Curve Friction

Introduction

When a train travels around a curve, due to the track resisting the direction of travel (ie the train wants to continue in a straight line), it experiences increased resistance as it is “pushed” around the curve.

Over the years there has been much discussion about how to accurately calculate curve friction. The calculation methodology presented (and used in OR) is meant to be representative of the impacts that curve friction will have on rolling stock performance.

Factors Impacting Curve Friction

A number of factors impact upon the value of resistance that the curve presents to the trains movement, and these are as follows:

i) Curve radius – the tighter the curve radius the higher the higher the resistance to the train
ii) Rolling Stock Rigid Wheelbase – the longer the rigid wheelbase of the vehicle, the higher the resistance to the train. Modern bogie stock tends to have shorter rigid wheelbase values and is not as bad as the older style 4 wheel wagons.
iii) Speed – the speed of the train around the curve will impact upon the value of resistance, typically above and below the equilibrium speed (ie when all the wheels of the rolling stock are perfectly aligned between the tracks). See the section below “Impact of superelevation”.

The impact of wind resistance on the curve is ignored.

Impact of Rigid Wheelbase

The length of the rigid wheelbase of rolling stock will impact the value of curve resistance. Typically rolling stock with longer rigid wheelbases will experience a higher degree of “rubbing” or frictional resistance on tight curves, compared to stock with smaller wheelbases.

Steam locomotives usually created the biggest problem in regard to this as their drive wheels tended to be in a single rigid wheelbase as shown in Fig 1. In some instances on routes with tighter curve the “inside” wheels of the locomotive was sometimes made flangeless to allow it to “float” across the track head. Articulated locomotives, such as Shays, tended to have their drive wheels grouped in bogies similar to diesel locomotives and hence were favoured for routes with tight curves.

The value used for the rigid wheelbase is shown as W in Fig 1.

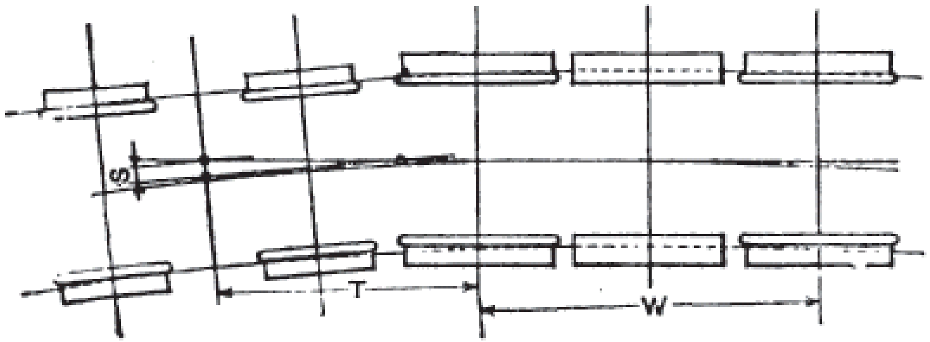

Figure 1 - Example of Rigid Wheelbase in steam locomotive

Impact of SuperElevation

On any curve whose outer rail is super-elevated there is, for any car, one speed of operation at which the car trucks have no more tendency to run toward either rail than they have on straight track, where both rail-heads are at the same level (known as the equilibrium speed). At lower speeds the trucks tend constantly to run down against the inside rail of the curve, and thereby increase the flange friction; whilst at higher speeds they run toward the outer rail, with the same effect. This may be made clearer by reference to Fig. 2, which represents the forces which operate on a car at its centre of gravity. With the car at rest on the curve there is a component of the weight W which tends to move the car down toward the inner rail. When the car moves along the track centrifugal force **Fc** comes into play and the car action is controlled by the force **Fr** which is the resultant of **W** and **Fc**. The force **Fr** likewise has a component which, still tends to move the car toward the inner rail. This tendency persists until, with increasing speed, the value of **Fc** becomes great enough to cause the line of operation of **Fr** to coincide with the centre line of the track perpendicular to the plane of the rails. At this equilibrium speed there is no longer any tendency of the trucks to run toward either rail. If the speed be still further increased, the component of **Fr** rises again, but now on the opposite side of the centre line of the track and is of opposite sense, causing the trucks to tend to move toward the outer instead of the inner rail, and thereby reviving the extra flange friction. It should be emphasized that the flange friction arising from the play of the forces here under discussion is distinct from and in excess of the flange friction which arises from the action of the flanges in forcing the truck to follow the track curvature. This excess being a variable element of curve resistance, we may expect to find that curve resistance reaches a minimum value when this excess reduces to zero, that is, when the car speed reaches the critical value referred to. This critical speed depends only on the super-elevation, the track gauge, and the radius of track curvature. The resulting variation of curve resistance with speed is indicated in Fig 3.

