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The Effect of Track Superelevation and Speed on Vehicle Curving:

Phase II In-service Test Results

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Summary

Vertical and lateral wheel forces have been measured in a 4.5-degree curve with 1 inch superelevation (track cant), which provided balance conditions for prevailing loaded coal trains at approximately 18 mph while allowing safe maximum speeds up to approximately 36 mph. This test is the second phase (Phase II) of two in-service tests. Prevailing heavy loaded traffic (loaded 286,000-pound car coal trains) operate against the grade through this curve at approximately 15 mph. Wheel loads measured in this test were then compared with those measured at the site in Phase I when the superelevation was 3.5 inches[3] providing balance conditions at approximately 33 mph. This effectively operated the coal trains at 3 inches underbalance, while allowing safe maximum speeds up to approximately 45 mph.

The Phase II tests showed the benefits of operating at balance speed:

- The majority of loaded coal trains operate at or close to balance speed as a result of the reduction in superelevation.
  - Vertical wheel loads are approximately equal on high and low rail.
- Lead axle low rail vertical loads and lateral to vertical (L/V) ratios have been reduced. This should lead to a reduction in low rail wear and rolling contact fatigue (RCF).
- High rail L/V ratios have been reduced, reducing in turn the propensity for flange climb derailments under adverse car, track and operating condition
- Gage spread forces have been reduced, reducing the stresses on track and rail fasteners and reducing the propensity for rail roll.
- It has been inferred from the tests that the rolling resistance in the curve has likely been reduced leading to potential benefits in fuel consumption.

The benefits of operating at balance speed and under the lower force regime associated with balance speed operation will be quantified by testing for wear and RCF using the rolling contact fatigue simulator recently constructed at the Transportation Technology Center.

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.

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INTRODUCTION

In 2012, Transportation Technology Center Inc. (TTCI) was tasked by the Association of American Railroads (AAR) to research the effect of superelevation on vehicle/track interaction, particularly under heavy axle load conditions.

In 2013, TTCI reported the results of theoretical studies and tests on single cars at the Transportation Technology Center (TTC)[1] and recommended that whenever possible curves are superelevated for the speeds of loaded trains, because theory and tests suggest that generally the following are reduced:

- Lead axle high rail L/V ratios, which reduce the propensity for flange climb
- Lead axle low rail L/V ratios, which reduce wear and the propensity for low rail rolling contact fatigue (RCF)
- Gage spread forces, which reduce track and fastener forces

In 2014, the project team selected a site to conduct in-service tests.[2] The site is in a 4.5-degree curve where typical loaded trains operated at approximately 14 mph due to a 1.22 percent grade and where:

- Few other trains operated at balance speed for the 3.5-inch superelevation
- A reduction in track speed associated with reducing superelevation for faster trains would not adversely impact capacity

In 2015, TTCI reported results from in-service (Phase I) tests.[3] Forces were generally as predicted from single car tests conducted at TTC. A reduction in superelevation from 3.5 inches to 1 inch was recommended, followed by validation tests. The superelevation was lowered to 1 inch and the timetable speed was reduced from 40 mph to 30 mph as specified by the host railroad.

This *Technology Digest* presents the results of the subsequent (Phase II) tests.

TEST SITE AND OPERATION

Table 1 shows operational details for Phases I and II for all traffic operating over the site. Figure 1 shows the train speeds in the east direction (against the grade) for all data collected in Phase II. The new balance speed of 17.8 mph is lower and closer to the prevailing speeds of the traffic operating through the site. The maximum speed through the curve was reduced (from 45.4 mph to 36.6 mph), but it only affected a small (< 1%) number of trains operating through the site.

In Phase II, similar trains were monitored to those monitored in Phase I. Track forces were measured in late summer to early fall for both phases.

- 100–110 loaded coal cars (against the grade)
- Two lead and two trail locomotives
- Train speeds (between 10 and 15 mph)

Table 1. Phases I & II In-service test site and Operational Details (All eastbound traffic against the grade)

	Phase I	Phase II
Superelevation (inch)	3.5	1
Curvature (degrees)	4.5	4.5
Grade (percent)	1.22	1.22
Average Speed (mph)	14.0	14.7
Balance Speed (mph)	33.3	17.8
Maximum Speed (mph)	45	36

