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Root Causes of Rail Roll/Reverse Rail Cant and Remedies

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Summary

Transportation Technology Center, Inc. (TTCI) has been working with Norfolk Southern (NS) to investigate the root causes of rail roll/reverse cant and the remedies for preventing rail rollover derailments under the Association of American Railroads' Strategic Research Initiatives Program.

The investigation indicates that the following vehicle/track conditions contribute to the initiation of reverse cant and the progression to rail roll, which increase the risk of rail rollover derailments:

- Rail cant restoration and re-gaging can cause very high lateral forces. These activities tend to move the contact position toward the field side of high and low rails if the rail profile is not corrected by rail grinding. The high rail tends to have strong two-point contact, resulting in poor curving performance.
- Excessive high rail gage corner relief during grinding also increases the instances of two-point contact.
- Weak rail restraint and field side tie plate cutting. The investigation indicated that cut spikes do not provide sufficient and sustainable restraint against rail roll on curves under adverse vehicle/wheel conditions.
- High wheel/rail lateral forces caused by wheel/rail contact conditions that do not generate sufficient truck steering moments.
- Vertical load applied toward the field side of rail due to poor wheel/rail profile contact, resulting in low B/H ratios (the ratio of the lateral distance of contact point to rail base field side corner and the height of the rail).
- Asymmetrically worn wheels which produce high lateral forces on both leading and trailing axles.
- High rail roll risk increases when the adjacent trucks both produce high lateral forces.

In April 2011, an instrumented test site was established in a 7.8-degree curve on NS track with timber ties/cut spikes and a history of reverse rail cant to investigate the effects of track maintenance practices on wheel/rail lateral forces. Through September 2011, the test site operated with five different track maintenance conditions: original condition with reverse rail cant, grinding cycle 1, high rail gaged with elastic fasteners, low rail gaged with elastic fasteners and application of top-of-rail friction modifier (TORFM), and grinding cycle 2.

The measured force data indicated that restoring and restraining the high rail produced very high lateral forces and significant low rail rotation. Application of TORFM, in combination with restoring the low rail and adjusting track gage, considerably reduced lateral forces even under undesired wheel/rail contact patterns. Rail cant caused an improper application of the grinding template in grinding cycle 1, resulting in excessive gage side and insufficient field side metal removal with no reduction in lateral forces. Rail grinding cycle 2 was more effective in reshaping the rail, and the slight change in wheel contact location on the high rail resulted in a measurable reduction in lateral forces.

Short-term remedies include rail grinding and consistent TORFM application. Long-term remedies focus on developing strategies for achieving stable and consistent wheel/rail contact geometry through rail profile management, improved rail restraint, improved truck/wheel maintenance methods, and wheel removal limits.

Additional testing is planned to distinguish the effects of rail grinding and the application of TORFM on lateral forces.

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INTRODUCTION

Railroads have reported rail rollover derailments, which often occur on curves with existing reverse rail cant (rail rotating to the field side of the track). Based on the track geometry car measurements, the outward rail cant on some curves can exceed 5 degrees under the load (Normal cant is 1:40 to the center of the track).

TTCI is working with NS to investigate the root causes of rail roll and reverse cant and to determine means to prevent rail rollover derailments.

Rail roll derailments have been investigated previously.[1,2,3] This *Technology Digest* confirms previous findings and reports new findings based on measurements made at a test site on NS track.

TRACK AND RAIL CONDITIONS INFLUENCING LATERAL WHEEL/RAIL FORCES

To investigate the effects of track and rail conditions on lateral wheel/rail forces, an instrumented test site was established in a 7.8-degree curve on NS mainline track close to Bluefield, WV. The track structure comprised of wood ties, 8 x18-inch tie plates, and cut spikes; the high rail gage face was well lubricated; the gage was generally 57-1/8 inches unloaded and 57-3/8 inches loaded; both rails showed reverse cant of 3 degrees. Traffic is mostly eastbound loaded coal and westbound empty hopper trains, with bi-directional double-stack and mixed freight traffic. Track speed is 25 mph, with a 0.7 percent ascending westbound grade and 4 inches superelevation (balance speed of 27.3 mph).

