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The Effect of Track Cant on Vehicle Curving: In-service Test Results Part III of III

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Summary

Revenue service tests in a 4.5-degree curve show:

- Significant (~10%) gain/loss in nominal vertical wheel load when curving at 3 inches under balance and a nominal wheel load gain/loss of 1.6 percent per locomotive due to in-train forces was measured.
- Lead axle low rail lateral forces measured in the middle of the train (zero coupler force) were of the order of those measured on 3-piece trucks at the Transportation Technology Center (TTC) in similar curves under a prevailing friction of approximately 0.45.¹ They did not change measurably (approximately 1 percent) through the length of the train. Nevertheless, many of the forces measured suggest limiting friction. If so, any attempts to reduce these forces could prove valuable.

The research indicates that the cant in the curve in question, as well as adjacent curves, be lowered to 1 inch (see also References 1 and 2) and the tests repeated to measure the degree of force reduction obtainable as well as possible reductions in curve resistance and gains in fuel savings.

This *Technology Digest* (TD) is the last of three TDs reporting the effect of superelevation on vehicle/track interaction.

The first TD reported on wheel/rail forces developed at balance and under imbalance conditions both from theory as well as limited parametric tests conducted at the TTC. It suggested that wheel / rail forces are minimized under balance conditions and that if balance was not always possible, curving with cant deficiency produced more favorable force conditions than curving with excess cant.

The second TD reported on the choice of test site for the generation of these test results. In that report, the cant design was analyzed with respect to railroad instructions. It was concluded that some railroad instructions favored curving with excess cant and suggested a possible alternative approach for the test curve in question.

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



INTRODUCTION

Transportation Technology Center, Inc. (TTCI) was tasked by the Association of American Railroads 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 conditions¹
- Tests on single cars in curves at the TTC¹
- In-service tests at an instrumented crib in a 4.5-degree curve on a 1.22 percent grade with 3.5 inches cant²

The theoretical studies and single car tests¹ concluded:

- Consideration be given to super-elevating curves considering:
 - The *spectrum* of prevailing train speeds.
 - Where possible, the speed of the prevailing *maximum* tonnage.
- Heavy trains curving with excess cant generally impose high vertical and lateral loads on the low rail. This is associated with low rail rolling contact fatigue (crack formation, material flow and wear).
- Trains curving with cant deficiency will impose higher vertical loads on the high rail; however, theory suggests that under cant deficiency, cars/trucks curve with:
 - Reduced angles of attack because of lower lateral forces to the center of the curve¹
 - Lower high rail L/V ratios (because of the higher vertical load, L)
- Consequently it is preferable to have the heavier traffic running under conditions of cant deficiency rather than with excess cant

A test site was chosen with the following characteristics:²

- Tight curvature to maximize the lateral components of the coupler forces and the influence of these forces on wheel/rail forces.
- Appreciable grade where all locomotives in the train are operating consistently at maximum power, tractive effort (and constant speed).
- Relatively consistent train configurations with predominantly similar cars so that results from the instrumented cribs could be analyzed statistically.

Details of the site are reported in reference 2.

This TD reports on the results of the in-service tests.

ANALYSIS

Review of test site:²

- 4.5-degree curve
- Cant = 3.5 inches
- 1.22 percent grade

Vertical and lateral wheel loads were measured at two closely spaced instrumented cribs.

- The data was from each crib was similar and so data from crib 1 only was used.
- Train configurations were inspected and data was only analyzed in detail for:
 - 100- to 110-car trains with two lead and two trailing locomotives (Figure 1)

Trains operated at speeds between 12 and 13 mph so as to maintain an inferred tractive effort within 6 percent (Figure 2).



