TECHNOLOGY DIGEST
TD-14-013
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# The Effect of Track Cant on Vehicle Curving:

## Theory & Single Car Test Results

## Part I of III

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**Summary**

Optimum vehicle/track interaction conditions are achieved when vehicles negotiate curves at balance speed. This ideal may often not be realized in service as train speeds vary and drawbar forces in long heavy trains create lateral forces on the railcars that compromise steering.

The reasons for choosing a superelevation for a specific curve are complex, depending primarily on operational considerations; however this research suggests that wheel / rail forces can be minimized if curves are superelevated:

- Considering the *spectrum* of prevailing train speeds
- Where possible, for the speed of the prevailing *maximum* tonnage

This research suggests that heavy trains curving with excess cant generally impose high vertical and lateral loads on the track, and this condition should be avoided This *Technology Digest* (TD) is the first of three TDs reporting the effect of superelevation on vehicle/track interaction.

The second TD describes the chosen test site and includes an analysis of the site with reference to prevailing railroad instructions, suggesting that these instructions can bias curves towards use of excess cant; this is an undesirable condition as described in this TD.

The third TD provides test results at an instrumented crib at the chosen test site.

Transportation Technology Center, Inc. was tasked by the Association of American Railroads to report on the effect of superelevation on vehicle/track interaction, particularly under heavy axle load conditions.

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## INTRODUCTION

Transportation Technology Center, Inc. (TTCI) was tasked by the Association of American Railroads (AAR) to research optimum heavy haul design, operating and maintenance practices for curves negotiated by trains with 286,000-pound car loads. TTCI has conducted:

- Theoretical studies of vertical and lateral loads on single cars under different cant conditions
- Tests on single cars in curves at the Transportation Technology Center (TTC) near Pueblo, Colo.
- In-service tests at an instrumented crib in a 4.5-degree curve on a 1.22 percent grade

This TD reports on the theoretical studies and tests at the TTC. In-service tests are reported in associated TDs.[2,3].

## Theory

Curves are superelevated to balance the centripetal forces, associated with the speed of the vehicle, with gravitational forces related to the cant of the track (Figure 1).

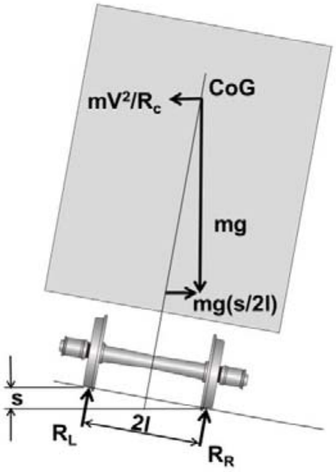


Figure 1. Forces at Balance Speed in a Superelevated Curve

The ideal (or so-called balance speed) is given by:

$V^2 = (g\ s/2l)\ R_c$ …………………………………… (1)

where: $g = 32\ ft/s^2$; $R_c$ = curve radius (ft); 2l = 59.5 inches (track gage + rail head width); s = superelevation (inches) and V = speed (ft/s)

This equation is closely-related to the equation provided by the Federal Railroad Administration (FRA):[1]

$V_{max} = \sqrt{[(E_a+3)/0.0007D]}$ ……………………...... (2)

where: D = curvature (degrees); V = speed (mph); $E_a$ = s inches (Figure 1) and the additional factor of 3 inches is the cant deficiency generally allowed by FRA.

***Influence of cant deficiency/excess cant on vertical loads***

Curving with cant imbalance transfers vertical load between high and low rails. Figure 2 shows 2W (equal to the weight on 1 truck), acting at a distance, d from the centerline of the track, towards the low rail for an excess cant = $s_u$.

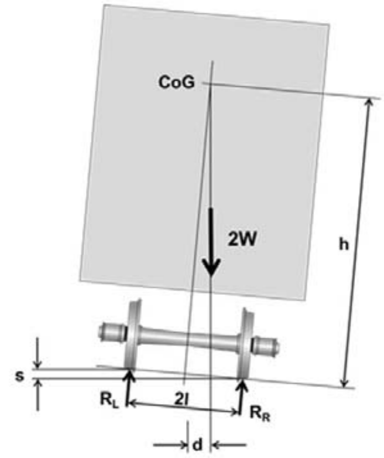


Figure 2. Vertical Reaction Forces under Imbalance Conditions

For a center of gravity (CoG) height, h, axle load, W and zero lateral or roll deflection of the carbody on the truck:

$d = s_u h/2l$

consequently, reactions, $R_L$ & $R_R$ are:

$R = W/2\ (1 \pm d/l)$ respectively …………...…….. (3)

For example, for h = 96 inches (h for high CoG car), 5.4 percent of nominal wheel load is gained/lost on each wheel per inch of cant imbalance. This is a *minimum* value, as suspension deflection causes lateral deflection of the carbody and carbody roll that will further increase the load transfer across low and high rails.

***Influence of coupler forces on vertical loads in curves***

Couplers become angled to the car longitudinal centerline in curves. This angle is a function of car geometry and coupler design and that of the adjacent car or locomotive.