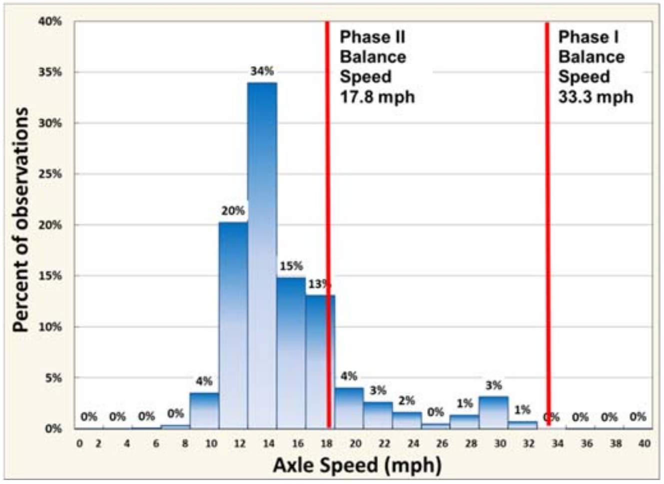

Figure 1. Axle (Train) Speed for All East Traffic – Phase II

Loaded train consists and operations against the grade were the same for Phase I and Phase II with locomotives operating in Notch 8 throttle position.

WHEEL LOADS

Vertical Wheel Loads

Figure 2 shows the difference in vertical wheel loads between the low and the high rail (low rail vertical – high rail vertical) for Phase I and II tests. Table 2 summarizes and compares these results.

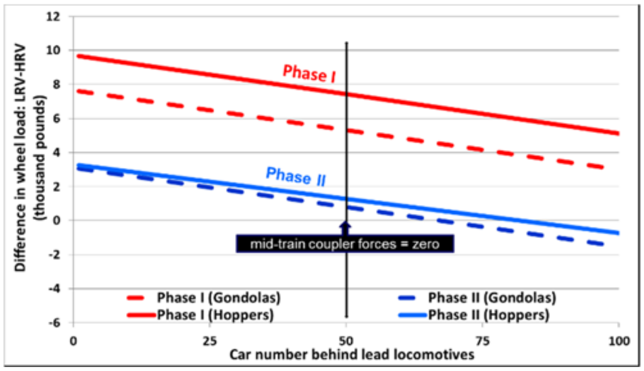

Figure 2. Superposition of Regression Lines of Wheel Load Differentials (low rail vertical minus high rail vertical) across Lead Axles vs. the Position in the Train for Multiple Gondola and Hopper Car Trains

Table 2. Difference in Wheel Load across Lead Wheelsets

		Load Transfer across Lead Wheelset (x 1,000 pounds)		
		Lead Car	**Mid Train Car**	**Trail Car**
Gondolas	Phase I	7.61	5.33	3.01
	Phase II	3.07	0.80	-1.51
Hoppers	Phase I	9.68	7.43	5.13
	Phase II	3.27	1.29	-0.73

Note:

- The difference in mid-train wheel loads between high and low rail have been reduced almost to zero by reducing the superelevation by 2.5 inches.
- For Phase II, the wheel load differential between high and low rail for hopper cars approaches that of gondola cars. Reference to Equation 3 in Reference 1 indicates that this differential approaches zero as balancing speed is reached.[1]
- A reduction in wheel load differential implies a reduction in low rail wheel load. This has the potential to reduce low rail wear and RCF, especially if associated with a reduction in low rail L/V. This will be quantified in future research using the rolling contact fatigue simulator (RCFS).
- The slope of the graphs in Figure 2 is approximately equal for both Phase I and II tests. This is because the slope is a function of coupler force; coupler force is a function of tractive effort and, since the locomotives are operating in Notch 8 throttle position in both tests, tractive effort is approximately equal for each phase.
- Given the same locomotive consists and throttle positions (Notch 8), the trains traveled at a higher speed (14.7 mph vs. 14.0 mph). Reference to the locomotive tractive effort characteristic (Figure 2 in Reference 3) suggests, a lower curving resistance (associated with lower flange and low rail forces). This reduction may be as high as 5,000 pounds x 4 locomotives = 20,000 pounds and reflects potential fuel savings as the train negotiates sharp curves at balance speed vs. curve negotiation underbalance.

Lateral Wheel Loads

Lateral wheel loads are expressed in terms of high rail and low rail L/V ratios and gage spread forces. Figure 3 shows the distribution of low rail L/V forces for Phases I and II.