Figure 1. Train Configuration

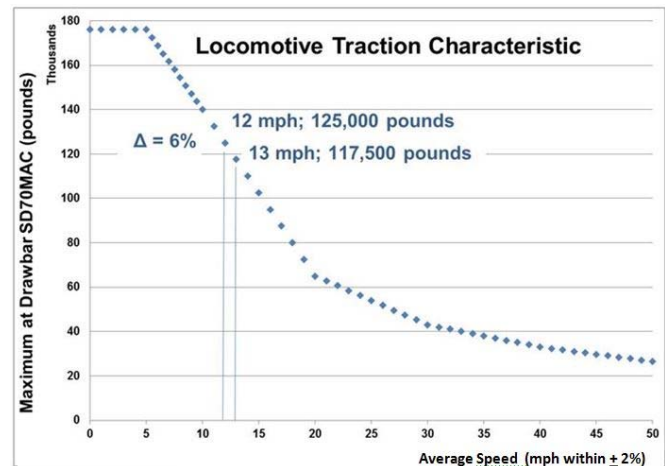


Figure 2. Locomotive Traction Characteristic

This approach was considered convenient, as coupler forces within the train could be assumed, statistically, to vary linearly from a maximum tension on the lead car to an equal but opposite compressive force on the trail car with approximately zero force in the middle of the train.

Vertical Forces

Each train of the chosen type was analyzed separately with vertical force data presented, typically in Figure 3.

The difference in vertical wheel load between high and low rail for all lead axles is plotted against position in train. A linear regression line was then determined for the train being analyzed. This line will later be compared with other trains; however, it is indicative of the load transfer across the axles of the cars as a result of the following:

- Curving with excess cant (this is the value of approximately 5,700 pounds experienced by the middle car in the consist)
- The lateral component of the coupler force (this is the difference in the value of 7,100 pounds at the lead locomotive and the 5,700 pounds at the middle car)

Interestingly, the speed of each train, measured at the instrumented crib, reduced from approximately 11.8 mph for the lead car to 11.4 mph for the 40th car passing the crib; it then increased to approximately 12 mph as the last car passed

the crib. It is presumed that the reduction in speed is because of the increased rolling resistance of the train as it spans three 4.5-degree curves when the 40th car passes the instrumented crib (see inserted track diagram in Figure 3). This resistance will reduce as the train exits the trailing 4.5-degree curve and enters the next (2-degree) curve (inserted diagram Figure 5). This observation may be useful in any future tests where the cant might be reduced, as it may provide information on possible energy savings to be obtained through a more optimal cant design.