Longitudinal train forces act at a height of the coupler. The lateral component of the coupler force, when the coupler is angled in a curve results in wheel load transfer between high and low rail[2].

***Influence of cant deficiency/excess cant on lateral loads***

Curve negotiation with cant imbalance will also result in increased lateral loads on both rails. Figure 3 shows that lateral loads, L, must be generated at the wheel/rail interface to counter the gravitational component of the vertical load.

If 2W equals the weight of half a car, the lateral wheel/rail contact forces required to be reacted by one truck, L:

$L = 2W\ s_u/2l$ ……………………..……….. (4)

Considering a car weight of 286,000 pounds, L = 2,403 pounds per inch of cant imbalance (or for $s_u = 1$). This implies that if the lateral force was to be "shared" equally between the 4 wheels of the truck, each wheel would experience a lateral load of 2,403/4 = 601 pounds per inch of cant imbalance.

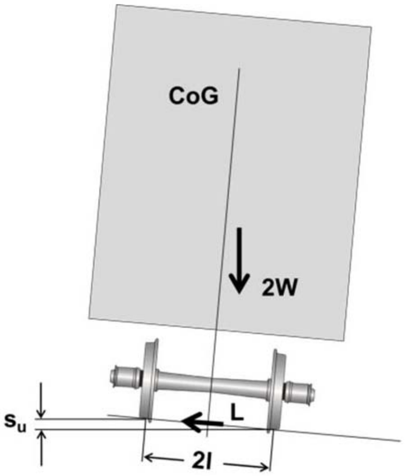


Figure 3. Overall Lateral Forces on a Truck/Car

Railway wheelsets produce lateral forces at the wheel/rail interface in reaction to lateral forces at the bearings by aligning at an angle of attack, α to the track (Figure 4a). Similarly, wheelsets in trucks produce lateral forces at the wheel/rail interface in reaction to lateral forces at the center plate by aligning at an angle of attack, α to the track (Figure 4b). Consequently, trucks align in curves with increased angles of attack under excess cant conditions and with reduced angles of attack under conditions of cant deficiency.

Generally, because of the geometry of the curve and of the truck, the angle of attack of the lead wheelset is greater than that of the trail wheelset with the angle of attack of the trail wheelset being approximately zero. Consequently, most of the lateral force to counter cant imbalance is generated by the lead wheelset.

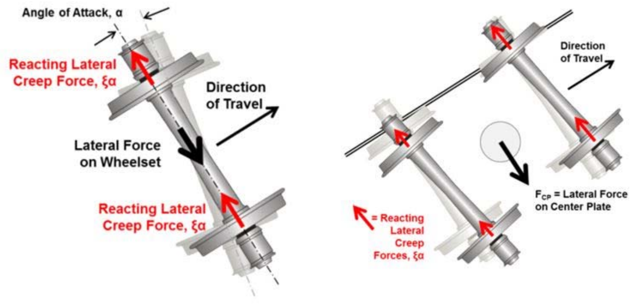
High rail flange contact creates flange forces on the lead wheelset that act in a similar sense to forces due to curving with excess cant (Figure 4c). This can increase the lateral forces on the lead wheelset when curving with flange contact under conditions of excess cant.

## Tests

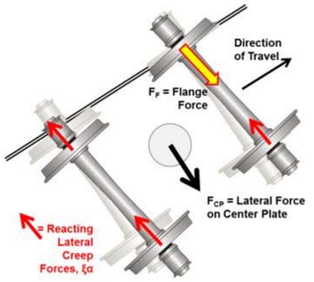
The influence of cant deficiency on vertical wheel loads is simple to establish quasi-statically given the height of the CoG of the car and details of the suspension system. A catalog or "map" of all possible combinations is, however, complex and considered to be beyond the scope of this TD.

Quantifying lateral forces is a more complex problem. Consequently, it was decided to conduct tests and measure the lead axle low rail lateral forces in curves at different cant deficiencies. As mentioned, because of low angles of attack, forces on the trail axle are low (approximately zero). High rail forces tend to oppose low rail forces, so generally, the lead axle low rail lateral traction force is considered a good measure of the influence of cant imbalance on lateral forces in curves.

Lead axle low rail lateral forces were measured using an instrumented wheelset on the wheel rail mechanism (WRM) loop at TTC in 3-, 4-, 5-, 7.5-, 10-, and 12-degree curves under different cant (speed) conditions and in two senses (clockwise and counterclockwise).



(a) Single Wheelset (b) Truck



(c) Influence of Flange Forces

Figure 4. Lateral Forces

Figures 5a and 5b show the following test results:

- The measured lead axle low rail lateral forces at balance speed show an increase with curvature (as expected). Zero cant imbalance is the intercept on the y-axis. These forces are slightly lower on the M-976 truck than on the 3-piece truck in shallower curves with little difference in sharper curves (as expected).
- Of interest is the slope of the graphs: Slopes are approximately 1,500 pounds per inch of cant imbalance in the tighter curves (5-degree and higher); this, compared with the average of 600 pounds per inch cant imbalance. The higher measured value (250 percent of the nominal) confirms the statement that the trailing axle in the truck cannot support a high lateral force, as its angle of attack is approximately zero, and the lateral force due to cant imbalance is carried mainly by the lead axle. It also suggests that the lead axle low rail wheel carries approximately 66 percent more lateral load than the lead axle high rail wheel. This, combined with the calculated vertical load transfer of 5.4 percent of nominal per inch of cant, explains the observed low rail rolling contact fatigue (RCF) damage under excess cant conditions and might assist in explaining high tractions in the formation of high impact wheels.

