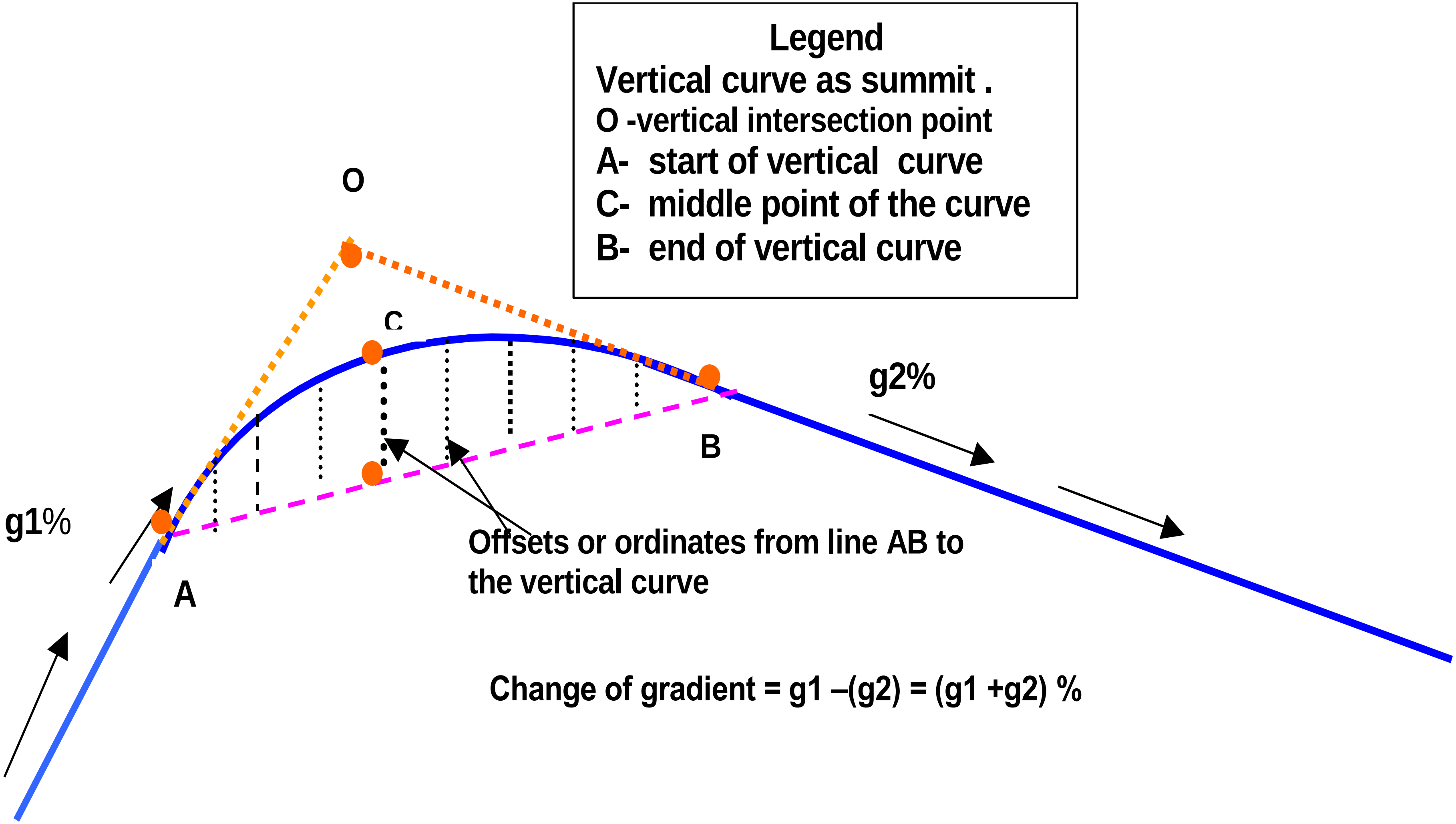
Vertical curve offsets calculation –example



