

European Curve and Turnout Mechanics

Railroading is railroading, although the methods that we use to get to the end product may vary significantly. An in-depth understanding of the geometrical relationships that are common to all railway configurations is essential, whether designing, building or maintaining a high-speed passenger line or a 40 mph drag coal line.

12.1 Introduction

The purpose of this chapter is to examine mathematically some key components of the track structure, curves and turnouts, but from a European perspective. The European railway, in many ways, is significantly different than the typical railway of North America. High-speed rail plays a very significant role in not only Western Europe, but also in Eastern Europe as well. In Europe, curves are built broad and long, favoring high-speed operations. The approach in North America is entirely different. Privatized North American railways were built to keep construction costs down and to bridge great distances as quickly as possible. This translates into sharp curvature and heavy grades, even for heavy haul activities. The need to move bulk commodities over great distances favored the loading and design approach used by North American railways. The excellent road system developed over the vast majority of the populated segments of North America has relegated the majority of passenger rail travel to a limited few heavily populated corridors. In Europe, the exorbitant cost of fuel, a very high population density within countries the size of states or provinces, along with a nationalized system of railways, has necessitated and enabled the development of an extensive passenger rail based system.

Naturally, the European and North American rail networks evolved in two very different directions. The one system is based solely on the reliable movement of heavy

tonnage at the lowest cost. The other on pure speed. Vehicle and truck/suspension development also took diverging paths between the two continents. European trucks are set much further in than their North American counterparts. Truck (bogey) suspensions handle track anomalies much differently in Europe. Europeans do not stagger joints as is done in North America. Rock-off is unheard of in jointed territory. On the other hand, vehicle bounce can be accentuated.

Today though, the North American engineer may need to take a new look at how our counterparts "across the pond" have surmounted the problems of dealing with operating at high speeds within existing alignments. North American railways are looking for ways to operate faster at lower costs. European tangential turnouts have been successfully installed in a number of heavy-haul territories. There is renewed interest in high-speed inter-city passenger trains with a number of feasibility studies underway. A new 110-mph Amtrak/IDOT service between Chicago and Springfield, Illinois will soon initiate service.

This chapter does not pretend to cover all the significant design approaches used by European railways in the handling of curvature and turnouts, particularly at high speed. Nor does it present itself as being totally inclusive of European practices. There is wide variance between systems in Western and Eastern Europe. But the reader hopefully will get an appreciation of why Europeans have taken the approach they have to these two topics. In addition, the commonality will also be apparent and hopefully, the reader will secure a better appreciation of why we in North America have developed the standards that we have.

12.2 Curves

12.2.1 Curve Definition

Prior to discussing curve engineering, one must have a common method of defining a curve. There are two ways of describing curvature in common practice. In North America, a railway curve is described by the angle in degrees subtended by two radii, whose end points on the curve form a chord of 100 feet in length. In other parts of the railway world, the length of the radius described above, measured in meters, describes the curve.

The circumference of a complete circle is $2 \cdot R \cdot \Pi$. Since the full body of a curve is theoretically circular in construction, each degree of curvature will describe 100 feet of chord (at relatively small degrees of curvature, the arc distance is approximately equal to the chord distance). Thus, the circumference for such a circle made up of 100 foot chords, each describing 1° of curvature, would for practical purposes, be 3600 feet and the radius would be:

$$v = \frac{dh}{dt} = n \cdot V$$

The maximum permissible rate of elevation increase will vary with different railway companies. The SNCF network permits up to 70mm/sec on the DB (Deutsche Bahn) network up to 35mm/sec and on the JNR (Japanese National Railroad) up to 42mm/sec.

According to Prof. A. Prud'homme, a rate of elevation increase of 100mm/sec. is theoretically possible for high-speed trains, but is not the practice of the European railways.⁵⁶

If the rate of elevation increase on the ramp is 28mm/sec, we can get the horizontal component length of the ramp by:

$$l = 10 \cdot V \cdot h$$

The value determined is generally rounded to the nearest 5m or so.

For heavy curvature or gradients, the permissible rate of elevation of increase is increased to 35mm/sec. or:

$$l = 8 \cdot V \cdot h$$

For high-speed rides, Deutsche-Bahn AG recommends:

$$l = 12 \cdot V \cdot h$$

Shock (Jerk)

In Europe, a parameter called shock (jerk) is utilized to determine the configuration of the ramp. The magnitude of the vertical jerk is defined as a change in the vertical acceleration within a given time span:

$$\Psi = \frac{da}{dt} \left(\frac{m}{s^3} \right)$$

The maximum jerk value is set at by experience at:

$$\Psi = 1.0 \frac{m}{s^3}$$

and the common range of values of the jerk is:

⁵⁶ Professor A. Prud'homme, "General Revue for French Railroad," November 1976, Paris, France.

$$\Psi = 0.3 - 0.5 \frac{m}{s^3}$$

The curved ramp is the second type of ramp configuration used in Europe to transition in superelevation and is shown in Figure 12.7.