Between April 19 and September 6, 2011, lateral forces were measured under five different conditions:

- April 19: Measurements commenced with the track in original condition; both rails had 3 degrees of reverse cant and loaded gage was 57-3/8 inches.
- April 26: First grinding cycle was conducted.
- June 6: High rail rotation was restrained using 8x18-inch tie plates modified for use with elastic fasteners; the track was re-gaged to 56-3/8 inches.
- June 20-21: Low rail rotation was restrained using 8x18-inch tie plates modified for use with elastic fasteners; the track was re-gaged to 56-3/4 inches. Two nearby TORFM units were activated.
- August 23: Second grinding cycle was conducted.

Figure 1 shows the lateral force history for 406 loaded coal trains negotiating the test curve for these five maintenance conditions (the green arrows indicate the beginning of each condition). This data was for trains having at least 75 cars and an average wheel vertical load greater than 28,000 pounds. The root mean square (RMS) value for the lateral forces in the complete train was used to represent the force level for each train.

The reverse rail cant and weak rail restraint resulted in an improper application of the rail grinding template during the first grinding cycle. The ground rail showed excess gage side and insufficient field side metal removal, resulting in two-point contact on the high rail and field side contact on the low rail. Consequently, the strain gage data indicated no improvement in lateral forces as a result of this grinding.

On June 6, when the high rail was restored and the track was gaged to 56-3/8 inches on 18-inch wide tie plates with cut spikes and elastic fasteners, the lateral forces increased significantly. Constraining high rail resulted in strong two-point contact and, consequently, very poor curving performance. Lateral displacement was transferred to the low rail, which rotated up to 7 degrees under a loaded coal train; the risk of rail rollover was increased. The spikes at gage side were found to be raised 7/8 inch over a distance of 40 feet.

Figure 2 displays a frame from a video showing the low rail rotation. The low rail at that section was restrained only by its torsional rigidity and the vertical force applied by adjacent wheels. (The red arrows in Figure 1 indicate when this video, as well as a second, were recorded.)

The bottom graph in Figure 1 shows an increase in lateral forces on the trailing wheels almost equal to the forces of the lead wheels after the high rail was restored (between trains 141 and 181), which suggests the trucks could have had a significant degree of warp.

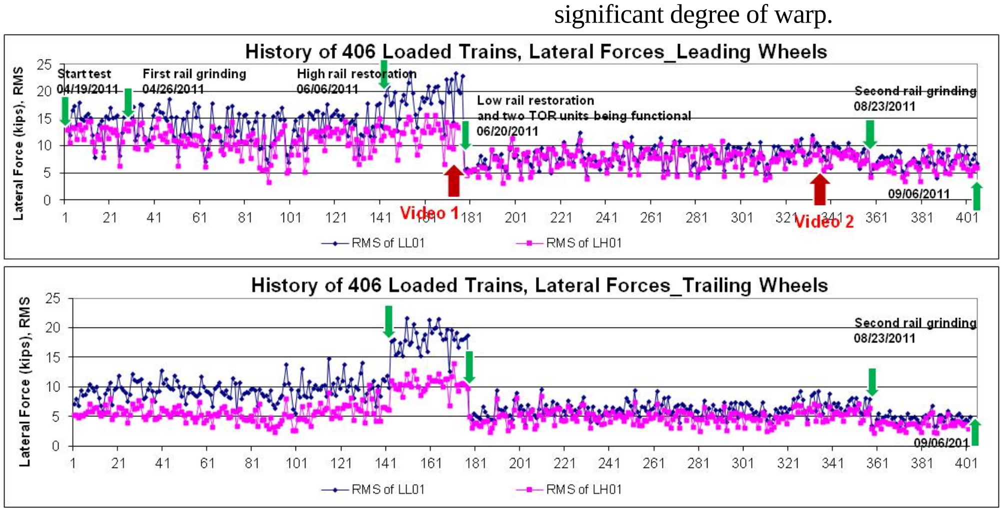

Figure 1. Lateral Force History for 406 Loaded Train Passes (average wheel force > 28,000 pounds, cars per train >75), LL01 – low rail lateral force, LH01 – high rail lateral force. Both high and low rail lateral forces are gage spreading forces.