DD1= CC1- CC2=
Versine on chord AB- Versine on DE

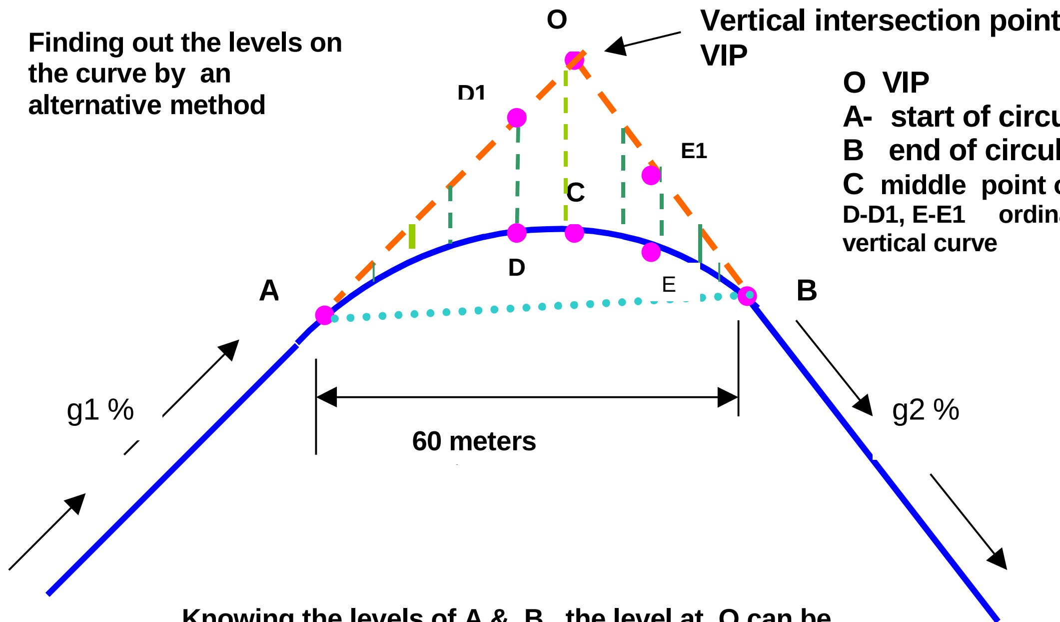
Legend
Vertical curve as summit.
O -vertical intersection point
A. start of vertical curve , AB chord , DE chord
C- middle point of the curve
B -end of vertical curve
C-C1, D -D1 etc - offset to the vertical curve
C, D ,E points on vertical curve

Distance from A in meters	**Level along AB (C1,D1 etc …)**	**Offsets/Ordinate in meter**	**Reduced Level on the vertical curve**
0 (at A)	**99.88**	nil	**99.88**
10	99.86	$(30^2 - 20^2)$ /2 x5000= 0.05	99.86+ 0.05= **99.91**
20	99.84	$(30^2 - 10^2)$ /2 x5000= 0.08	99.84+ 0.08= **99.92**
30	99.82	(30^2) /2 x 5000 = 0.09	99.82+ 0.09= **99.91**
40	99.80	$(30^2 - 10^2)$ /2 x5000= 0.08	99.80+ 0.08= **99.88**
50	99.78	$(30^2 - 20^2)$ /2 x5000= 0.05	99.78+ 0.05= **99.83**
60 (at B)	**99.76**	nil	**99.76**


Legend
Vertical curve as summit .
O -vertical intersection point
A- start of vertical curve
C- middle point of the curve
B- end of vertical curve
O
C
g1%
A
B
g2%
Offsets or ordinates from line AB to the vertical curve
Change of gradient = g1 –(g2) = (g1 +g2) %

Vertical curve -calculation of reduced level -example

Finding out the levels on the curve by an alternative method



O VIP
A- start of circular curve
B end of circular curve
C middle point of circular curve
D-D1, E-E1 ordinates /offsets to the vertical curve

Knowing the levels of A & B, the level at O can be calculated and the levels at D1, E1 etc can be found out. The offset D1-D = AD1^2 /2R, the offset E1-E= AE1^2 /2R and so on . Then we can find out the levels on the circular curve at points D, E etc

Distance from A in meters	Level along line OA/OB (D1 ,E1---etc) X	D1-D, E1-E, Offsets/Ordinates etc in meter Y	Reduced Level on the vertical curve X -Y
0 (at A)	**99.88**	nil	**99.88**
10	99.92	0.01	99.91
20	99.96	0.04	99.92
30	100.00	0.09	99.91
40	99.92	0.04	99.88
50	99.84	0.01	99.83
60 (at B)	**99.76**	nil	**99.76**

