Effects of Superelevation and Speed on Vehicle Curving

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- "I added 2 inches of elevation to all of my curves!"

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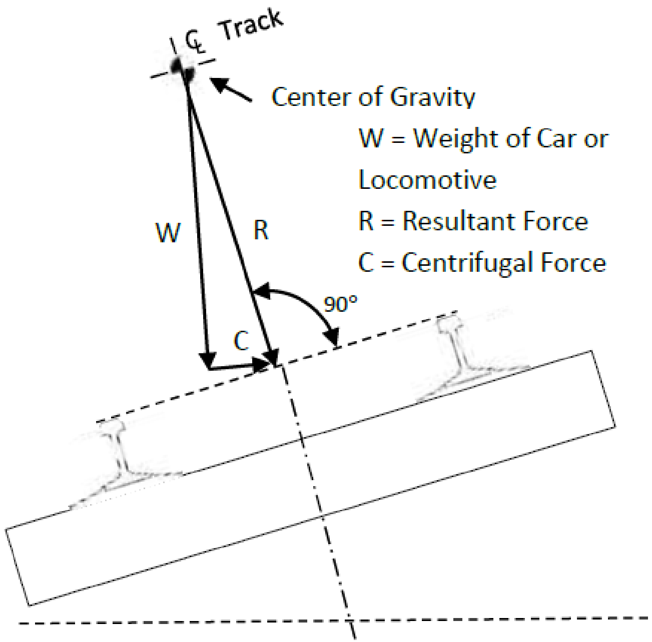
- "I added 2 inches of elevation to all of my curves!"
- The supervisor is thinking of the highway vehicle dynamics model, where over-balancing centrifugal force causes a vehicle to move toward the low side.
- He believes that as he adds elevation, high rail lateral forces will decrease.

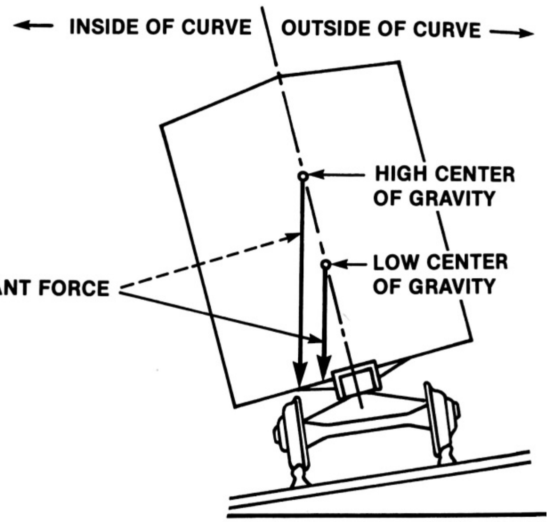
What is the 2nd myth of track maintenance?

- “More elevation is better.”

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



In theory…



Source: AAR, FRA, RPI, TDC: Track Train Dynamics to Improve Freight Train Performance, Report R-185, 2nd Edition, 1986

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

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

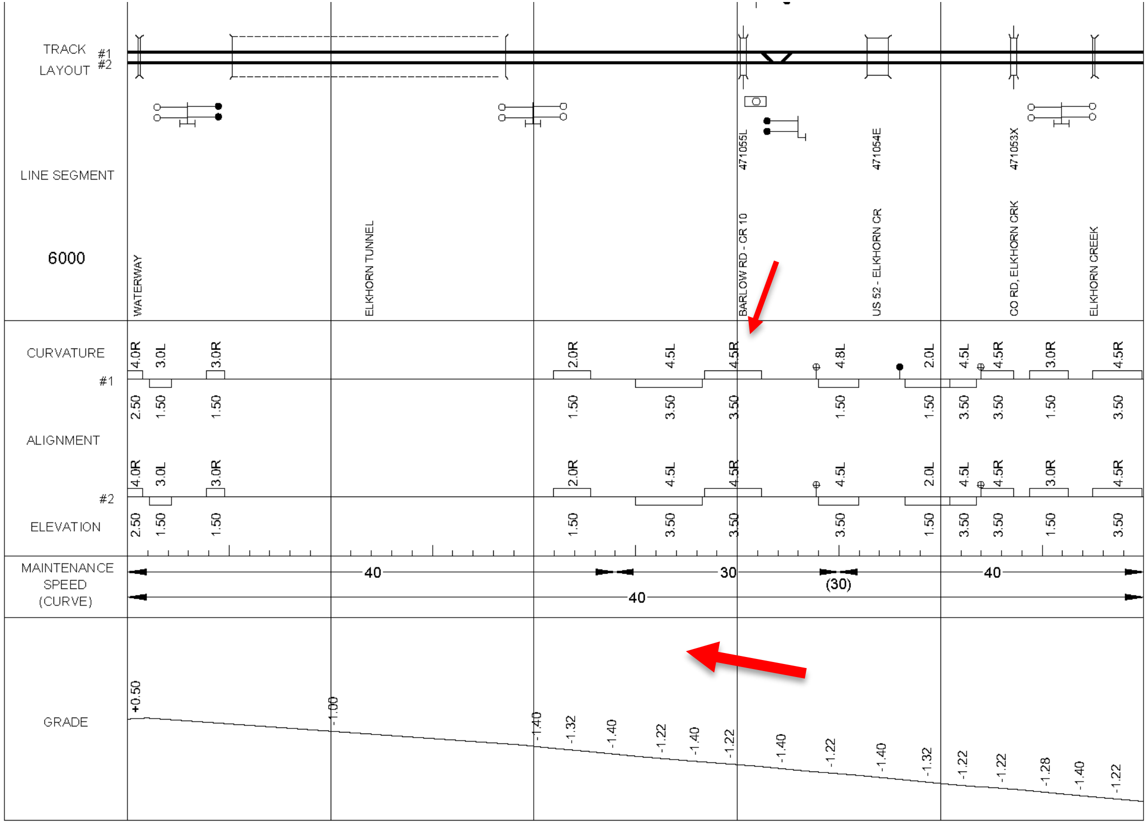
Can we validate these theories with a field test?

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 <u>maximize the lateral component of coupler force</u>.
- Heavy axle load trains of similar car types, car weight and train length, such as loaded unit coal trains.
- An ascending grade that made trains operate at maximum power and constant speed.

