Effects of Superelevation and Speed on Vehicle Curving in Heavy Axle Load Service

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Research & Tests
“I have a problem with rail wear and gage widening.
I think I found the solution!”

- “I added 2” of elevation to all of my curves!”

- The supervisor is thinking of the highway vehicle dynamics model, where over-balancing centrifugal force causes a vehicle to move toward the low side.

- He believes that as he adds elevation, high rail lateral forces will decrease.
What is the 2\textsuperscript{nd} myth of track maintenance?

- More elevation is better. I can fix my rail wear and gage-widening problems by adding more elevation!

- In theory and in practice, the reverse is true. Elevation above what is needed to achieve balance speed actually increases rail wear and gage-widening!
In theory...

1. Trains curving with excess elevation generally impose greater vertical loads on the low rail and greater steering tractions on the lead axle, resulting in low rail RCF and high gage-spread forces.

2. Trains curving at underbalance elevation impose greater vertical loads on the high rail, however trucks curve with a reduced angle of attack and generate lower lead axle steering tractions with resulting lower L/V ratios.

Can we validate these theories with a field test?

TTCI and NS proposed a revenue service test where these theories could be validated. We looked for a site with these characteristics:

- A high-degree curve to maximize the lateral component of coupler force.
- Repeatable, heavy axle load train consists (similar car types, car weight and train length), such as loaded unit coal and grain trains.
- An ascending grade that causes trains to operate at maximum power and constant speed.
Test site established at Maybeury, WV

- NS’s Bluefield - Portsmouth Line
- 4.5° curve
- 3.5” elevation
- 1.22% ascending grade
- Timetable speed 40 mph
- Balance speed 33 mph
- Consistent unit train make-up
Which trains did we evaluate?

To remove car weight, train length & train tonnage as variables, we looked at trains with:

- 100 – 110 loaded cars (unit trains)
- 4 locomotives – 2 pulling & 2 pushing

Trains were generally all gondolas or all hoppers. Because of the grade, all locomotives operated through the test site in notch 8.
What data did we collect?

- For each axle: speed and vertical & lateral forces
- Date range June 13 – July 1, 2013
- 89 trains
Train speed distribution (Phase 1)

Axle speed distribution of all eastbound trains

Axle speed distribution of target trains
(eastbound, 100-110 cars, 2 + 2 locomotives)
What does a 100-car train, 2 + 2, at 12 mph look like?
What forces act on a car? How are these forces transmitted to the wheel/rail interface?

1. Gravity – the weight of the car

2. Centrifugal force – created by the combination of curvature and speed
   - the load differential between high & low rails is determined by centrifugal force and elevation

3. Coupler force; the lateral component of draft (tension) acts toward the low side; the lateral component of buff (compression) acts toward the high side
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4. **Axle steering forces**
Impact of coupler forces on vertical wheel load distribution between low and high rails

• First video segment: Coupler buff force rotates car body, and pushes truck, toward high rail.

• Second video segment: Coupler draft force rotates car body, and pulls truck, toward low rail.

How much of this model reflects full-scale conditions?

➢ Car body rotation and vertical load transfer – yes
➢ Truck translation – probably not
Vertical wheel load differentials, lead axles, vs. position in train (Phase 1)

100-110-car unit trains with locomotives 2 + 2

- Graph shows wheel load differentials (low rail minus high rail) of multiple trains: top bundle includes hopper trains (higher CG); bottom bundle includes gondola trains (lower CG).

- Wheel load differential at mid-train (red circles), the point of zero coupler force, is due entirely to elevation: 7+ kips for hoppers & 5+ kips for gons.

- Differentials above and below these values are due to coupler draft (head half) and buff (rear half) force.
For a one train, vertical wheel load differential and speed, lead axles, vs. position in train (Phase 1)

- Train is represented head-end (left) to rear-end (right)
- Blue lines represent vertical wheel load differentials; the differential is greatest at the head end
  - Vertical differential varied from roughly 7 kips (more weight on low rail) to 4 kips.
- Red line represents train speed
  - Train speed varied between 12.0 and 11.4 mph; minimum speed was recorded when the train occupied the three 4.5° curves simultaneously

Tournay, Harry, et al: The Effect of Track Cant on Vehicle Curving: In-service Test Results Part III of III, TD14-015, Transportation Technology Center, July 2014
Lateral force on low rail (lead axles of lead trucks) vs. position in train (Phase 1)

- Lateral force lines for most trains show a very slight decrease from head end to rear end.
- We do not see the same coupler force effect on lateral wheel/rail forces that we do on vertical wheel/rail forces; lateral forces appear to be largely independent of position in train.

Tournay, Harry, et al: The Effect of Track Cant on Vehicle Curving: In-service Test Results Part III of III, TD14-015, Transportation Technology Center, July 2014
Conclusions (Phase 1)

- Balance elevation for trains operating on a 4.5° curve at 11.5 mph is 0.4”. With actual elevation 3.5”, the majority of tonnage trains operate at 3.1” excess (overbalance) elevation.