Legend

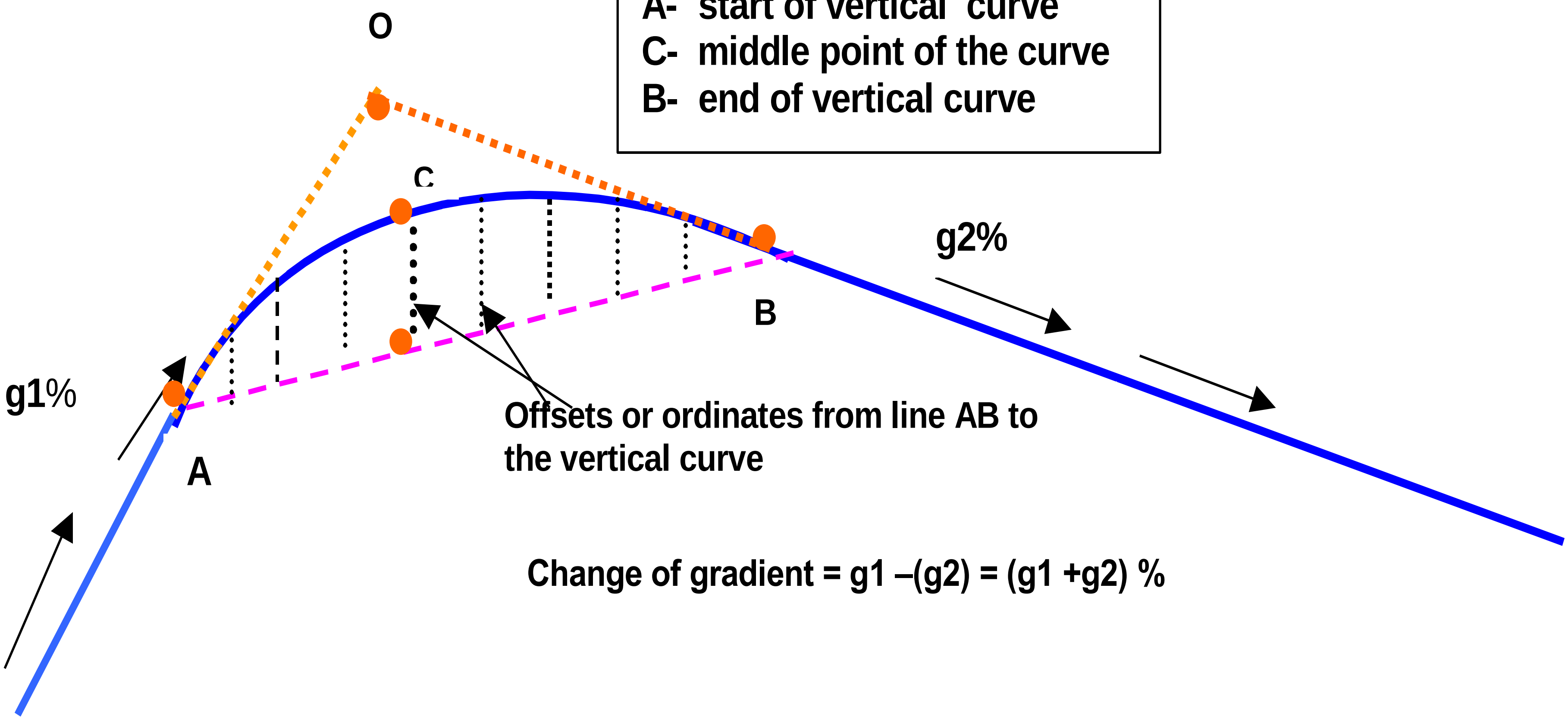
Vertical curve as summit .