Test site established at Maybeury, WV

- Former N&W main between Bluefield & Portsmouth
- 4.5˚ curve
- 3.5 inches elevation
- 1.22% ascending grade
- Timetable speed 40 mph
- Balance speed 33 mph
- Consistent unit train make-up



Which trains did we evaluate?

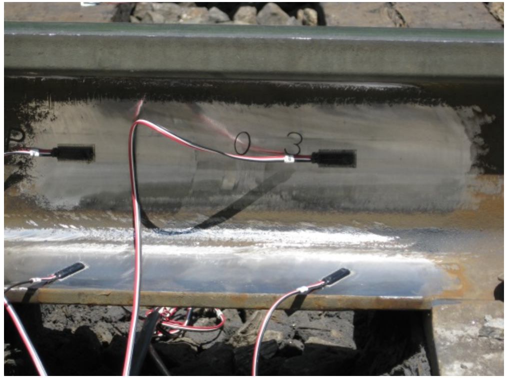
To remove car weight, train length & train tonnage as variables, we looked only at trains with:

- 100 – 110 loaded 286,000 lb. cars (unit trains)
- 4 locomotives – 2 pulling & 2 pushing

Trains were generally all hoppers or all gondolas (tubs)

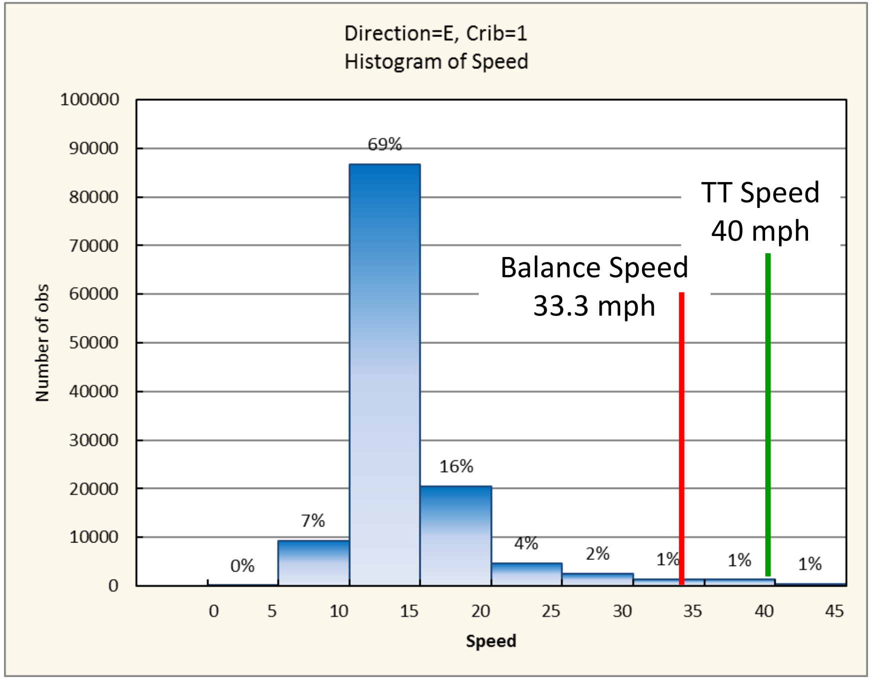
Because of the grade, all locomotives operated through the test site in notch 8.

What data did we collect?

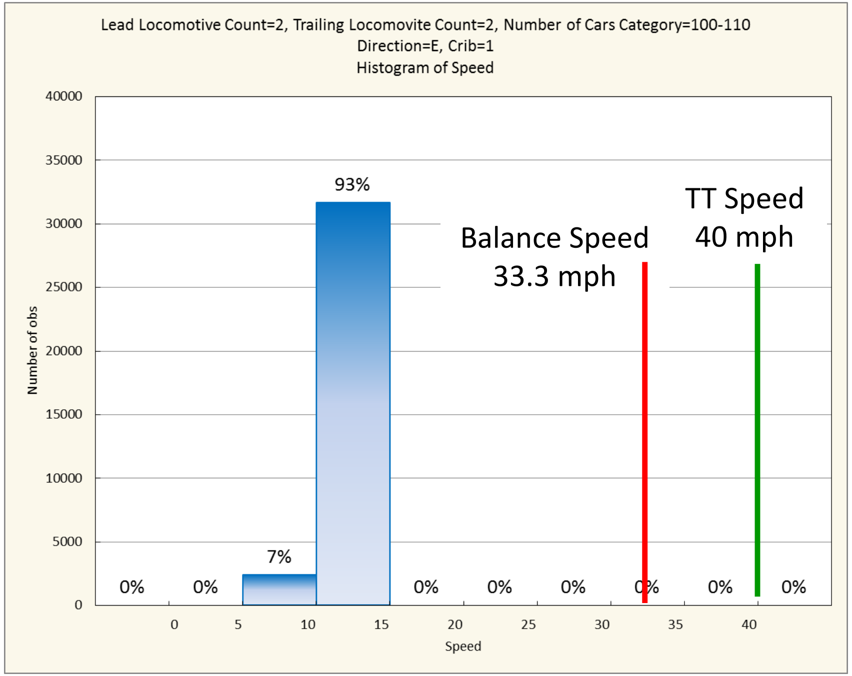


- For each axle: speed and vertical & lateral forces
- Date range June 13 – July 1, 2013 (18 days)
- 89 trains

Train speed distribution



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?

(video 1)

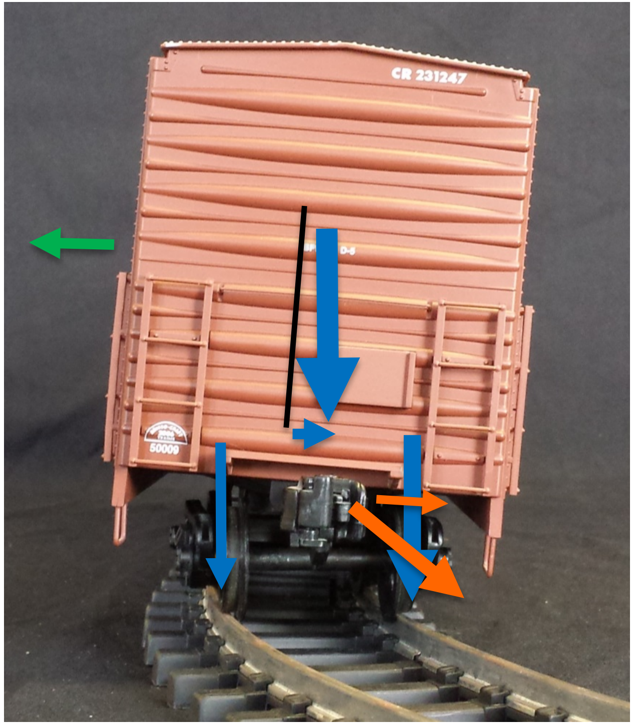
What does a 100-car train, 2 + 2, at 12 mph look like?