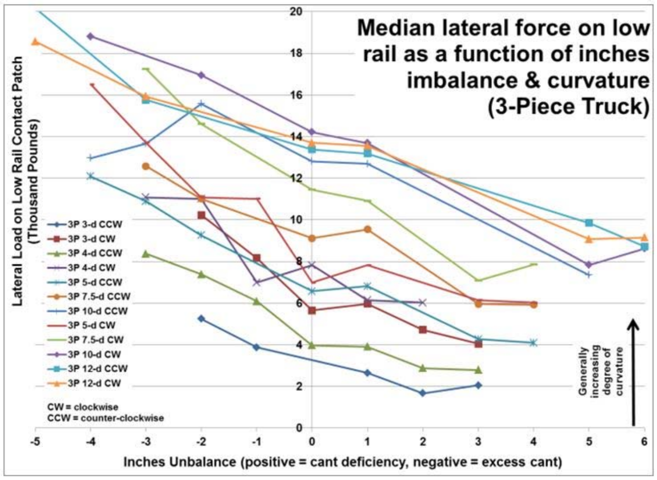


**Figure 5(a). Lead Axle Low Rail Forces on a 3-piece Truck in Curves (Note: n-d denotes curvature, n in degrees)**

## RECOMMENDATIONS

There are no clear technical reasons to define optimal cant.

Cant for the speed of prevailing tonnage is obviously the most desired condition for vertical loads; however railroad operations do not always permit:

- Trains can come to a halt in curves (signals etc.).
- Train speeds in curves can differ because of train type (high speed, high rated goods and passenger trains versus heavy, slow speed trains) and directional speed differences on steep grades.

It is difficult to maintain track cant when prevailing heavy traffic and tonnage operates at speeds predominantly over or under the balance speed as this can lead to differential settlement between high and low rail.

Currently, there are no clear limits to contact stresses. (These limits will be determined under the Root Cause for RCF Strategic Research Initiatives project).

Curving with excess cant generally increases high rail L/V ratios, because vertical load is transferred from the high to the low rail; this reduces the high rail load for substantially the same high rail lateral load.

This study confirms that balance conditions for the prevailing tonnage is the optimum condition. It strongly suggests that, if anything, curves should be negotiated with cant deficiency because:

- Lead axle low rail vertical and lateral forces are lower, reducing RCF
- Lead axle high rail L/V ratios are lower because of increased vertical loads (and, incidentally, lower lateral loads and angles of attack not shown explicitly in this TD)

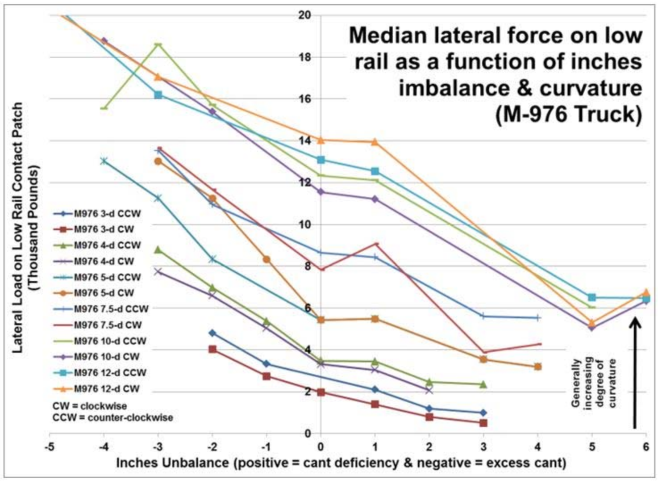


**Figure 5(b). Lead Axle Low Rail Forces on an M-976 Truck in Curves (Note: n-d denotes curvature, n in degrees)**

## CONCLUSIONS

The reasons for choosing a superelevation for a specific curve are complex, depending primarily on operational considerations; however this research indicates curves should be superelevated:

- Considering the *spectrum* of prevailing train speeds
- Where possible, for the speed of the prevailing *maximum* tonnage

Heavy trains curving with excess cant generally impose high vertical and lateral loads on the track, and this condition should be avoided wherever possible.

## REFERENCES

1. Tournay, H, et al. July 2014. “The Effect of Track Cant on Vehicle Curving (2): In-service Site Analysis,” *Technology Digest* TD-14-014, Association of American Railroads, Transportation Technology Center Inc., Pueblo, Colorado.
2. Tournay, H, et al. July 2014. “The Effect of Track Cant on Vehicle Curving (3): In-service Test Results,” *Technology Digest* TD-14-015, Association of American Railroads, Transportation Technology Center Inc., Pueblo, Colorado.

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