O -vertical intersection point

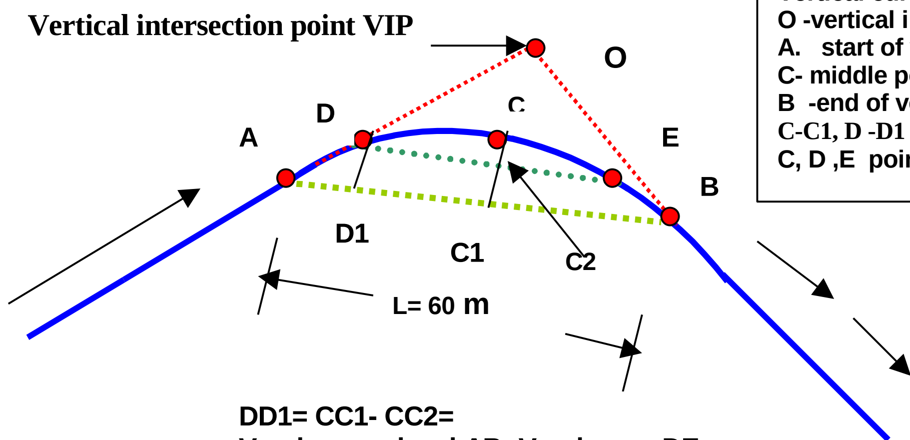
A- start of vertical curve

C- middle point of the curve

B- end of vertical curve



Vertical curve- offsets calculation –example



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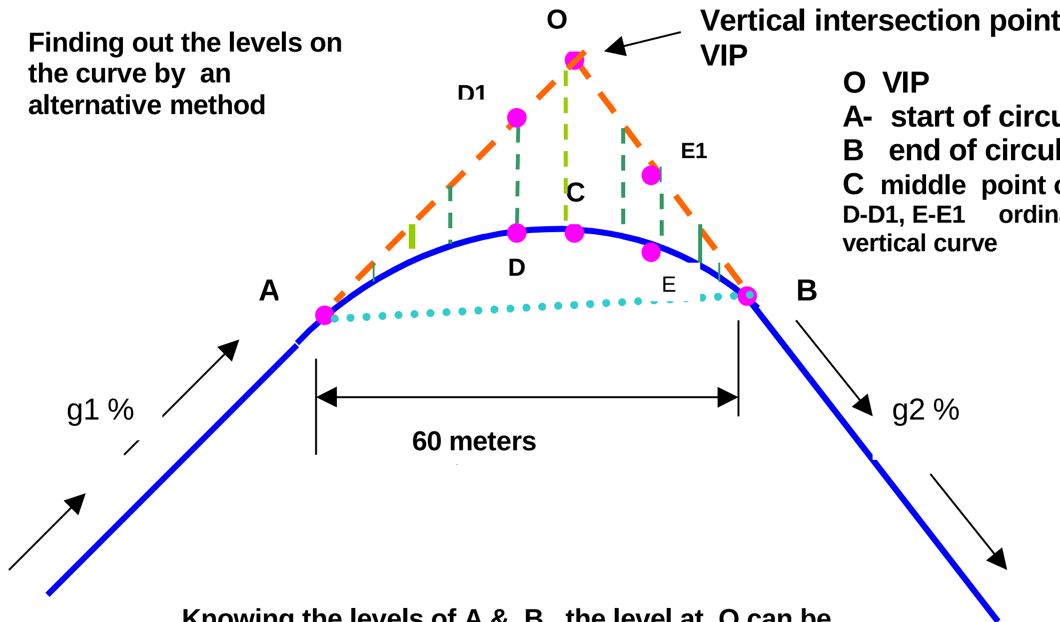
Vertical curve -calculation of reduced level -example

Finding out the levels on the curve by an alternative method



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50	99.84	0.01	99.83
60 (at B)	**99.76**	nil	**99.76**

SOME DESIGN SOFTWARE

There are two major computer aided drafting (CAD) programs used in the industry

- AutoCAD (railroads, private industries)
- Microstation (state D.O.T.s, government)

Each program has add-on Design software programs that are used for designing the horizontal alignments, vertical profiles, cross-sections

Bentley http://www.bentley.com/en-US

- Rail Track: (specifically rail design) Civil 3D
- Geopak: (highway or rail design)
- Inroads: (highway or rail design)

