Speed Limit on Railway Curves

(Use of SuperElevation on Railways)

Introduction

When a train rounds a curve, it has a tendency to want to travel in a straight direction and the track must resist this movement, and force the train to turn. The opposing movement of the train and the track result in a number of different forces being at play.

19th & 20th Century Vs Modern Day Railway Design

In the early days of railway construction financial considerations were a big factor in the route design and selection. Given that the speed of competing transport, such as horses and water transport was not very fast, speed was not seen as a major factor in the design process.

However as railway transportation became a more vital need for society, the need to increase the speed of trains became more and more important. This lead to many improvements in railway practices and engineering.

A number of factors, such as the design of the rolling stock, as well as the track design, ultimately influence the maximum speed of a train. Todays' high speed railway routes are specifically designed for the speeds expected of the rolling stock.

Centrifugal Force

Railway locomotives, wagons and carriages, hereafter referred to as rolling stock, when rounding a curve may be considered as coming under the influence of centrifugal force. Centrifugal force is commonly defined as:

- The apparent force that is felt by an object moving in a curved path that acts outwardly away from the centre of rotation.
- An outward force on a body rotating about an axis, assumed equal and opposite to the centripetal force and postulated to account for the phenomena seen by an observer in the rotating body.

For this article the use of the phrase centrifugal force shall be understood to be an apparent force as defined above.

Effect of Centrifugal Force

When rolling stock rounds a curve, if the rails of the track are at the same elevation (ie two tracks are at the same level) the combination of centrifugal force **Fc** and the weight of the rolling stock **W** will produce a resulting force **Fr** that does not coincide with the centre line of track, thus producing a downward force on the outside rail of the curve that is greater than the downward force on the inside rail (Refer to Figure 1). The greater the velocity or the smaller the radius of the curve becomes (some railways have curve radius as low as 100m), the farther the resulting force **Fr** will move away from the centre line of track. *Equilibrium velocity* was the velocity a train could negotiate a curve will the rolling stock weight equally distributed across all the wheels.

If the resulting force **Fr** approaches the outside rail, then the rolling stock is at risk of "falling" off the track or overturning. The following drawing, illustrates the basic concept described. Lateral displacement of the centre of gravity permitted by the suspension system of the rolling stock is not illustrated.

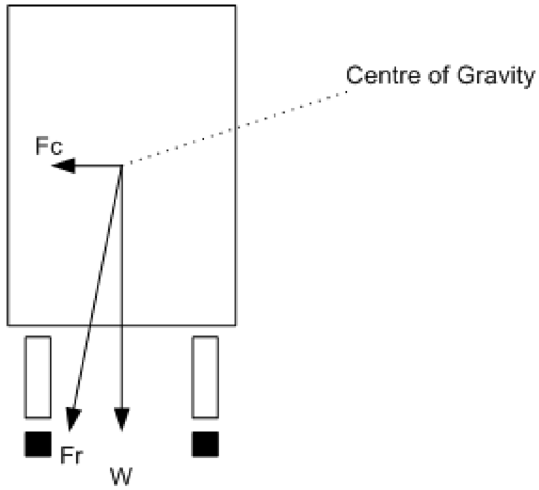

Figure 1 - Forces at work when train rounds a curve

Use of SuperElevation

In order to counteract the effect of centrifugal force **Fc** the outside rail of the curve may be elevated above the inside rail effectively moving the centre of gravity of the rolling stock laterally toward the inside rail.

This procedure is generally referred to as superelevation. If the combination of lateral displacement of the centre of gravity provided by the superelevation, velocity of the rolling stock and radius of curve is such that resulting force **Fr** becomes centred between and perpendicular to a line across the running rails the downward pressure on the outside and inside rails of the curve will be the same. The superelevation that produces this condition for a given velocity and radius of curve is known as the *balanced or equilibrium elevation.* Figure 2 below illustrates the above concept.