(video 1)

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 draft - the lateral component of draft acts toward the low side



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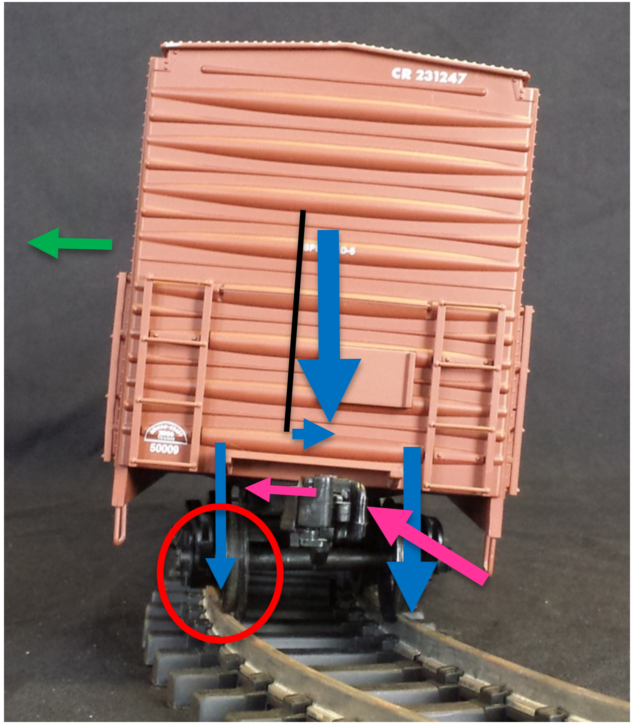
3. Coupler force buff - the lateral component of buff acts toward the high side
4. Axle steering forces



Impact of coupler forces on vehicle curving

(video 2)

- First video segment: Coupler <u>buff</u> force rotates car body, and pushes truck, toward high rail.
- Second video segment: Coupler <u>draft</u> force rotates car body, and pulls truck, toward low rail.

Impact of coupler forces on vehicle curving

(video 2)

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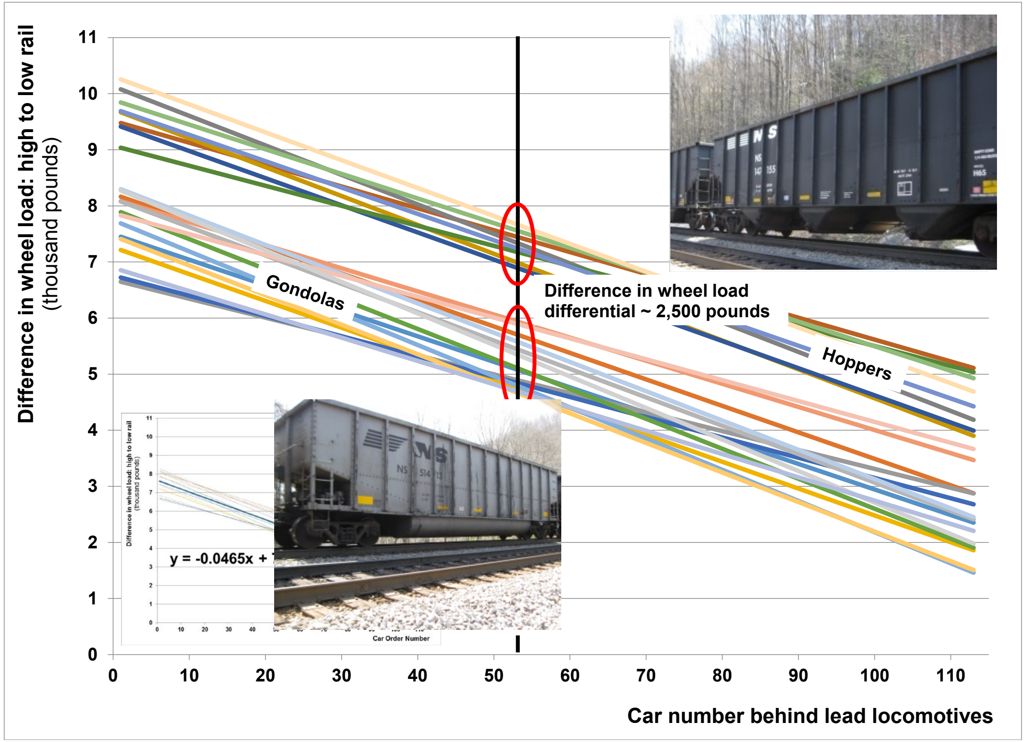
Impact of coupler forces on vehicle curving

(video 2)

How much of this model reflects reality?

- Car body rotation and vertical load transfer – yes (though exaggerated)
- Truck translation – No! Steering forces dominate, keeping the lead axle flanging on the high rail.