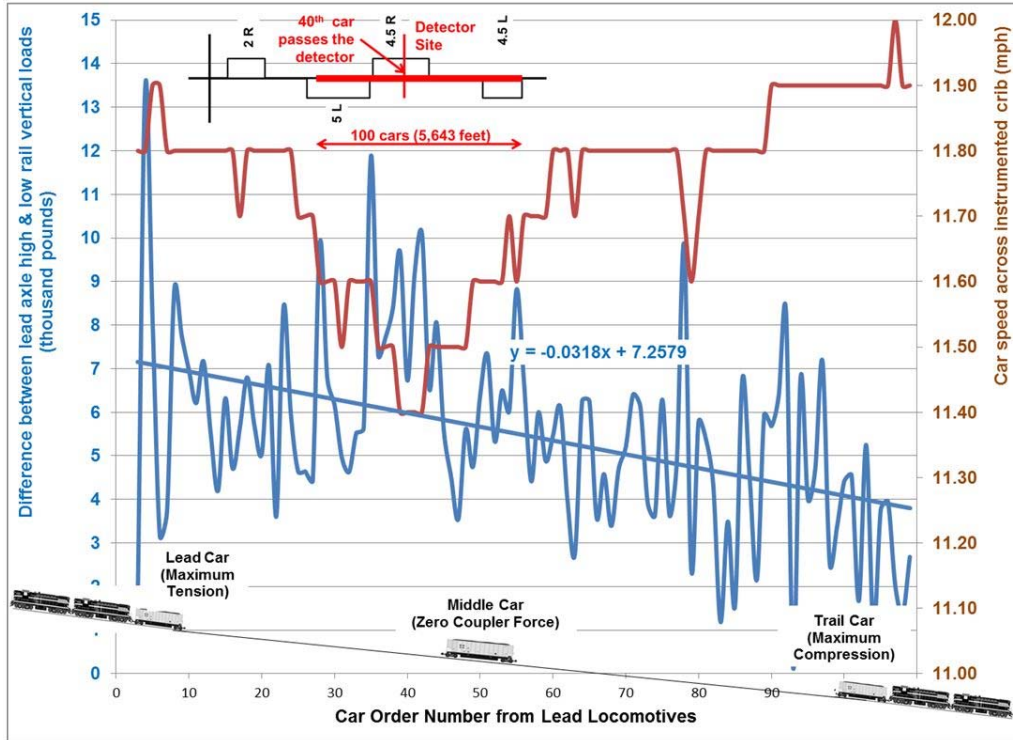


Figure 3. Car Vertical Wheel Load Differential across each Lead Axle in a Truck and Car Speed vs. Car Position in Train

The vertical load transfer data from each train was then superimposed (Figure 4). The superimposed regression lines formed two groups of trains: those formed of gondola cars and those with mixed hopper and gondola cars. A net linear regression line was formed for each group of trains with equations:

$$y = -0.0465x + 7.6607 \text{ (gondolas) } \dots\dots\dots (1)$$

$$y = -0.046x + 9.7286 \text{ (hoppers) } \dots\dots\dots (2)$$

If these equations are solved for x = 1 (lead car), x = 50 (mid train car/s) and x = 100 (trail car), Table 1 shows the load transfer across the lead wheelset of the trucks in these positions in the train.

Table 1. Load Transfer Across Lead Wheelsets

	Load Transfer Across Lead Wheelset (x 1,000 pounds)		
	Lead Car	Mid Train Car	Trail Car
Gondolas	7.61	5.33	3.01
Hoppers	9.68	7.43	5.13

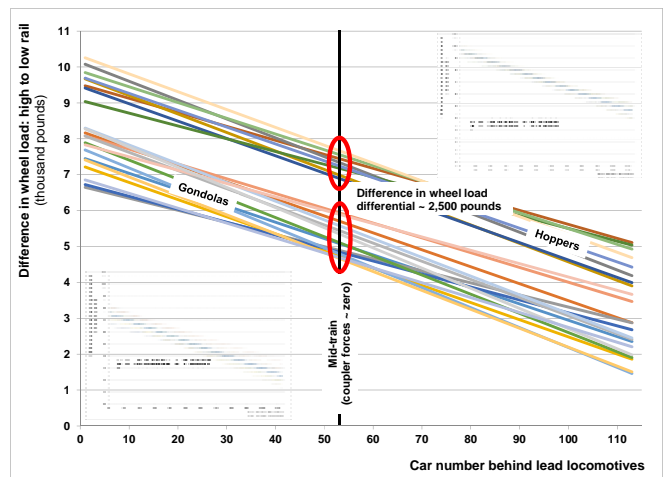


Figure 4. Superposition of Regression Lines of Wheel Load Differentials across Lead Axles vs. Position in Train for Multiple Trains

The mid train values approximate the load transfer due to the excess cant ($3.5 - 0.4 = 3.1$ inch) in this curve 0.4 inches is the balance elevation at 11.5 mph. Consequently, the nominal gain/loss of nominal wheel load is:

$$\begin{aligned} \text{Gondolas:} & \quad (5,330/2)/35,750 = 7.5\% \\ \text{Hoppers:} & \quad (7,430/2)/35,750 = 10.4\% \end{aligned}$$

These values are compared with a theoretical nominal gain/loss of nominal wheel load of 5.4 percent for a car with maximum (96 inches) center of gravity height.¹ Note: the latter value does not account for the lateral or roll deflection of the suspension.

