Chapter
6

Railway Track Design

Basic considerations and guidelines to be used in the establishment of railway horizontal and vertical alignments.

The route upon which a train travels and the track is constructed is defined as an alignment. An alignment is defined in two fashions. First, the horizontal alignment defines physically where the route or track goes (mathematically the XY plane). The second component is a vertical alignment, which defines the elevation, rise and fall (the Z component).

Alignment considerations weigh more heavily on railway design versus highway design for several reasons. First, unlike most other transportation modes, the operator of a train has no control over horizontal movements (i.e. steering). The guidance mechanism for railway vehicles is defined almost exclusively by track location and thus the track alignment. The operator only has direct control over longitudinal aspects of train movement over an alignment defined by the track, such as speed and forward/reverse direction. Secondly, the relative power available for locomotion relative to the mass to be moved is significantly less than for other forms of transportation, such as air or highway vehicles. (See Table 6-1) Finally, the physical dimension of the vehicular unit (the train) is extremely long and thin, sometimes approaching two miles in length. This compares, for example, with a barge tow, which may encompass 2-3 full trains, but may only be 1200 feet in length.

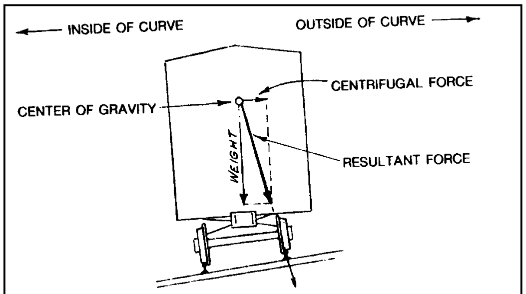
These factors result in much more limited constraints to the designer when considering alignments of small terminal and yard facilities as well as new routes between distant locations.

The designer MUST take into account the type of train traffic (freight, passenger, light rail, length, etc.), volume of traffic (number of vehicles per day, week, year, life cycle) and speed when establishing alignments. The design criteria for a new coal route across the prairie handling 15,000 ton coal trains a mile and a half long ten times per day will be significantly different than the extension of a light rail (trolley) line in downtown San Francisco.

curves as D (degrees per 20 meter arc). However, there does not seem to be any widespread incorporation of this practice. When working with light rail or in metric units, current practice employs curves defined by radius.

As a vehicle traverses a curve, the vehicle transmits a centrifugal force to the rail at the point of wheel contact. This force is a function of the severity of the curve, speed of the vehicle and the mass (weight) of the vehicle. This force acts at the center of gravity of the rail vehicle. This force is resisted by the track. If the vehicle is traveling fast enough, it may derail due to rail rollover, the car rolling over or simply derailing from the combined transverse force exceeding the limit allowed by rail-flange contact.

This centrifugal force can be counteracted by the application of superelevation (or banking), which effectively raises the outside rail in the curve by rotating the track structure about the inside rail. (See Figure 6-6) The point, at which this elevation of the outer rail relative to the inner rail is such that the weight is again equally distributed on both rails, is considered the equilibrium elevation. Track is rarely superelevated to the equilibrium elevation. The difference between the equilibrium elevation and the actual superelevation is termed underbalance.



Effect of Centrifugal Force

Centrifugal force, which is designated "F" in the following equation, increases with the square of the speed and increases in direct proportion to the degree of curvature:

$$F = \frac{W}{g} \times \frac{V^2}{r}$$

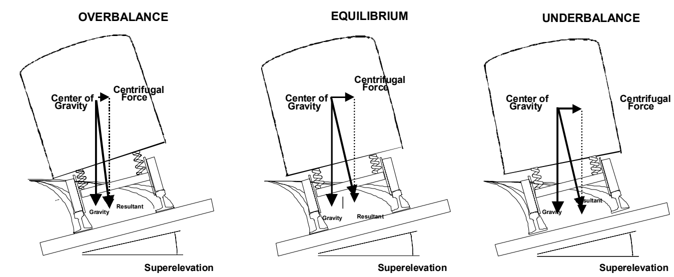
W = weight in pounds
g = gravity (32 ft/sec/sec)
v = velocity in ft. per sec.
r = radius of curvature in feet

Figure 6-6 Effects of Centrifugal Force

Though trains rarely overturn strictly from centrifugal force from speed (they usually derail first). This same logic can be used to derive the overturning speed. Conventional wisdom dictates that the rail vehicle is generally considered stable if the resultant of forces falls within the middle third of the track. This equates to the middle 20 inches for standard gauge track assuming that the wheel load upon the rail head is approximately 60-inches apart. As this resultant force begins to fall outside the two rails, the vehicle will begin to tip and eventually overturn. It should be noted that this overturning speed would vary depending upon where the center of gravity of the vehicle is assumed to be.