The slope of this ramp varies along the curve and the greatest slope is located in the middle of the ramp, at point S in Figure 12.6. It follows:

$$1 : n_s = \frac{2h}{1000 \cdot l}$$

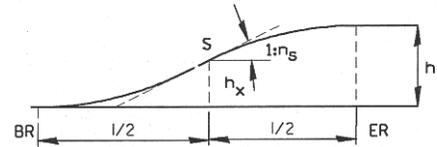


Figure 12-6 JZ (Yugoslavian) Superstructure Regulations

The curved ramp (spiral) is longer than the linear ramp and thus, it is more suitable for higher speeds. The curved ramp is used for speeds up to $V=180$ km/h (112 mph) and its length is defined by:

$$L_{curve} = 1.41 \cdot L_{straight}$$

where $L_{straight}$ is the length of the associated linear ramp (i.e., about 41% longer)

The greater the rate in acceleration change, the longer the required ramp must be. In the sinusoidal ramps (utilized in the Tokaido Railroad), the length of ramp is calculated by:

$$L_{sin} = 1.60 \cdot L_{straight}$$

In the case of the curved ramps, the resultant curve and the slope increase in the form of two squared parabolas touching, but whose slope constantly changes.

In the case of sinusoidal ramp, the largest curve is at the beginning and at the end of the ramp, while the vertical velocity is continual.

Sinusoidal Ramp

Sinusoidal ramps are longer in length than the other forms of transition ramps and allow higher speeds. For

$$V \leq 180 \text{ km/h}$$

$$\max .n_s = 4V \quad \text{and} \quad n_s = 400$$

12.4.2 Turnout Calculations

Conventional European turnout calculations are based on a geometric projection of the length and the relative direction at the points where the connections are made. This method assumes that kinematic forces rather than dynamic forces determine vehicle response.⁵⁷ To determine the essential equations, one uses one of the projection methods.

The open polygon method option is shown on Figure 12-23 and the closed polygon method is shown on Figure 12-24. Elements of the turnout are projected on a convenient coordinate system. From the geometric length relations, the equation can be written as:

The equation representing the open polygon of Figure 12-23 is:

$$A'E' = a \cdot \cos \alpha + b \cdot \cos \beta + c \cdot \cos \gamma - d \cdot \cos \delta$$

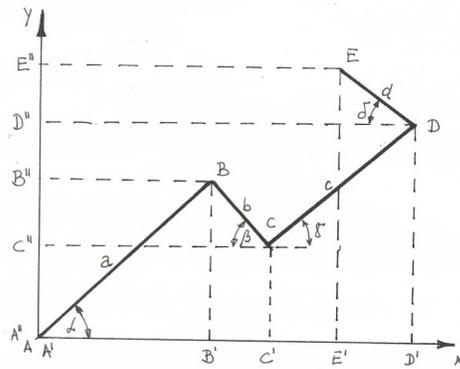


Figure 12-23 – Courtesy of University of Zagreb

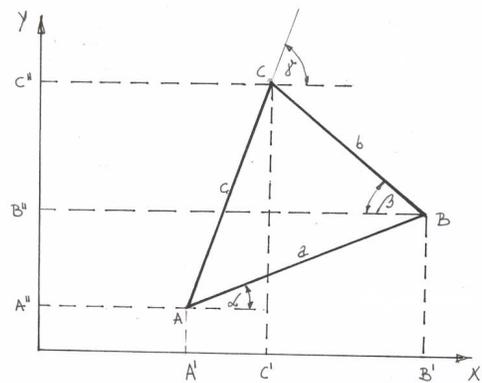


Figure 12-24 – Courtesy of University of Zagreb

The equations representing the closed polygon in Figure 12-24 are:

$$a \cdot \cos \alpha - b \cdot \cos \beta - c \cdot \cos \gamma = 0$$

$$a \cdot \sin \alpha + b \cdot \sin \beta - c \cdot \sin \gamma = 0$$

On the European Railway network, the tangent of an angle rounded off to the nearest degree expresses the diverging angle.

⁵⁷ Mejgyeri, J., Geometric Movement in Turnout Development, Austrian Railway Archive Volume 40, Pages 59–65, 1985.

For example:

$$1 : n = 1 : 10 \therefore (\alpha = 5^{\circ}42'38'') \text{ or}$$

$$1 : n = 1 : 14 \therefore (\alpha = 4^{\circ}05'08'')$$

The maximum permissible lateral acceleration is 0.8m/sec². Thus, one could develop a curve in the closure rail with a radius that, for a desired diverging speed, generated a lateral acceleration of $a = V^2/R$, not exceeding 0.8m/sec². This curve would be independent of the frog number utilized. In effect, Europeans will utilize a variety of turnout closure rail curves with the same movable point frog in order to secure different diverging speeds. The resultant turnout, obviously lengthens significantly as the radius of the curve grows. This is in direct opposition to the turnout practices of North American railways, that utilize one given closure rail curve for a given turnout number.

The effective radius is performed by calculating the offset at the switch heel, based on a chord (12.2m or 40') centered about the switch heel. The calculated offset will provide the effective radius (R) at the switch heel by using:

$$R = \frac{C^2}{8 \cdot V}$$

On the JZ (Jugoslavian Railroad), the chord length of 12.2m is the shortest distance between wheel set centers (truck centers currently in service).

Thus, for example, in high-speed operations, the diverging angle can be:

$$\alpha = 2^{\circ}29'22'' \therefore (\tan \alpha = 1 : 23.5)$$

and the permissible diverging radius is R=1390m (4,560 ft.). This permits a diverging speed of 80 km/h in 120 km/H territory.

For 100km/h in a diverging route, we need a curve with a radius of 1500m.

As determined by the following equation:

$$V_{\max} = 2.91 R^{1/2}$$

This radius is coupled with a $\tan \alpha = 1:18.5$ or diverging angle $\alpha = 3^{\circ}05'38.4''$.

For Turnout Model EW (1:40.154) (DB Railroad), $\alpha=1^{\circ}12' 7.5''$ ($\tan \alpha=1:40.154$) with a radius of 6100m (20,013 ft), which allows a diverging speed of 200 km/h.