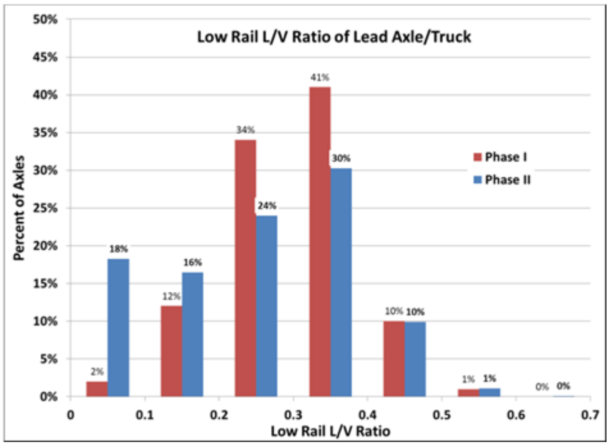

Figure 3. Phase I and Phase II Low Rail L/V Ratios for Lead Wheelsets from Monitored Trains

Note:

- Low rail L/V ratios are generally lower in Phase II tests. Because low rail vertical wheel loads are also lower, the low rail lateral wheel loads are generally lower. This is understandable; as explained in Reference 1, it is the lead axle in low rail contact that reacts to the underbalance forces on the car to the radial center of the curve.
- There are 11 percent fewer wheel loads with low rail L/V ratios > 0.3. These ratios are associated with low rail wear and increased RCF damage (to be quantified in future RCFS research).

Figure 4 shows lower high rail L/V ratios. This is attributed to higher high rail vertical loads for approximately the same high rail lateral loads, which resulted from lower vertical load differentials.

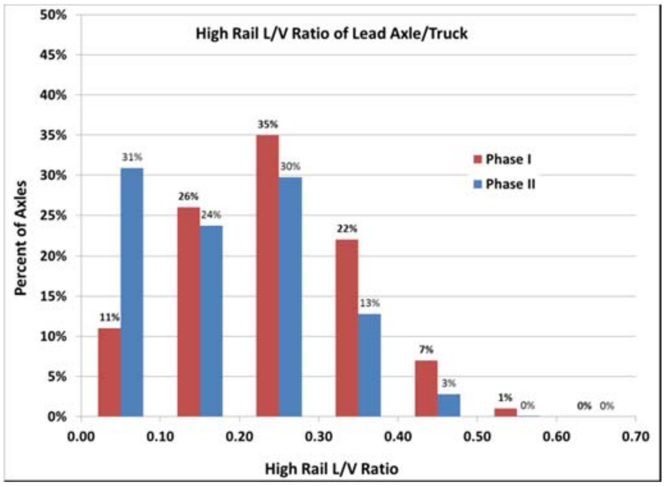

Figure 4. Phase I and Phase II High Rail L/V Ratios for Lead Wheelsets from Monitored Trains

Figure 5 shows lower gage spread forces as anticipated through lower low rail lateral loads, which have the potential to reduce track and track component damage, particularly:

- Damage to rail fasteners
- Fastener and tie damage resulting in rail roll conditions

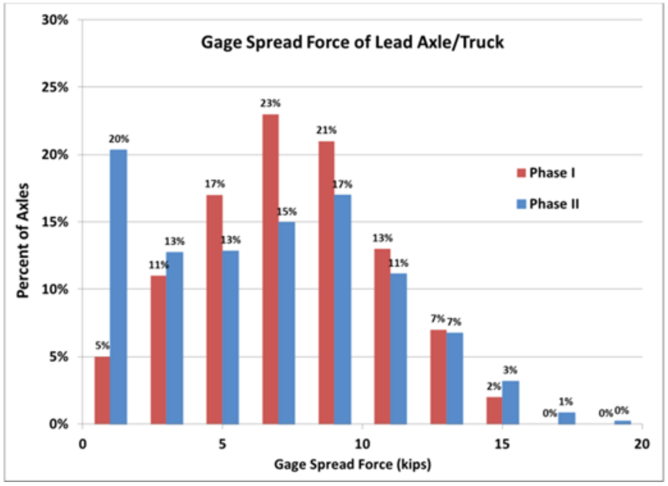

Figure 5. Phase I and Phase II Gage Spread Forces for Lead Wheelsets from Monitored Trains

CONCLUSIONS

Phase II tests have shown:

- The majority of loaded coal trains to be at or close to balance speed as a result of a reduction in superelevation
- A reduction in lead axle low rail vertical loads and L/V ratios, which should lead to a reduction in low rail RCF
- A reduction in high rail L/V, which should reduce the propensity for flange climb derailments under adverse car, track, and operating conditions
- An inferred reduction in rolling resistance in the curve, which could lead to benefits in fuel consumption

WAY FORWARD

TTCI will use the recently constructed RCFS to further quantify the benefits to rail wear and RCF provided by operating trains closer to balance speed.

ACKNOWLEDGEMENTS

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