Figure 2. Frame from a Video Showing Low Rail Rotation under Loaded Coal Train

On June 20, to increase the low rail constraint, wide tie plates and elastic fasteners, similar to those applied previously to the high rail, were also installed (Figure 3). The track was regaged (widened) to 56-3/4 inches.

Figure 3. 18-inch Tie Plates and Elastic Fasteners

On June 21, two TORFM units located 0.5 mile east and 0.5 mile west of the test site were repaired. The combination of 3/8-inch gage widening and the TORFM application lowered lateral forces significantly (Figure 1). The individual contributions of each of these actions are being investigated.

On August 8, the second video was recorded and it showed no rail rotation. Even with greatly reduced lateral forces and the absence of rail rotation, wheel/rail contact patterns were still poor. Many wheels continued to contact the field side of both the high and low rails (Figure 4).

Figure 4. Contact Position toward the Field Side of Both High and Low Rails after Rail Cant Restoration

On August 23, a second grinding cycle included two passes that removed additional metal from the field side of the high rail and five passes that reshaped the low rail, resulting in a further reduction in lateral forces (Figure 1). TORFM was applied before and after the second grinding cycle.

ROOT CAUSES OF RAIL ROLL/REVERSE CANT AND HIGH RISK CONDITIONS

Based on the field observations and analysis of wheel/rail contact patterns and wheel/rail forces, the root causes of rail roll and reverse cant (including both static and dynamic cants) can be summarized as follows:

- High wheel/rail lateral forces caused by poor steering trucks and extreme two-point contact (Figures 4 & 5).[1]

Figure 5. High Rail Showing Strong Two-Point Contact

- Vertical load applied toward the field side of the rails (both high and low) due to undesirable rail profiles, can result in low B/H ratios illustrated in Figures 6 and 7.[2] Excessive wide gage and hollow worn wheels also , contribute to the contact toward the field side.

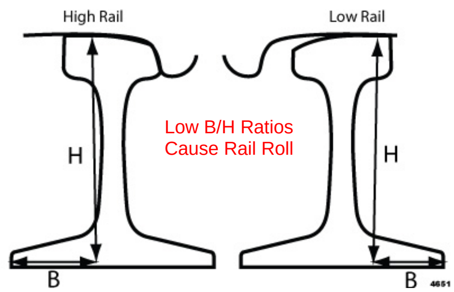

Figure 6. High Risk of Rail Roll under Low B/H Ratios

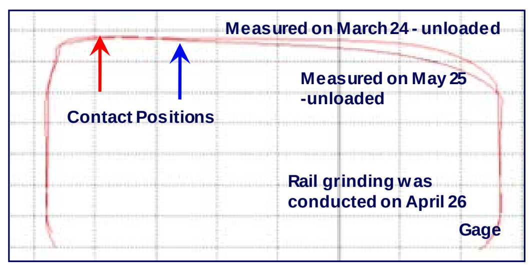

Figure 7. Low Rail Contact Position toward the Field Side

- Weak rail restraint (Figures 2 and 8).[3] The investigation indicated that cut spikes do not provide sufficient and sustainable restraint against rail roll on curves under the adverse vehicle/wheel conditions.
- Field side tie plate cutting (Figure 8).[3]

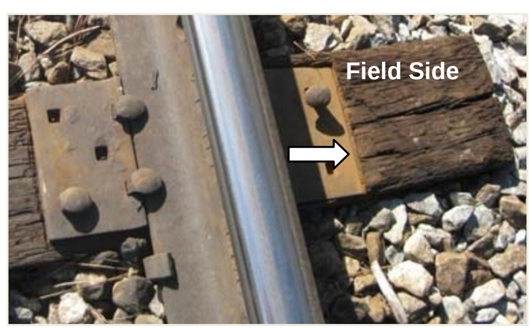

Figure 8. Tie Plate Cutting

- Certain track maintenance tasks, such as gaging and tie renewal, can have the unintended consequence of causing poor wheel/rail contact, resulting in high lateral forces. Figure 4 illustrates that a high rail restored to a 1:40 cant without rail grinding can result in strong two-point contact and produce high lateral forces.
- Asymmetrically worn wheels can produce high lateral forces on both leading and trailing axles. The wheel profile analysis on passing trains indicated the existence of many asymmetrically worn wheels in the coal cars passing the test site.
- Combinations of the above undesired conditions increase the risk of rail rollover derailments.