The difference between the mid train load differential values and those for the lead/ trail cars is the load transfer due to the coupler force in buff of two locomotives. This difference is approximately 2,300 pounds for both car types, and it is equivalent to a gain/loss of nominal wheel load of: $(2,300/2)/35,750 = 3.2\%$ for two locomotives, or $3.2\%/2 = 1.6\%$ per locomotive in a 4.5-degree curve, or 6.4% for a car immediately trailing a 4-locomotive consist without the benefit of distributed power.

Consequently, it is concluded that curving with (~3 inches) excess cant in a 4.5-degree curve can produce a gain/loss in nominal wheel load of up to 10 percent with a further gain/loss of approximately 6 percent if head-end power is used.

Lateral Forces

Figure 5 shows the results of a similar analysis of the lead axle low rail forces.

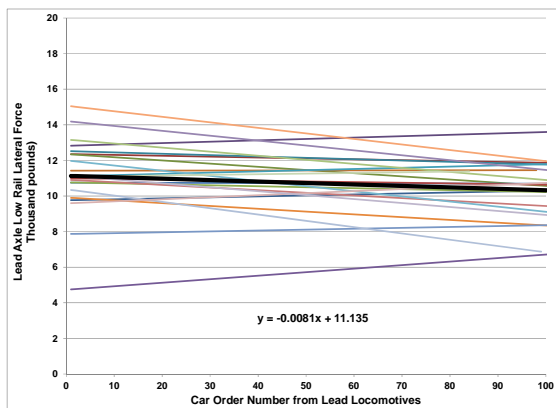


Figure 5. Lead Axle Lateral Wheel Load vs. Car Position in Train

It may be seen that the variation in lateral wheel loads between trains is greater than any variation within a train; this is assumed to be due to frictional variations (limiting friction of 0.45, considering both lateral and longitudinal tractions on the low rail; it possibly occurs under lateral loads of 14,000 pounds).

- The general slope of the curves (0.0081) suggests a maximum 1 percent difference within a unit train of 286,000-pound cars similar in length to coal cars coal train in a 4.5-degree curve.

- The general level of lead axle lateral force of 11,000 pounds measured in the middle of the train (zero coupler force) is similar to forces measured on single cars, equipped with 3-piece trucks, at the TTC.¹

CONCLUSIONS

Revenue service tests in a 4.5-degree curve show the following:

- Significant (~10%) gain/loss in nominal wheel load when curving at 3 inches under balance. This condition can be improved at this site by reducing the cant in the curve from 3.5 inches to 1 inch.²
- Nominal wheel load gain/loss of 1.6 percent due to in-train forces was measured. This becomes significant ($1.6\% \times 4 = 6.4\%$) for trains with head-end power vs. 3.2 percent for trains with the equivalent distributed power.
- Lead axle low rail lateral forces:
 - Measured in the middle of the train (zero coupler force) were of the order of those measured on 3-piece trucks at TTCI¹ in similar curves under a prevailing friction of approximately 0.45
 - Did not change measurably (approximately 1 percent) through the length of the train

Nevertheless, many of the forces measured suggest limiting friction. If so, any attempts to reduce these forces could prove valuable.

The research indicates that the cant in the curve in question, as well as adjacent curves, be lowered to 1 inch (see also References 1 and 2) and the tests repeated to measure the degree of force reduction obtainable as well as possible reductions in curve resistance and gains in fuel savings.

ACKNOWLEDGEMENTS

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REFERENCES

1. Tournay, H. et al. July 2014. "The Effect of Track Cant on Vehicle Curving (1): Theory & Single Car Test Results," *Technology Digest* TD-14-013, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colo.
2. Tournay, H. et al. July 2014. "The Effect of Track Cant on Vehicle Curving (2): In-service Site Selection & Analysis," *Technology Digest* TD-14-014, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colo.
3. Federal Railroad Administration. October 1, 2011. US Department of Transportation, FRA Office of Safety, Track Safety Standards, Part 213, Washington, DC.