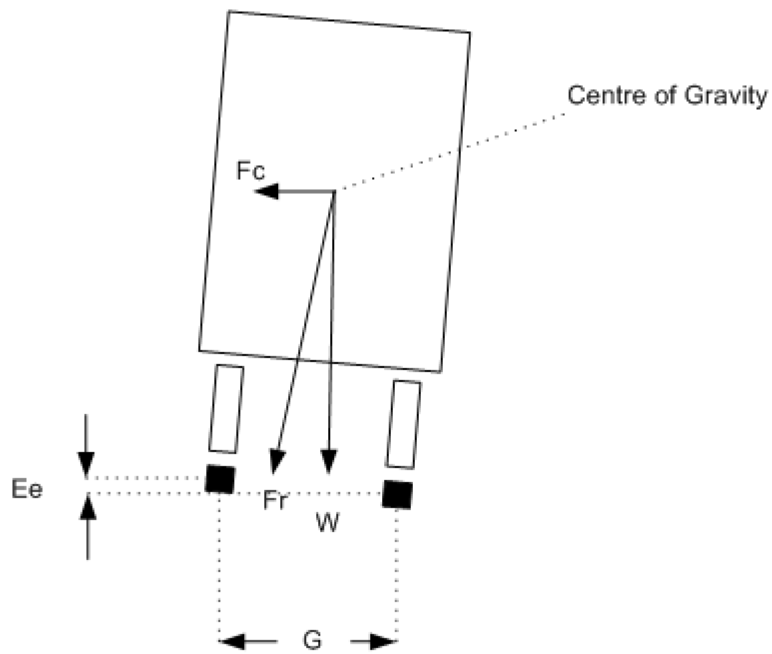

Figure 2 - Description of forces on rolling stock transitioning a curve

Calculation of Curve Resistance

$$R = \frac{WF(D+L)}{2r}$$

Where

R = Curve resistance
W = vehicle weight
F = Coefficient of Friction,
u = 0.5 for dry, smooth steel-to-steel, wet rail 0.1 - 0.3
D = track gauge
L = Rigid wheelbase
r = curve radius

Source: The Modern locomotive by C. Edgar Allen - 1912

Calculation of Curve Speed Impact

The above value represents the least value amount of resistance, which occurs at the equilibrium speed, and as described above will increase as the train speed increases and decreases from the equilibrium speed.

This concept is shown pictorially in the following graph.

Open Rails uses the following formula to model the speed impact on curve resistance:

$$Speed\ Factor = ABS\left(\frac{(Equilibrium\ Speed - Train\ Speed)}{(Equilibrium\ Speed)}\right) * \ ResistanceFactor\ @\ start$$