EFFECTS OF LATERAL FORCES ON ADJACENT TRUCKS

Figure 9 shows the force and railhead lateral displacement data from the instrumented site. The rail rotation angle can be computed by the railhead lateral displacement and the height relative to the rail base. The results indicate large rail rotation occurs when adjacent trucks (trail truck of the previous car and lead truck of the following car) both produce high lateral forces (see middle circle, 5 degrees rotation).

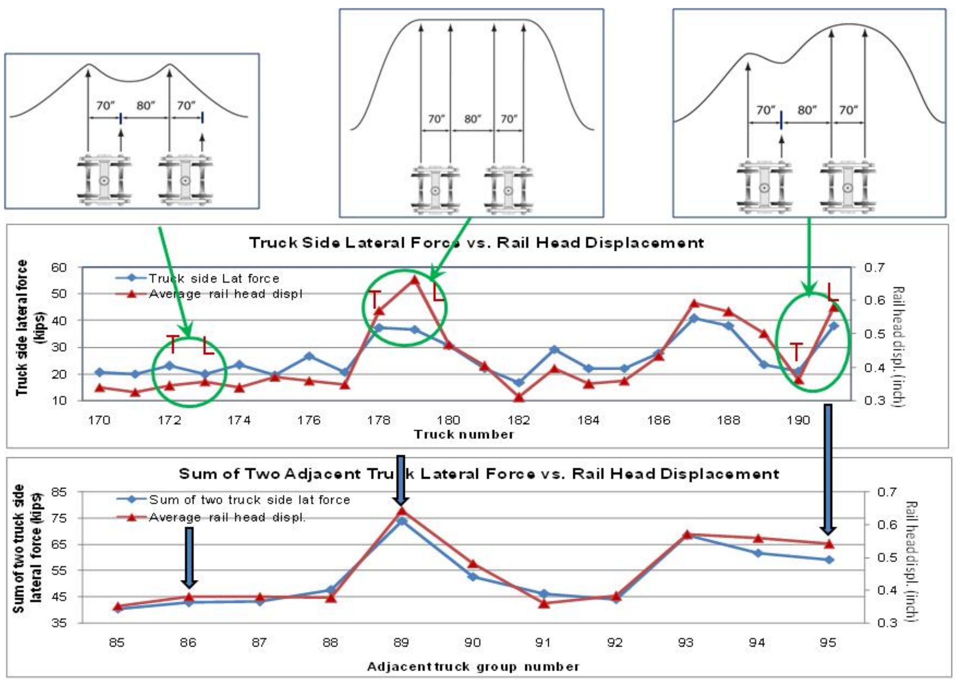

Figure 9. Summation of Adjacent Truck Side Lateral Force (blue) and Railhead Lateral Displacement (red)

CONCLUSIONS

Rail roll and reverse cant on curves are caused primarily by poor wheel/rail profile contact, resulting in the following:

- Insufficient longitudinal truck steering forces and resulting moments and, in turn, high lateral forces
- Field side contact on both high and low rails leading to low B/H ratios

Two important new findings are:

- Rail cant restoration combined with rail re-gaging can cause very high lateral forces if done without coordinating with rail grinding to correct wheel/rail contact patterns.
- Using current technology, the rail grinding cannot be properly conducted on the track with weak rail restraint and varied reverse rail cant.

RECOMMENDATIONS

Short-term remedies include the following:

- Restore designed rail profiles by grinding after rail cant restoration. This is particularly important with the high rail.
- Maintain controlled TORFM and gage face lubrication.

Long-term approaches include the following:

- Develop strategies for achieving stable and consistent track conditions and wheel/rail contact geometry.
- Develop and implement improved truck and wheel maintenance methods and wheel removal limits.
- Develop a long-term plan to improve the rail restraint system on sharp curves.

NEXT STEPS

A third grinding cycle will be conducted to further optimize the wheel/rail contact patterns; the TORFM will be turned off and on to isolate the effects of rail grinding and application of TORFM; and track superelevation will be reduced from 4 inches to 2-1/2 inches (balance speed of 21.5 mph) to investigate the effects of over- and underbalance speed on the lateral force.

ACKNOWLEDGEMENT

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