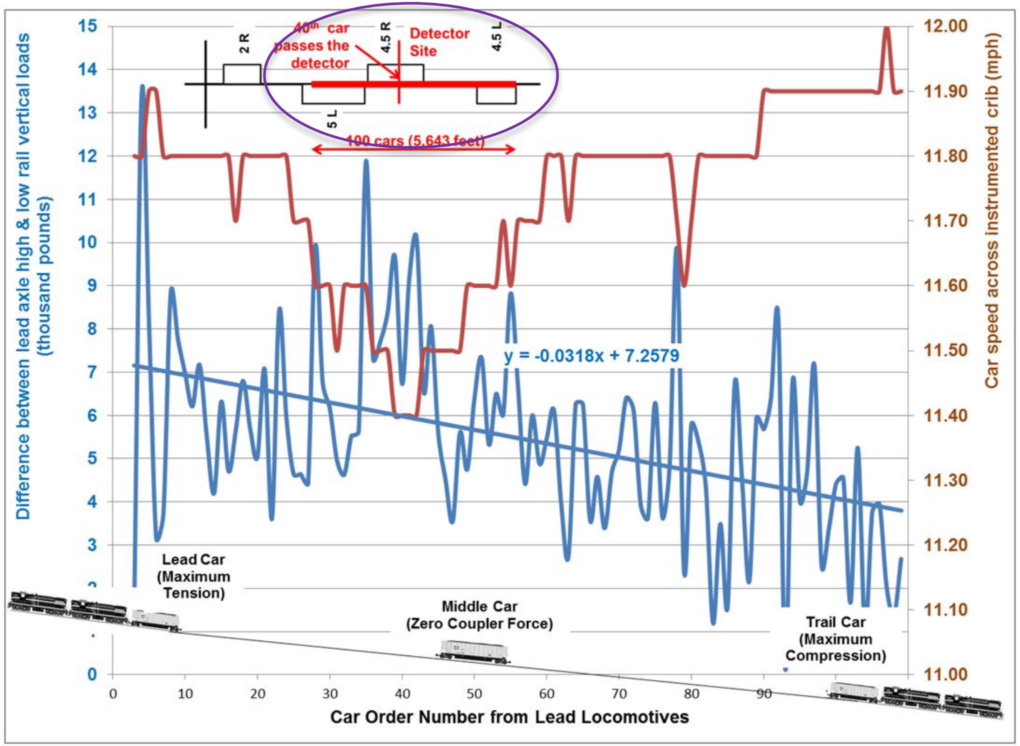
Vertical wheel load differential vs. position in train



- Graph shows wheel load differentials (low rail minus high rail) of multiple trains
- Top bundle - hoppers (higher CG)
- Bottom bundle - gondola
- Wheel load differential at mid-train (red circles), the point of zero coupler force, is due entirely to elevation: (hoppers 7 kips, gons 5 kips).
- Differentials above and below these values are due to coupler draft (head half) and buff (rear half) force.

Source: Tournay, Harry, et al: <u>The Effect of Track Cant on Vehicle Curving : In-service Test Results Part III of III</u>, TD14-015 , Transportation Technology Center, July 2014

Speed & vertical wheel load differential vs. position in train

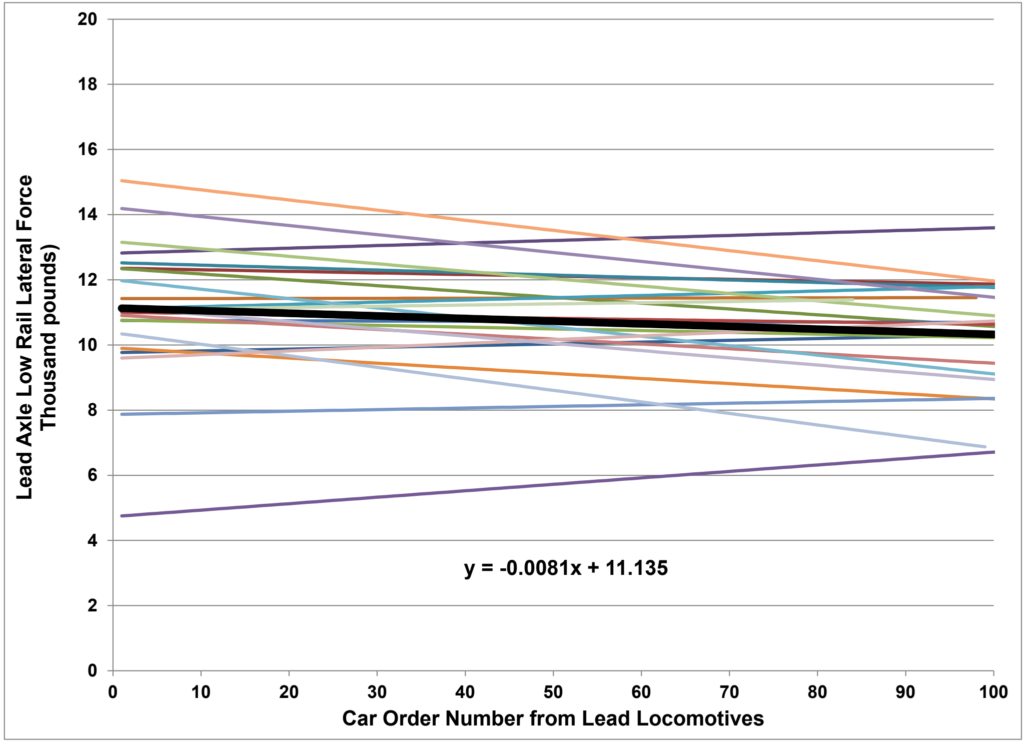


Source: Tournay, Harry, et al: The Effect of Track Cant on Vehicle Curving : In-service Test Results Part III of III, TD14-015 , Transportation Technology Center, July 2014

This graph shows one train

- 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.
- Blue line represents vertical wheel load differential; the differential is greatest at the head end
  - ➢ Calculated differential varied from 7 kips to 4 kips (more weight on low rail).

Lateral force on low rail vs. position in train



- 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 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

- Balance elevation for trains operating on a 4.5˚ curve at 11.5 mph is 0.4 inch. The majority of tonnage trains operate at 3.1 inches excess (overbalance) elevation.
- Significant wheel load transfer occurs at 3 inches underbalance. Load transfer was 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.
- 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

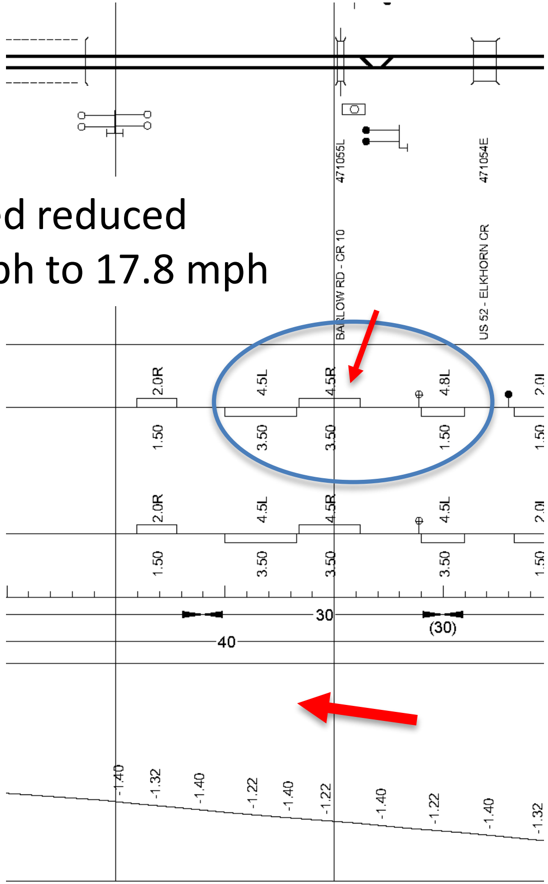
Conduct a phase 2t:

- Reduce the elevation of the the test curve and the two adjacent curves to 1 inch.
- Repeat the data collection to measure changes in speed and lateral & vertical forces.