There are several factors, which are considered in establishing the elevation for a curve. The limit established by many railways is between five and six-inches for freight operation and most passenger tracks. There is also a limit imposed by the Federal Railroad Administration (FRA) in the amount of underbalance employed, which is generally three inches for freight equipment and most passenger equipment.

Underbalance limits above three to four inches (to as much as five or six inches upon FRA approval of a waiver request) for specific passenger equipment may be granted after testing is conducted.



$$V_{\max} = \sqrt{\frac{E_a + 3}{0.0007D}}$$

← Amount of Underbalance

$V_{\max}$ = Maximum allowable operating speed (mph).
E_a = Average elevation of the outside rail (inches).
D = Degree of curvature (degrees).

Figure 6-7 Overbalance, Equilibrium and Underbalanced

Track is rarely elevated to equilibrium elevation because not all trains will be moving at equilibrium speed through the curve. Furthermore, to reduce both the maximum allowable superelevation along with a reduction of underbalance provides a margin for maintenance. Superelevation should be applied in 1/4-inch increments in most situations. In some situations, increments may be reduced to 1/8 inch if it can be determined that construction and maintenance equipment can establish and maintain such a tolerance. Even if it is determined that no superelevation is required for a curve, it is generally accepted practice to superelevate all curves a minimum amount (1/2 to 3/4 of an inch). Each railway will have its own standards for superelevation and underbalance, which should be used unless directed otherwise.

The transition from level track on tangents to curves can be accomplished in two ways. For low speed tracks with minimum superelevation, which is commonly found in yards and industry tracks, the superelevation is run-out before and after the curve, or through the beginning of the curve if space prevents the latter. A commonly used value for this run-out is 31-feet per half inch of superelevation.

On main tracks, it is preferred to establish the transition from tangent level track and curved superelevated track by the use of a spiral or easement curve. A spiral is a curve whose degree of curve varies exponentially from infinity (tangent) to the degree of the body curve. The spiral completes two functions, including the gradual introduction of superelevation as well as guiding the railway vehicle from tangent track to curved track. Without it, there would be very high lateral dynamic load acting on the first portion of the curve and the first portion of tangent past the curve due to the sudden introduction and removal of centrifugal forces associated with the body curve.

There are several different types of mathematical spirals available for use, including the clothoid, the cubic parabola and the lemniscate. Of more common use on railways are the Searles, the Talbot and the AREMA 10-Chord spirals, which are empirical approximations of true spirals. Though all have been applied to railway applications to

6.4 Alignment Design

In a perfect world, all railway alignments would be tangent and flat, thus providing for the most economical operations and the least amount of maintenance. Though this is never the set of circumstances from which the designer will work, it is that ideal that he/she must be cognizant to optimize any design.

From the macro perspective, there has been for over 150 years, the classic railway location problem where a route between two points must be constructed. One option is to construct a shorter route with steep grades. The second option is to build a longer route with greater curvature along gentle sloping topography. The challenge is for the designer to choose the better route based upon overall construction, operational and maintenance criteria. Such an example is shown below.

Figure 6-9 Heavy Curvature on the Santa Fe - Railway Technical Manual – Courtesy of BNSF

Suffice it to say that in today's environment, the designer must also add to the decision model environmental concerns, politics, land use issues, economics, long-term traffic levels and other economic criteria far beyond what has traditionally been considered. These added considerations are well beyond what is normally the designer's task of alignment design, but they all affect it. The designer will have to work with these issues occasionally, dependent upon the size and scope of the project.

On a more discrete level, the designer must take the basic components of alignments, tangents, grades, horizontal and vertical curves, spirals and superelevation and construct an alignment, which is cost effective to construct, easy to maintain, efficient and safe to operate. There have been a number of guidelines, which have been developed over the past 175 years, which take the foregoing into account. The application of these guidelines will suffice for approximately 75% of most design situations. For the remaining situations, the designer must take into account how the track is going to be used (train type, speed, frequency, length, etc.) and drawing upon experience and judgment, must make an educated decision. The decision must be in concurrence with that of the eventual owner or operator of the track as to how to produce the alignment with the release of at least one of the restraining guidelines.

Though AREMA has some general guidance for alignment design, each railway usually has its own design guidelines, which complement and expand the AREMA recommendations. Sometimes, a less restrictive guideline from another entity can be employed to solve the design problem. Other times, a specific project constraint can be changed to allow for the exception. Other times, it's more complicated, and the designer must understand how a train is going to perform to be able to make an educated decision. The following are brief discussions of some of the concepts which must be considered when evaluating how the most common guidelines were established.

