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Circular Curves | Simple Curves

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Terminologies used in simple curve

- PC = Point of curvature. It is the beginning of curve.
- PT = Point of tangency. It is the end of curve.
- PI = Point of intersection of the tangents.
- T = Length of tangent from PC to PI and from PI to PT. It is known as subtangent.
- R = Radius of simple curve, or simply radius.
- L = Length of chord from PC to PT. Point Q as shown in the the figure is the midpoint of L.
- L_c = Length of curve from PC to PT. Point M as shown in the the figure is the midpoint of L_c .
- E = External distance. It is the nearest distance from PI to the curve. From the above figure, point M is the midpoint of the curve and E is the distance from PI to M.
- m = Middle ordinate. It is the distance from the midpoint of the curve to the midpoint of the chord. From the figure above, m is the distance MQ.
- I = Deflection angle (also called *angle of intersection* and *central angle*). It is the angle of intersection of the tangents. The angle subtended by PC and PT at O is also equal to I, where O is the center of the circular curve from the above figure.
- x = offset distance from tangent to any point in the curve; note that x is perpendicular to T.
- θ = offset angle subtended at PC between PI and any point in the curve
- D = Degree of curve. It is the central angle subtended by a length of curve equal to one station. In English system, one station is equal to 100 ft and in SI, one station is equal to 20 m.
- Sub chord = chord distance between two adjacent full stations.

Sharpness of circular curve

The smaller is the degree of curve, the flatter is the curve and vice versa. The sharpness of simple curve is also determined by radius R . Large radius are flat whereas small radius are sharp.

Formulas for Circular Curves

The formulas we are about to present need not be memorized. All we need is geometry plus names of all elements in simple curve. Note that we are only dealing with circular arc, it is in our great advantage if we deal it at geometry level rather than memorize these formulas. For easy reference, the figure shown in the previous page will be shown again here.

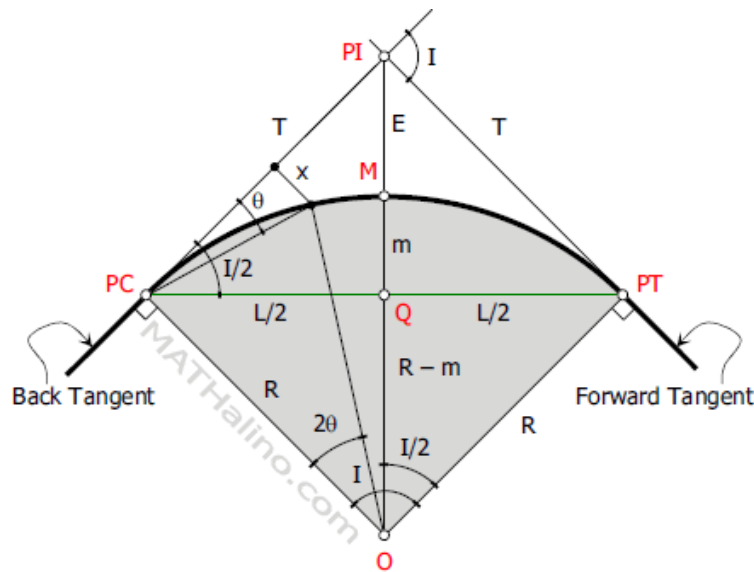


Figure 001. Circular Curve

Length of tangent, T

Length of tangent (also referred to as subtangent) is the distance from PC to PI. It is the same distance from PI to PT. From the right triangle PI-PT-O,

$$\tan \frac{I}{2} = \frac{T}{R}$$

$$T = R \tan \frac{I}{2}$$

External distance, E

External distance is the distance from PI to the midpoint of the curve. From the same right triangle PI-PT-O,

$$\cos \frac{I}{2} = \frac{R}{R + E}$$

$$R + E = \frac{R}{\cos \frac{I}{2}}$$

$$E = R \sec \frac{I}{2} - R$$

Middle ordinate, m

Middle ordinate is the distance from the midpoint of the curve to the midpoint of the chord. From right triangle O-Q-PT,