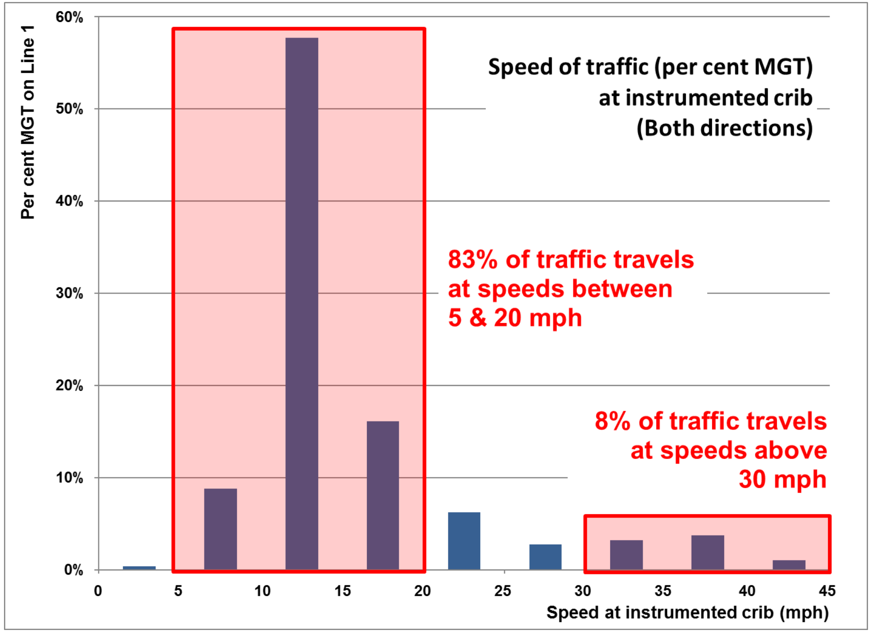
Speed and track changes for Phase 2

- Transportation agreed to reduce speed from 40 mph to 30 mph for a distance of 1.1 miles (through the three 4.5˚ curves).
- Engineering agreed to reduce elevation on those three curves from 3-1/2" to 1".

- Balance speed reduced from 33.8 mph to 17.8 mph



How did we justify our request?



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

Source: Tournay, Harry, et al: The Effect of Track Cant on Vehicle Curving : In-service Site Selection & Analysis Part II of III, TD14-014 , Transportation Technology Center, July 2014

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

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

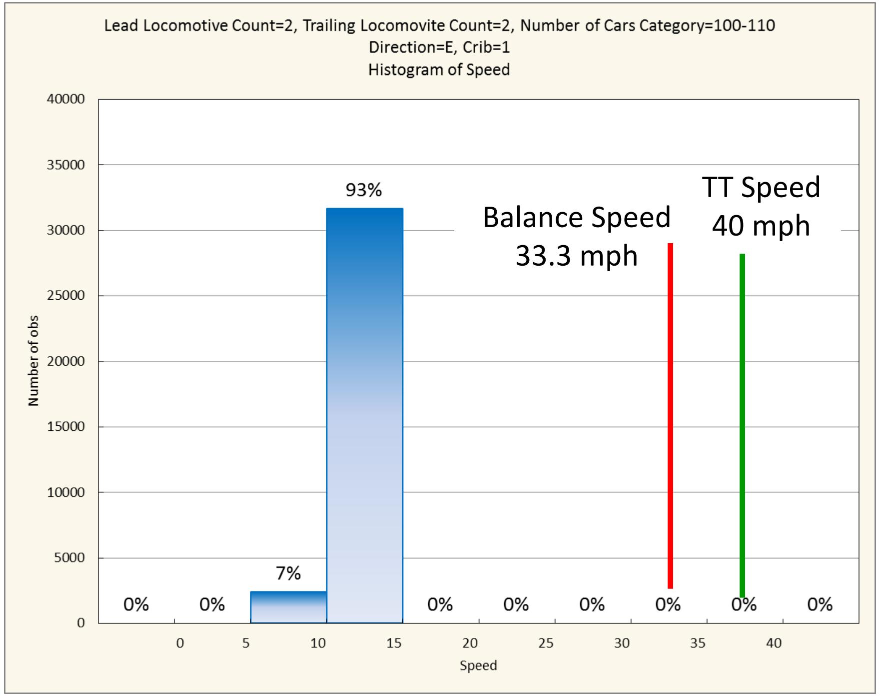
The same data:

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

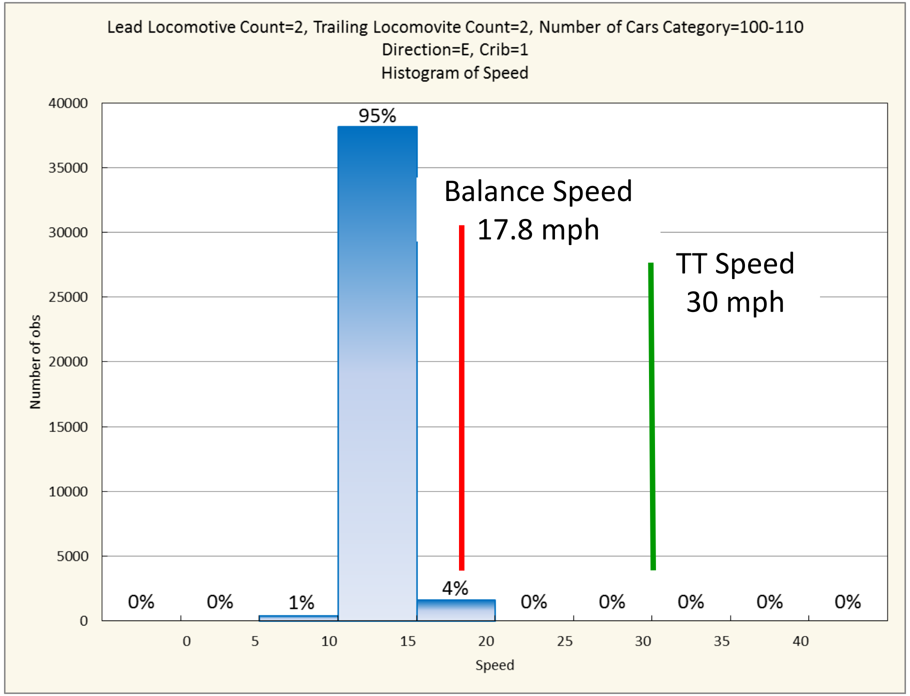
Data analysis – compare Phases 1 & 2

- Train speed
- Vertical wheel load differential
- L/V ratios, high and low rails
- Gage-spread force

Train speed distribution, Phases 1 & 2

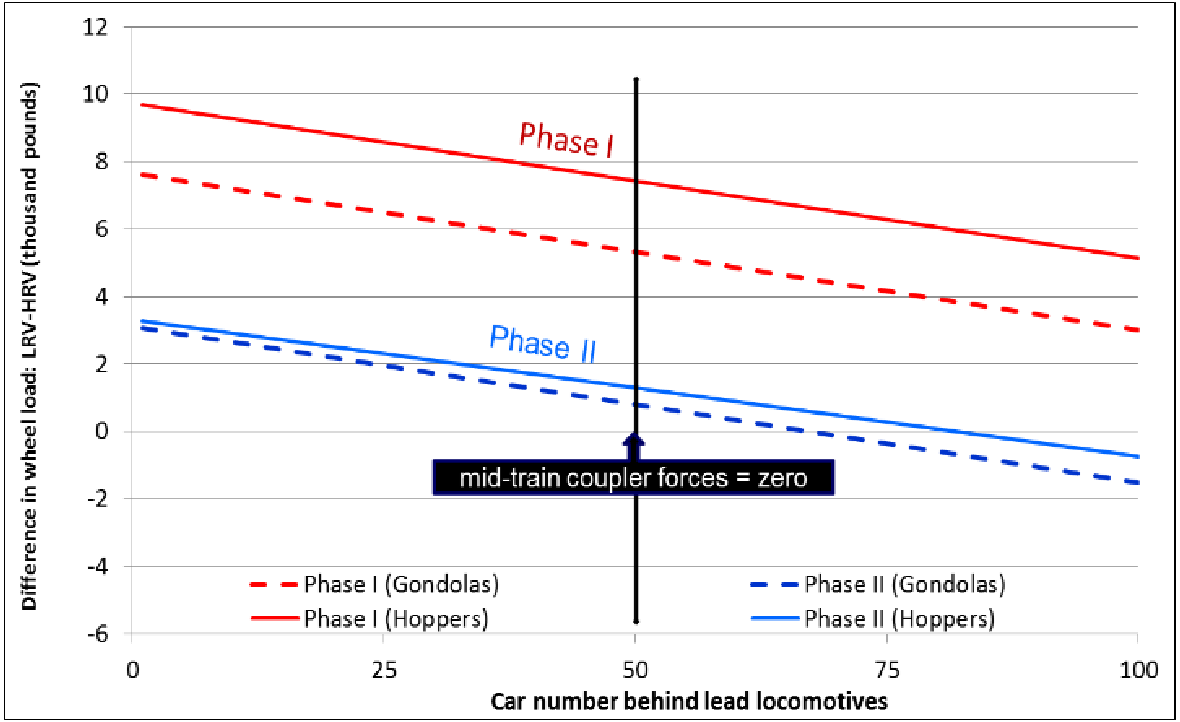


Phase 1 - Axle speed distribution of target trains (eastbound, 100-110 car and 2 + 2 locomotives)



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

Vertical wheel load differentials vs. position in train

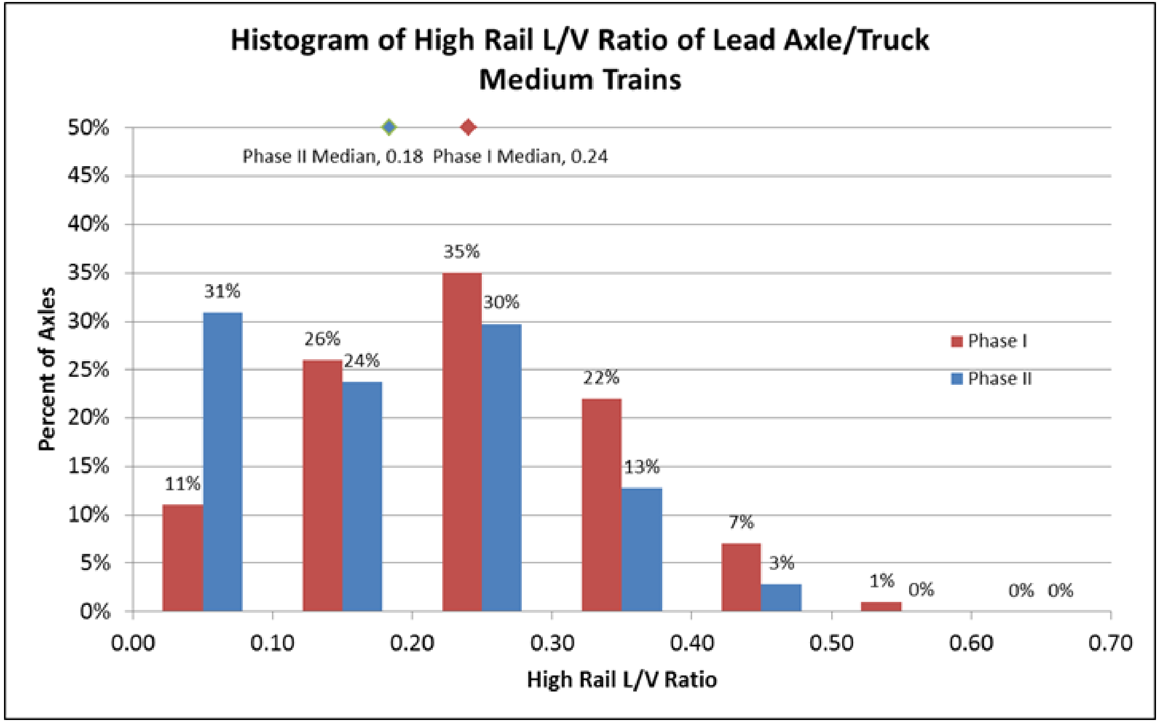


Average wheel load differentials across lead axles vs. position in train, multiple gondola and hopper trains