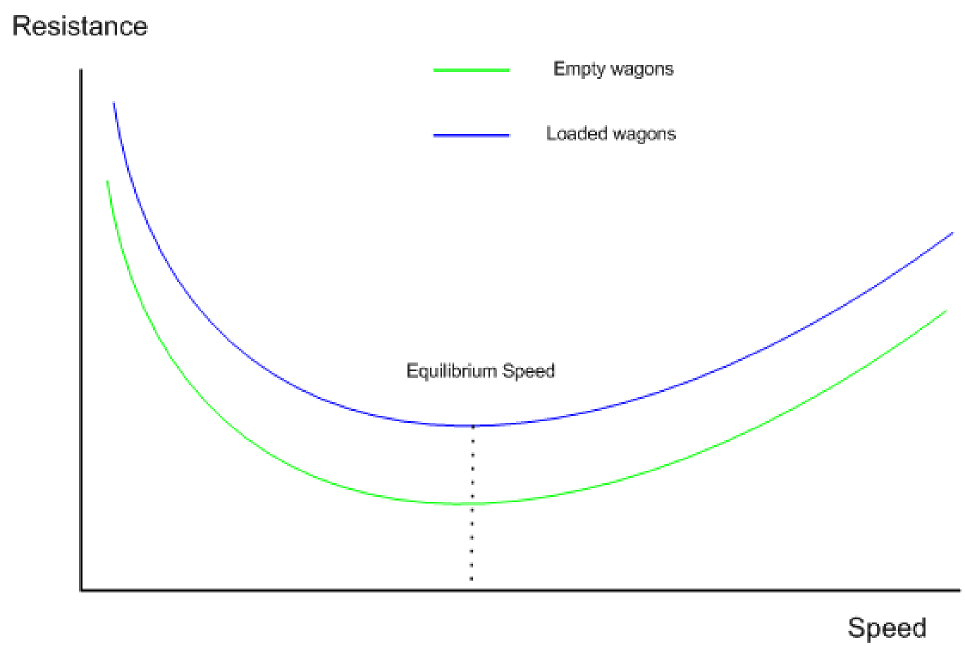

Figure 3 - Generalisation of variation of curve resistance with speed

Typical Rigid Wheelbase Values

The following values are used as defaults where actual values are not provided by the player.

Rolling Stock Type	Typical value
Freight Bogie type stock (2 wheel bogie)	5’ 6” (1.6764m)
Passenger Bogie type stock (2 wheel bogie)	8’ (2.4384m)
Passenger Bogie type stock (3 wheel bogie)	12’ (3.6576m)
Typical 4 wheel rigid wagon	11’ 6” (3.5052m)
Typical 6 wheel rigid wagon	12’ (3.6576m)
Tender (6 wheel)	14’ 3” (4.3434m)
Diesel, Electric Locomotives	Similar to passenger stock
Steam locomotives	Dependent on # of drive wheels, Can be up to 20'+ , eg large 2-10-0 locos

Modern publications suggest that an allowance of approximately 0.8 lb. per ton (us) per degree of curvature for standard gauge tracks. At very slow speeds, say 1 or 2 mph, the curve resistance is closer to 1.0 lb. (or 0.05% up grade) per ton per degree of curve.

Application in OR

Open Rails models this function, and the user may elect to specify the known wheelbase parameters, or the above “standard” default values will be used.

OR calculates the equilibrium speed in the speed curve module, however it is not necessary to select both of these functions in the simulator options TAB. Only select the function desired.

By studying the “Forces Information” table in the HUD, you will be able to observe the change in curve resistance as the speed, curve radius, etc vary.

OR Parameters

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

ORTSRigidWheelBase (3in)

ORTSTrackGauge (4ft 8.5in) (also used in curve speed module)

OR Default

The above values can be entered into the relevant files, or alternatively if they are not present, then OR will use default values as described below.

Rigid Wheelbase – as a default OR uses the figures shown above in the "Typical Rigid Wheelbase Values" section.

Starting curve resistance value has been assumed to be 200%, and has been built into the speed impact curves.

OR calculates the curve resistance based upon actual wheelbases provided by the player or the appropriate defaults. It will use this as the value at "Equilibrium Speed", and then depending upon the actual calculated equilibrium speed (from the speed limit module) it will factor the resistance up as appropriate to the current train speed.

Steam locomotive wheelbase approximation – the following approximation is used to determine the default value for the fixed wheelbase of a steam locomotive.

WheelBase = 1.25 * (axles - 1) * DrvWheelDiameter