- There is significant wheel load transfer when curving at 3 inches underbalance. Load transfer was on the order of 10% (3.7 kips) for higher-CG hopper cars.

- Additional wheel load transfer of up to 3.2% (2.3 kips) was measured due to coupler forces applied by 2 locomotives (if all 4 locomotives were pulling, wheel load transfer would be up to 6.4% (4.6 kips)).

- Coupler buff & draft forces have a significant impact on vertical wheel load transfer, but a minimal impact on lateral forces as measured at the wheel/rail interface.

Recommendation

Add a phase 2 to the test:

- Reduce the elevation of the test curve and the two adjacent curves to 1” (minimum curve elevation on NS is 1”).

- Repeat the data collection to measure changes in speed and lateral & vertical forces.
Following Phase 1, we asked this question: Can we reduce elevation to see how vehicle dynamics change?

Objective: Convince Pocahontas Division Transportation to reduce speed on 1.1-miles of track from 40 mph to 30 mph, and ask Engineering to reduce elevation from 3-1/2” to 1”
How did we justify our request?

1. Advancement of our knowledge of train dynamics; in other words, research!

2. Only a small number of trains would be adversely affected by a 10 mph speed reduction

Speed of traffic as a function of MGT, all trains, both directions,

Tournay, Harry, et al: The Effect of Track Cant on Vehicle Curving : In-service Test Results Part III of III, TD14-015, Transportation Technology Center, July 2014
Speed and track changes for Phase 2

- Transportation agreed to reduce speed from 40 mph to 30 mph through the three 4.5° curves.
- Engineering was able to reduce elevation with a minimum of trackwork – elevation could be reduced on an inside track without concern for clearance because of wide track centers; and sufficient ballast was available on the shoulders.

Track 1 – elevation 1”
Track 2 – elevation 3-1/2”
In Phase 2, what trains and data did we evaluate?

The same type trains:
• 100 – 110 loaded cars (unit trains)
• 4 locomotives – 2 pulling & 2 pushing
• Operation - still in notch 8

The same data:
• For each axle: speed and vertical & lateral forces
• Date range Aug 27 – Oct 10, 2015
• 85 trains

Data analysis
• Train speed
• Vertical wheel load differential
• L/V ratios, high and low rails
• Gage-spread force
Train speed distribution, Phases 1 & 2

Phase 1 - Axle speed distribution of target trains (eastbound, 100-110 car and 2 + 2 locomotives)

Phase 2 - Axle speed distribution of target trains (eastbound, 100-110 car and 2 + 2 locomotives)
Vertical wheel load differentials (lead axles of lead trucks) vs. position in train, Phases 1 & 2

Regression Lines of Wheel Load Differentials Across Lead Axles vs. Position in Train for Multiple Gondola and Hopper Trains.

<table>
<thead>
<tr>
<th>Load Transfer Across Lead Wheelset (x1000 pounds)</th>
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<tbody>
<tr>
<td>Lead Car</td>
</tr>
<tr>
<td>Gondolas</td>
</tr>
<tr>
<td>Phase I</td>
</tr>
<tr>
<td>Phase II</td>
</tr>
<tr>
<td>Hoppers</td>
</tr>
<tr>
<td>Phase I</td>
</tr>
<tr>
<td>Phase II</td>
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</tbody>
</table>

Table: Load transfer (in kips) across lead axles for gondolas and hoppers at three locations in train (lead, middle & trail car). The difference between gondola and hopper values is due to a different CG.
High rail L/V ratio (lead axles of lead trucks), Phases 1 & 2

High rail L/V ratios decreased from Phase 1 to Phase 2.

Primary reason: The “V” in L/V increased, due to less wheel load transfer from the high rail.
Low rail L/V ratio (lead axles of lead trucks), Phases 1 & 2

• If high rail L/V decreased because of an increase in “V,” can we expect that low rail L/V would increase because of a corresponding decrease in “V”?  

• In fact, low rail L/V ratios actually decreased from Phase 1 to Phase 2!
Why did low rail L/V ratios decrease?

Lateral force on the low rail is generated by friction between wheel tread and rail. Maximum lateral force occurs when the friction is saturated - when \( F = N \times \mu \). By reducing \( N \) (due to load transfer), maximum lateral (friction) force is also reduced.
• Gage-spread force is the smaller of high and low rail lateral forces.

• Reducing the elevation reduced gage-spread forces – note a reduction in the 4 – 12 kip bins and a 15 percentage-point increase in the 0 – 2 kip bin.
Conclusions

When operating closer to balance speed, lead axles demonstrated:

- Smaller vertical wheel load differentials between high and low rails
- Reduced high rail L/V ratios
- Slightly reduced low rail L/V ratios
- Reduced gage-spreading forces
- No measurable change in speed

For the lowest stress and the least maintenance,

- Consider the full spectrum of train speeds
- Identify the dominate tonnage trains
- Try to balance the speed or elevation for those heavy trains
Acknowledgements – who gets the credit for this project?

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Questions & Discussion