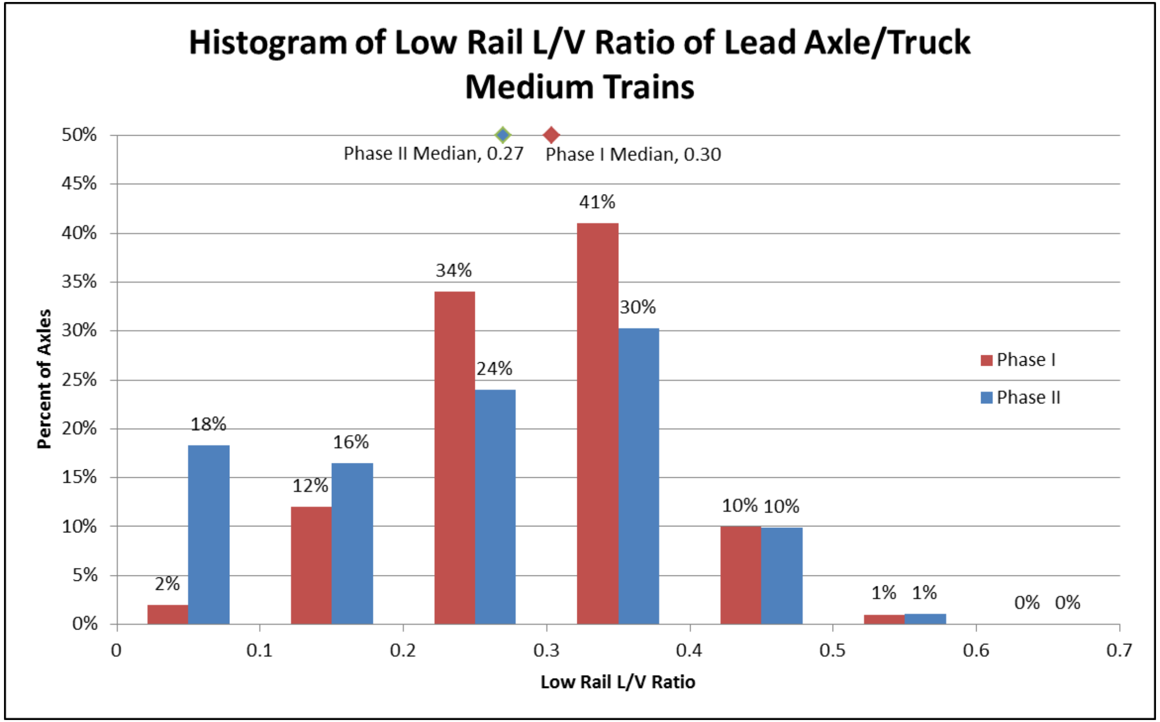
Source: Tournay, Harry, et al: The Effect of Track Cant on Vehicle Curving : In-service Site Selection & Analysis Part II of III, TD14-014 , Transportation Technology Center, July 2014

High rail L/V ratio, Phases 1 & 2

- High rail L/V ratios decreased from Phase 1 to Phase 2.
- Primary reason: In Phase 2, the vertical wheel load "V" in L/V increased, due to less wheel load transfer from the high rail.

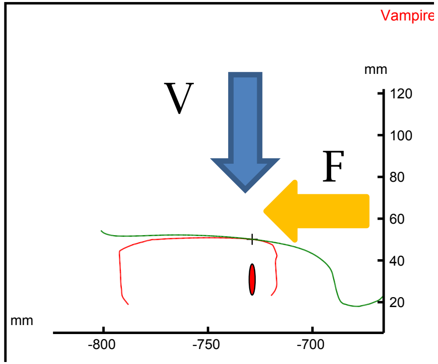


Low rail L/V ratio, Phases 1 & 2

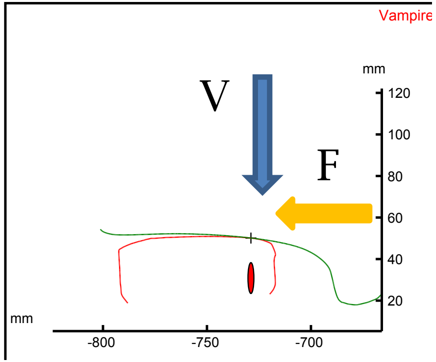


- Previous slide: High rail vertical wheel load "V" increased from Phase 1 to 2, thereby reducing L/V.
- This slide: Low rail vertical wheel load decreased; wouldn't that be expected to <u>increase</u> in L/V?
- In fact, low rail L/V ratios actually decreased from Phase 1 to Phase 2!

Why did low rail L/V ratios decrease?