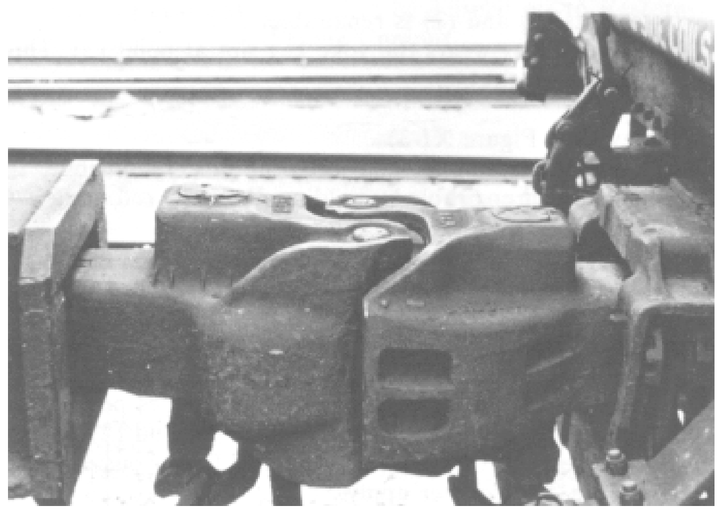


Figure 6-10 Automatic Coupler

A freight train is most commonly comprised of power and cars. The power may be one or several locomotives located at the front of a train. The cars are then located in a line behind the power. Occasionally, additional power is placed at the rear, or even in the center of the train and may be operated remotely from the head-end. The train can be effectively visualized for this discussion as a chain lying on a table. We will assume for the sake of simplicity that the power is all at one end of the chain.

Trains, and in this example the chain, will always have longitudinal forces acting along their length as the train speeds up or down, as well as reacting to changes in grade and curvature. It is not unusual for a train to be in compression over part of its length (negative longitudinal force) and in tension (positive) on another portion. These forces are often termed 'buff' (negative) and 'draft' (positive) forces. Trains are most often connected together with couplers (Figure 6-10). The mechanical connections of most couplers in North America have several inches (up to six or eight in some cases) of play between pulling and pushing. This is termed slack.

If one considers that a long train of 100 cars may be 6000' long, and that each car might account for six inches of slack, it becomes mathematically possible for a locomotive and the front end of a train to move fifty feet before the rear end moves at all. As a result, the dynamic portion of the buff and draft forces can become quite large if the operation of the train, or more importantly to the designer, the geometry of the alignment contribute significantly to the longitudinal forces.

As the train moves or accelerates, the chain is pulled from one end. The force at any point in the chain (Figure 6-11) is simply the force being applied to the front end of the chain minus the frictional resistance of the chain sliding on the table from the head end to the point under consideration.

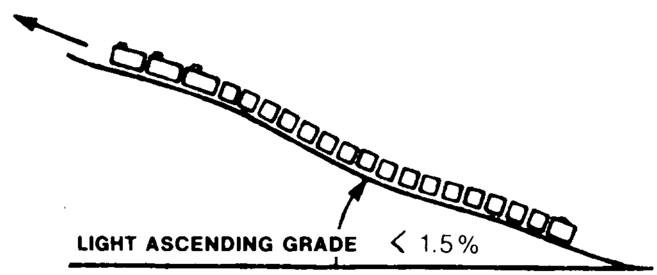


Figure 6-11 Force Applied Throughout the Train - ATSF Railroad Technical Manual - Courtesy of BNSF

As the chain is pulled in a straight line, the remainder of the chain follows an identical path. However, as the chain is pulled around a corner, the middle portion of the chain wants to deviate from the initial path of the front-end. On a train, there are three things preventing this from occurring. First, the centrifugal force, as the rail car moves about the curve, tends to push the car away from the inside of the curve. When this fails, the wheel treads are both canted inward to encourage the vehicle to maintain the course of the track. The last resort is the action of the wheel flange striking the rail and guiding the wheel back on course.

Attempting to push the chain causes a different situation. A gentle nudge on a short chain will generally allow for some movement along a line. However, as more force is applied and the chain becomes longer, the chain wants to buckle in much the same way an overloaded, un-braced column would buckle (See Figure 6-12). The same theories that Euler applied to column buckling theory can be conceptually applied to a train under heavy buff forces. Again, the only resistance to the buckling force becomes the wheel/rail interface.