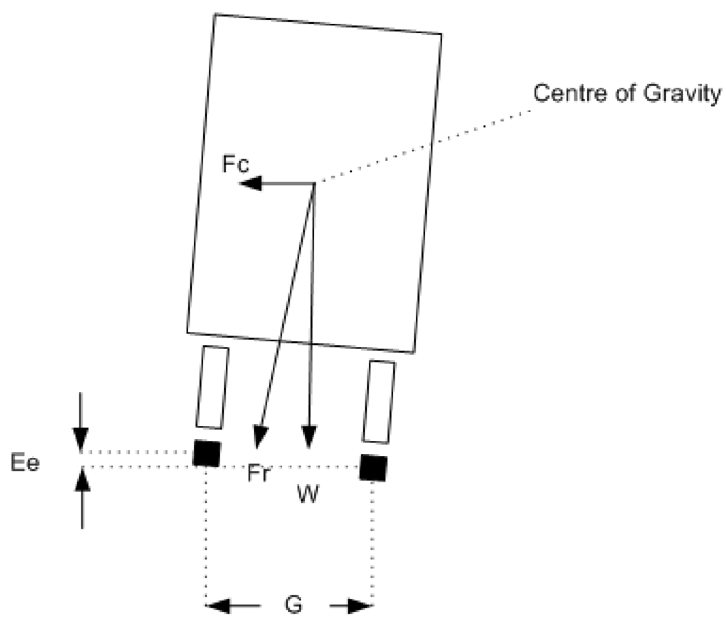

Figure 2 - Forces when train rounding a curve with superelevation.

Limitation of Superelevation

Mixed Passenger & Freight Routes

Typical early railway operation resulted in rolling stock being operated at less than *equilibrium velocity* (all wheels equally sharing the rolling stock weight), or coming to a complete stop on curves. Under such circumstances excess superelevation may lead to a downward force sufficient to damage the inside rail of the curve, or cause derailment of rolling stock toward the centre of the curve when draft force is applied to a train. Routine operation of loaded freight trains at low velocity on a curve superelevated to permit operation of higher velocity passenger trains will result in excess wear of the inside rail of the curve by the freight trains.

Thus on these types of routes, superelevation is generally limited to not more than 6 inches.

High Speed Passenger Routes

Modern high speed passenger routes, do not carry slower speed trains, nor expect trains to stop on curves, so it is possible to operate these routes with higher track superelevation values. Curves on these types of route are also designed to be relatively gentle radius, and are typically in excess of 2000m (2km) or 7000m (7km) depending on the speed limit of the route.

Parameters	France	Germany	Spain	Korea	Japan
Speed (km/h)	300/350	300	350	300/350	350
Horizontal curve radius (m)	10000 (10km)	7000 (7km)	7000 (7km)	7000 (7km)	4000 (4km)
Superelevation (mm)	180	170	150	130	180
Max Grade (mm/m)	35	40	12.5	25	15
Cant Gradient (mm/s)	50	34.7	32	N/A	N/A
Min vertical radius (m)	16000 (16km)	14000 (14km)	24000 (24km)	N/A	10000 (10km)

Table 1 - Curve Parameters for High Speed Operations (Railway Track Engineering by J. S. Mundrey)

Maximum Curve Velocity

Maximum velocity on a curve may exceed equilibrium velocity, but must be limited to provide a margin of safety before overturning velocity is reached or a downward force sufficient to damage the outside rail of the curve is developed. This velocity is generally referred to as maximum safe velocity or safe speed.

Although operation at maximum safe velocity will avoid overturning of rolling stock or rail damage, a passenger riding in a conventional passenger car will experience centrifugal force perceived as a tendency to slide laterally on their seat creating an uncomfortable sensation of instability. To avoid passenger discomfort maximum velocity on a curve is therefore limited to what is generally referred to as *maximum comfortable velocity* or *comfortable speed*. Operating experience with conventional passenger cars has led to the generally excepted, circa 1980, of designating the maximum velocity for a given curve to be equal to the result for the calculation of equilibrium velocity with an extra amount added to the actual superelevation that will be applied to the curve. This is often referred to as *unbalanced superelevation* or *cant deficiency*.

Tilt trains have been introduced to allow faster train operation on tracks not originally designed for "high speed" operation, as well as high speed railway operation. The tilting of the passenger cab allows greater values of unbalanced superelevation to be used.