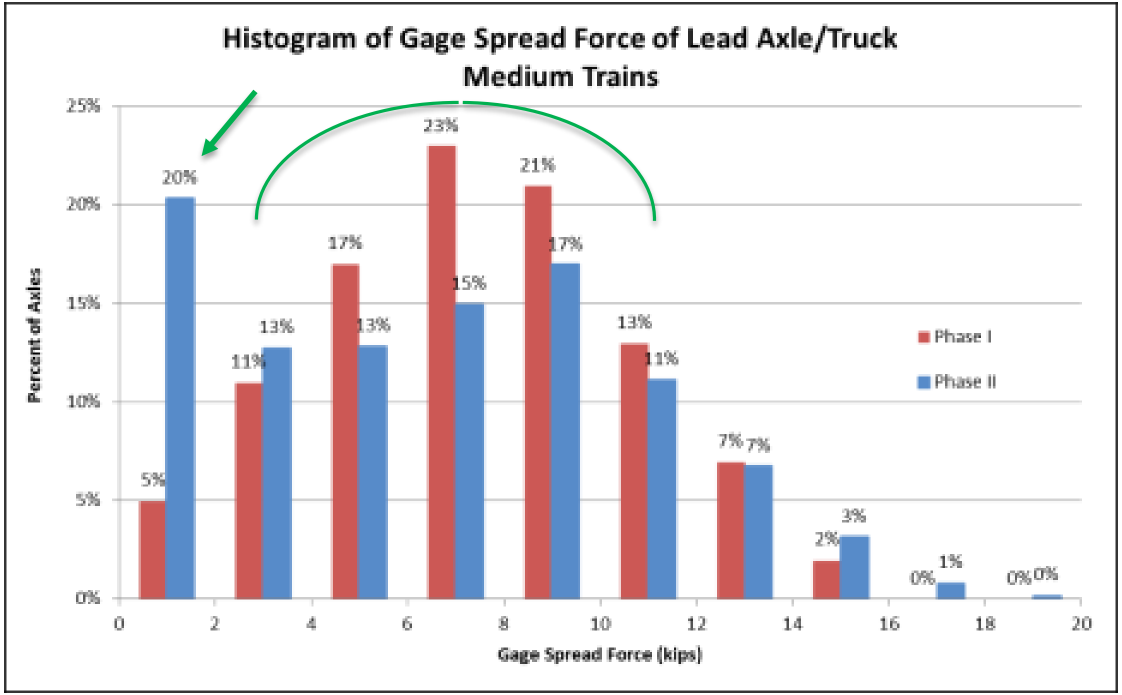
Large V results in large F

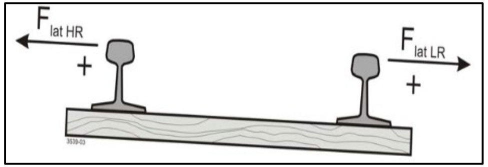


Reduced V results in reduced F

- 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 x µ. By reducing N (due to reduced load transfer), maximum friction force is also reduced.
- But this simply holds L/V constant. The additional reduction in lateral force (and thus the reduced L/V) shown in the previous slide can be explained by improved truck steering.

Gage-spread force, Phases 1 & 2





- Gage-spread force is the smaller of the high and low rail lateral forces
- Gage-spread forces were reduced in Phase 2 (note reduction in the 4 – 12 kip bins and a 15-point increase in the 0 – 2 kip bin)

Impact of Elevation on Rail Wear

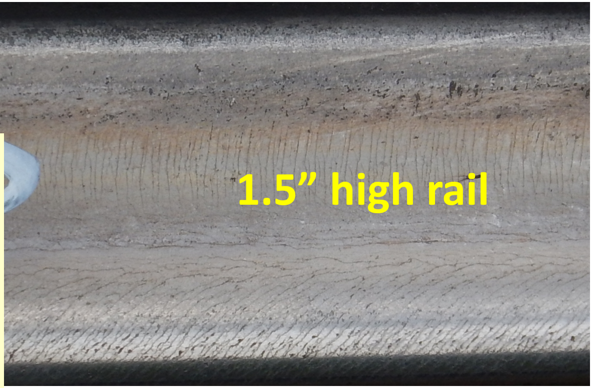
(a second field test, currently under way)

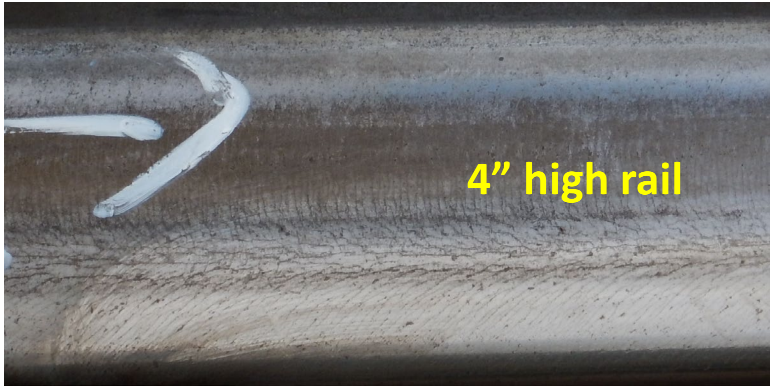
- Two LH 6.2^{o} curves a half mile apart
- New HH rail installed May 2017
- Timetable speed 25 mph (balance e = 2.7”)
- Difference is elevation: one curve has **1-1/2”**, the other **4”**
- Test objectives: Measure differences in geometry (gage, elevation) and rail condition (wear, RCF)
- Base line measurements September 2017
- No grinding
- Test plan - 2 years

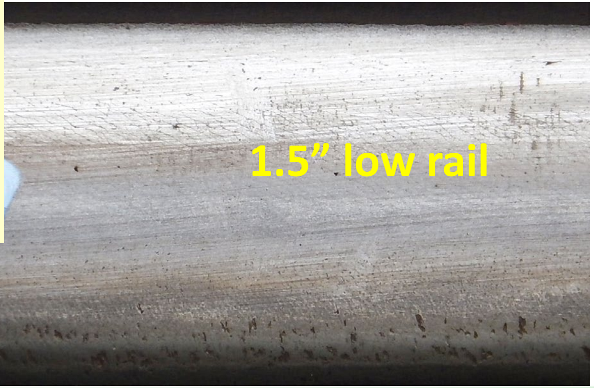
Impact of Elevation on Rail Wear- Results

Results after 18 months (start test Sept 2017, photos April 2019):

- No difference in gage or elevation
- 4” curve showing slightly more RCF (cracks and spalls) on both H and L rails







Conclusions

When operating closer to balance speed, lead axles demonstrated:

- Smaller vertical wheel load differentials between high and low rails
- Reduced high rail and low rail L/V ratios and gage-spreading forces

Early indications from the current rail performance test:

- When operating over balance speed, rail exhibits slightly less RCF.

For the lowest stress and the least maintenance,

- Identify the dominate tonnage trains
- Try to balance the speed or elevation for those heavy trains

Acknowledgements – who gets the credit for this project?

- Strain gauge & data collection equipment – Instrumentation Services & Kevin Conn (NS)
- Project originator and data analysis – Harry Tournay (TTCI)
- Additional data analysis & graphs – Chris Pinney, Russ Walker, Ryan Alishio, Sabri Cakdi & Kenny Morrison (TTCI)
- Changes to train speed and track elevation – NS's Pocahontas Division

Questions & Discussion