$$\cos \frac{I}{2} = \frac{R - m}{R}$$

$$R \cos \frac{I}{2} = R - m$$

$$m = R - R \cos \frac{I}{2}$$

Length of long chord, L

Length of long chord or simply length of chord is the distance from PC to PT. Again, from right triangle O-Q-PT,

$$\sin \frac{I}{2} = \frac{L/2}{R}$$

$$R \sin \frac{I}{2} = L/2$$

$$L = 2R \sin \frac{I}{2}$$

Length of curve, L_c

Length of curve from PC to PT is the road distance between ends of the simple curve. By ratio and proportion,

$$\frac{L_c}{I} = \frac{2\pi R}{360^\circ}$$

$$L_c = \frac{\pi RI}{180^\circ}$$

An alternate formula for the length of curve is by ratio and proportion with its degree of curve.

$$\frac{L_c}{I} = \frac{1 \text{ station}}{D}$$

$$L_c = \frac{1 \text{ station} \times I}{D}$$

SI units: 1 station = 20 m

$$L_c = \frac{20I}{D}$$

English system: 1 station = 100 ft

$$L_c = \frac{100I}{D}$$

If given the stationing of PC and PT

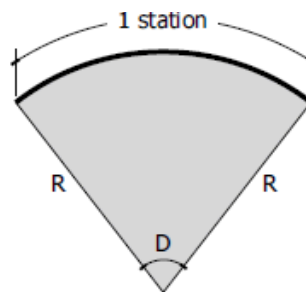
$$L_c = \text{Stationing of PT} - \text{Stationing of PC}$$

Degree of curve, D

The degree of curve is the central angle subtended by an arc (arc basis) or chord (chord basis) of one station. It will define the sharpness of the curve. In English system, 1 station is equal to 100 ft and in SI, 1 station is equal to 20 m. It is important to note that 100 ft is equal to 30.48 m not 20 m.

Arc Basis

In arc definition, the degree of curve is the central angle subtended by one station of circular arc. This definition is used in highways. Using ratio and proportion,



$$\frac{1 \text{ station}}{D} = \frac{2\pi R}{360^\circ}$$

SI units (1 station = 20 m):

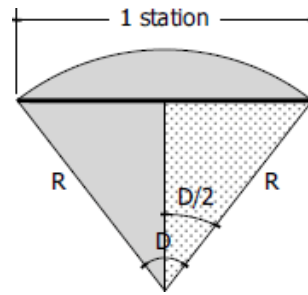
$$\frac{20}{D} = \frac{2\pi R}{360^\circ}$$

English system (1 station = 100 ft):

$$\frac{100}{D} = \frac{2\pi R}{360^\circ}$$

Chord Basis

Chord definition is used in railway design. The degree of curve is the central angle subtended by one station length of chord. From the right triangle shaded in green color,



$$\sin \frac{D}{2} = \frac{\text{half station}}{R}$$

SI units (half station = 10 m):

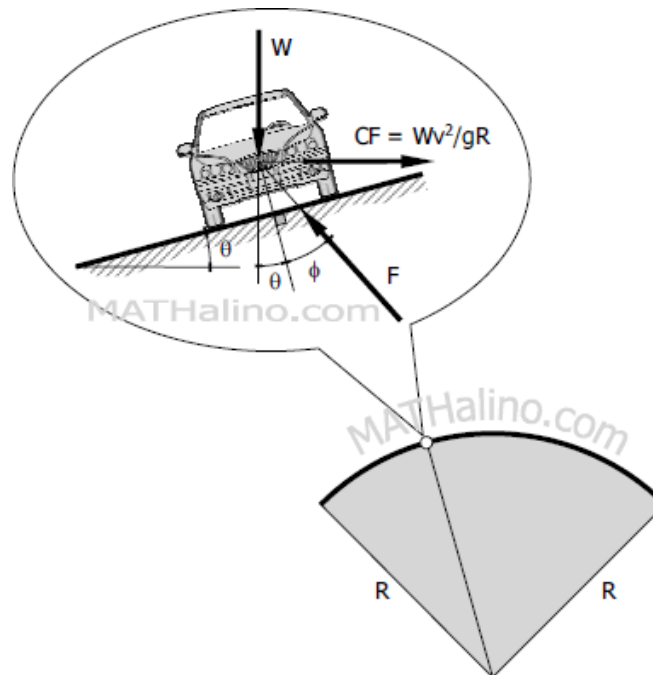
$$\sin \frac{D}{2} = \frac{10}{R}$$

English system (half station = 50 ft):