Limitation of Velocity on Curved Track at Zero Cross Level

The concept of maximum comfortable velocity may also be used to determine the maximum velocity at which rolling stock is permitted to round curved track without superelevation and maintained at zero cross level. The lead curve of a turnout located between the heel of the switch and the toe of the frog is an example of curved track that is generally not superelevated. Other similar locations would include yard tracks and industrial tracks where increased velocity made possible by superelevation is not required. In such circumstances the maximum comfortable velocity for a given curve may also be the maximum velocity permitted on tangent track adjoining the curve.

Height of Centre of Gravity

Operation on a curve at equilibrium velocity results in the centre of gravity of the rolling stock coinciding with a point on a line that is perpendicular to a line across the running rails and the origin of which is midway between the rails. Under such condition the height of centre of gravity is of no consequence as resulting force **Fr** coincides with the perpendicular line described. When rolling stock stops on a superelevated curve or rounds a curve under any condition of non-equilibrium resulting force **Fr** will not coincide with the perpendicular line previously described and the height of the centre of gravity then becomes consequential in determining the location of resulting force **Fr** relative to the centre line of the track. The elasticity of the suspension system of rolling stock under conditions of non-equilibrium will introduce a roll element that effects the horizontal displacement of the centre of gravity that must also be considered when determining the location of resulting force **Fr**.

Calculation of Curve Velocity

The generic formula for calculating the various curve velocities is as follows:

$$V = \sqrt{\frac{Egr}{G}}$$

Where

E = Ea (track superelevation) + Ec (unbalanced superelevation)
g = acceleration due to gravity
r = radius of curve
G = track gauge

Typical SuperElevation Values & Speed Impact

The values quoted below are "typical" but may vary from country to country.

Mixed Passenger & Freight Routes

Track superelevation typically will not be more than <u>6 inches (150mm)</u>. Naturally depending upon the radius of the curve speed restrictions may apply.

Normally unbalanced superelevation is typically restricted to 3 inches (75mm), and is usually only allowed for passenger stock.

Tilt trains may have values of up to 12 inches (305mm).

High Speed Passenger Routes

As freight trains normally don't run on high speed routes, track superelevation values may be up to 12 inches (300mm), depending upon the country. Track designs ensure that curve radius is designed to the relevant route speed without the need to exceed this value.

Typical values for some specific countries are shown in the table below.

	Cant D (SuperElevation) (mm)	Cant deficiency (Unbalanced SuperElevation) I (mm)
CEN (draft) – Tilting trains	180-200	300
Czech Rep. – Tilting trains	150	270
France – Tilting trains	180	260
Germany – Tilting trains	180	300
Italy – Tilting trains	160	275
Norway – Tilting trains	150	280
Spain – Tilting trains (equivalent for standard gauge)	160 (139)	210 (182)
Sweden – Tilting trains	150	245
UK – Tilting trains	180	300

Table 2 - Superelevation limits (source - Tracks for tilting trains - A study within the Fast And Comfortable Trains (FACT) project by B. Kufver, R. Persson)

Application in OR

Open Rails implements this function, and has "standard" default values applied. The user may elect to specify some of the standard parameters from the above formula.

OR Parameters

Typical OR parameters can be entered in the Wagon section of the WAG or ENG file, and are formatted as below.

ORTSUnbalancedSuperElevation (3in)

ORTSTrackGauge(4ft 8.5in)

OR Default

The above values can be entered into the relevant files, or alternatively OR will default to the following functionality.

OR will firstly use the speed limit value from the TRK file to determine whether the route is a conventional mixed freight and passenger route or a high speed route.

Speed limit < 200km/h (125mph) – Mixed Freight and Pass route

Speed limit > 200km/h (125mph) – High speed passenger route

“Default” values of track superelevation will be applied based upon the above separations.

Track gauge will default to the standard value of 4’ 8.5” (1435mm).

Unbalanced superelevation (Cant Deficiency) will be determined off the value entered by the user, or will default to the following values:

- Conventional Freight – 0” (0mm)
- Conventional Passenger – 3” (75mm)
- Engines & tenders – 6” (150mm)

By default OR cannot identify tilt trains so these types of trains will require the addition of the relevant unbalanced superelevation information into the relevant rolling stock files.