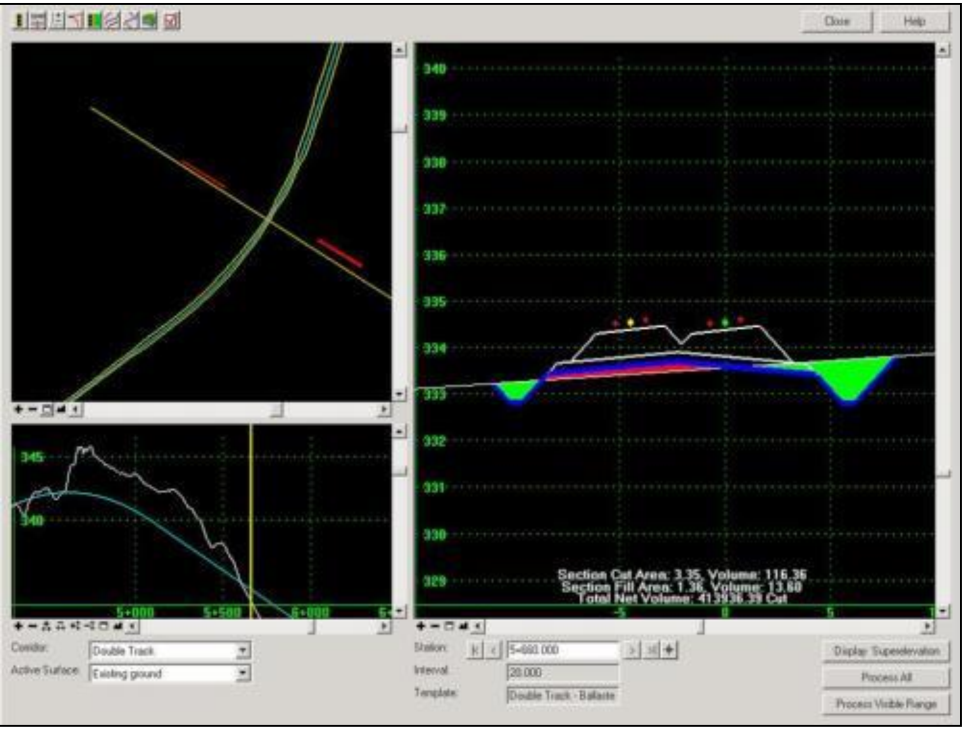
Autodesk http://usa.autodesk.com/

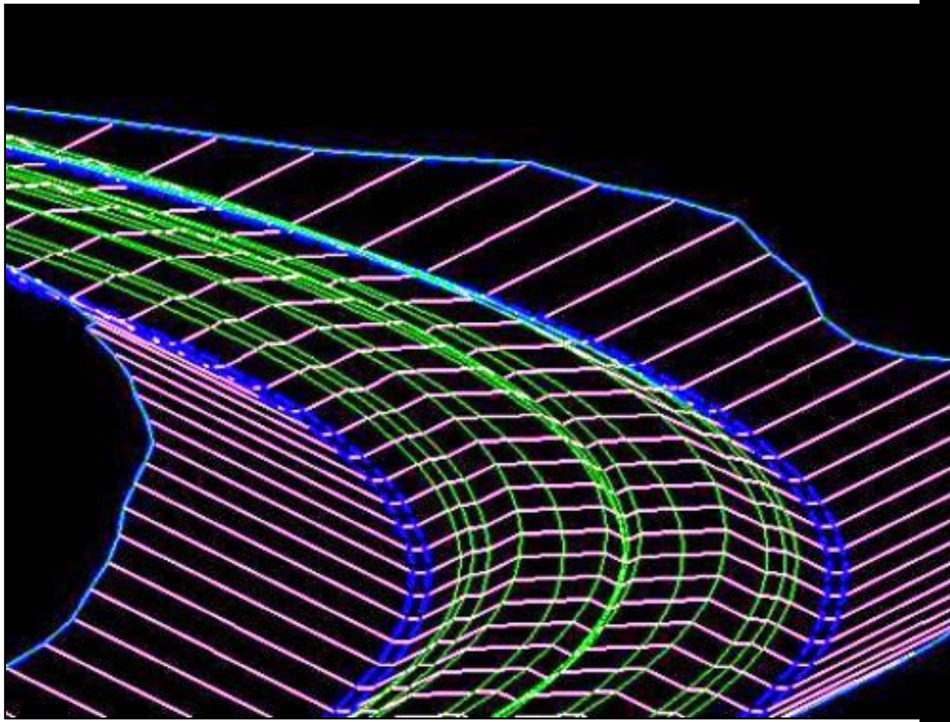
- Civil 3D (highway or rail design)

DESIGN SOFTWARE VIEWS

- Rail Track Interface

3-D model






TERIMA KASIH
THANK YOU