$$\sin \frac{D}{2} = \frac{50}{R}$$

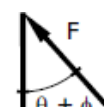
Minimum Radius of Curvature

Vehicle traveling on a horizontal curve may either skid or overturn off the road due to centrifugal force. Side friction f and superelevation e are the factors that will stabilize this force. The **superelevation** $e = \tan(\theta)$ and the **friction factor** $f = \tan(\phi)$. The minimum radius of curve so that the vehicle can round the curve without skidding is determined as follows.



From the force polygon shown in the right

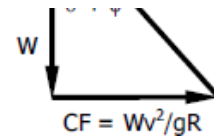
$$\tan(\theta + \phi) = \frac{CF}{W}$$



$$\tan(\theta + \phi) = \frac{\frac{Wv^2}{gR}}{W}$$

$$\tan(\theta + \phi) = \frac{Wv^2}{WgR}$$

$$\tan(\theta + \phi) = \frac{v^2}{gR}$$



The quantity v^2/gR is called *impact factor*.

Impact factor

$$i_f = \frac{v^2}{gR}$$

Back to the equation $\tan(\theta + \phi) = v^2/gR$

$$\tan(\theta + \phi) = \frac{v^2}{gR}$$

$$\frac{\tan \theta + \tan \phi}{1 - \tan \theta \tan \phi} = \frac{v^2}{gR}$$

Recall that $\tan \theta = e$ and $\tan \phi = f$

$$\frac{e + f}{1 - ef} = \frac{v^2}{gR}$$

But $ef \equiv 0$, thus

$$e + f = \frac{v^2}{gR}$$

Radius of curvature with R in meter and v in meter per second

$$R = \frac{v^2}{g(e + f)}$$

For the above formula, v must be in meter per second (m/s) and R in meter (m). For v in kilometer per hour (kph) and R in meter, the following convenient formula is being used.

$$R = \frac{\left(v \frac{\text{km}}{\text{hr}}\right)^2 \left(\frac{1000 \text{ m}}{\text{km}} \times \frac{1 \text{ hr}}{3600 \text{ sec}}\right)^2}{g(e + f)}$$

$$R = \frac{v^2 \left(\frac{1}{3.6}\right)^2}{g(e + f)}$$

$$R = \frac{v^2}{(3.6^2)g(e + f)}$$

$$R = \frac{v^2}{(3.6^2)(9.80)(e + f)}$$

Radius of curvature with R in meter and v in kilometer per hour

$$R = \frac{v^2}{127(e + f)}$$

Using the above formula, R must be in meter (m) and v in kilometer per hour (kph).

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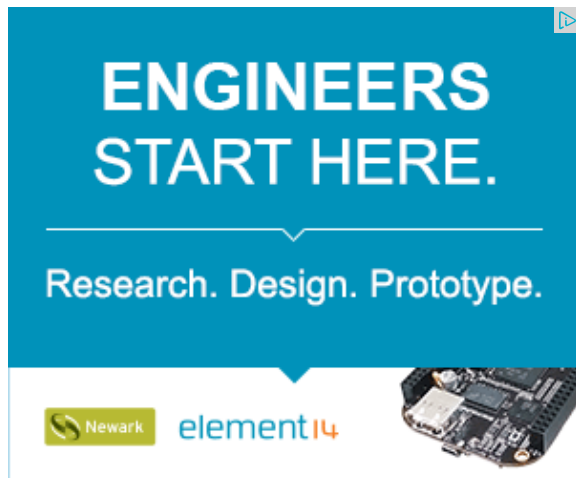
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