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Test Results of Top of Rail Friction Modifier Application to One Rail Only

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Summary

Transportation Technology Center, Inc. (TTCI) and Norfolk Southern Railroad (NS) conducted a test to investigate the effects on lateral forces when TORFM (top of rail friction modifier) is applied to one rail only and to understand the outcome when one of the applicators fails.

Four scenarios were included in the test:

- Both TORFM applicators on
- Apply TORFM to high rail only
- Apply TORFM to low rail only
- Both TORFM applicators off

Test results indicated that when TORFM was applied to high rail only, considerably higher lateral forces were produced, increasing the risk of rail roll. Measured low rail lateral forces exceeded 7.5 kips for 92 percent of the leading wheels in a loaded coal train; high rail lateral forces exceeded 7.5 kips for 78 percent of the leading wheels. This compares unfavorably to about 50 percent for both high and low rails with no TORFM application.

TORFM applied to the low rail only can result in low lateral forces that are similar as when TORFM is applied to both rails. Only 20 percent of wheels in these trains produced lateral forces above 7.5 kips.

Under given vehicle and track conditions, the lateral force level primarily depends on wheelset steering ability and friction condition at the wheel/rail interface of low rail. Therefore, it is important to maintain TORFM application consistently, especially to make sure there is no low rail application interruption.

Testing application to low rail only on track with a single curve or single direction of curves within one TORFM effective distance range can provide useful results for evaluating cost benefits.

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INTRODUCTION

TTCI and NS conducted a TORFM test at a rail roll derailment investigation site[1] in April 2013 to investigate the effects in lateral forces when TORFM is applied to only one rail.

TORFM has been widely used on railway curves for reducing lateral forces, wear, and rolling contact fatigue.[2] The current practice is to apply TORFM on both rails at the same application rate. Thus, the test was conducted to understand the effect, especially on wheel/rail lateral forces, when one of the applicators fails.

TEST SITE CONDITIONS

The 5.7-degree test curve on NS single-track main line has 3.5 inches superelevation, wood ties, and cut spikes, and gage-face lubrication regularly applied. Loaded trains travel eastbound and empty trains travel westbound. Lateral force, vertical force, and speed were measured for each passing train using strain gages installed in the body of the curve.

The TORFM applicators were 1,300 feet west of the force measurement site. TORFM was applied only to eastbound trains with an application rate of pumping 0.25 second every12 axles at each side of rail.

TORFM APPLICATION RESULTS IN 2012

The 2012 results of TORFM application on this curve, displayed in Figures 1–3, show the lateral force history and trend with both applicators off and on.

TORFM was first applied at this site in July 2012, when track geometry car data indicated the curve had over 2 degrees reverse rail cant and a walking inspection revealed field side tie plate wear close to 3/16 inch under the low rail.

Figures 1–3 show the lateral forces and truck side L/V ratios before and after application of TORFM under the track conditions described above. The truck side L/V ratio is defined by Equation 1.

$$\frac{L}{V_{(truck\ side)}} = \frac{L_{(leading\ wheel)} + L_{(trailing\ wheel)}}{V_{(leading\ wheel)} + V_{(trailing\ wheel)}} \qquad (1)$$

Note the points in Figures 1–3 represent the root-mean-square (RMS) force level (Equation 2) for one passing loaded train. Therefore, these figures represent the data of 190 loaded trains without the application of TORFM and 160 loaded trains with the application.

$$Lateral\ Force_{RMS} = \sqrt{\frac{1}{n}(F_1^2 + F_2^2 + \ldots..F_n^2} \qquad (2)$$

The lateral forces (RMS values) measured on both high and low rails under leading wheels were about 12 kips without TORFM application and about 8 kips with the application, which was about a 30 percent reduction (Figure 1).There was a smaller reduction in lateral forces under trailing wheels (Figure 2). A reduction in track side L/V ratios was achieved right after TORFM was applied (Figure 3), mainly caused by the lateral force reduction on the leading wheels. Reduction in lateral forces and truck side L/V ratios reduced the risk of rail roll.

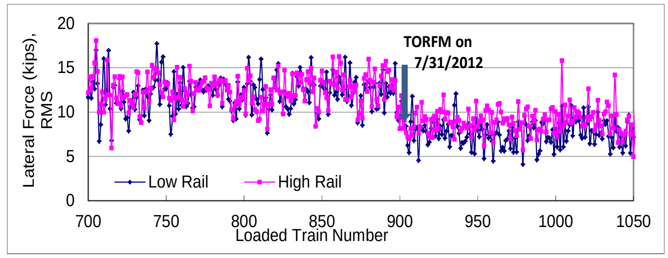


Figure 1. Lateral Forces on Leading Wheels

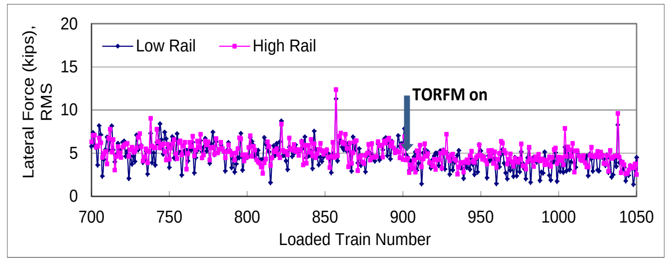


Figure 2. Lateral Forces on Trailing Wheels

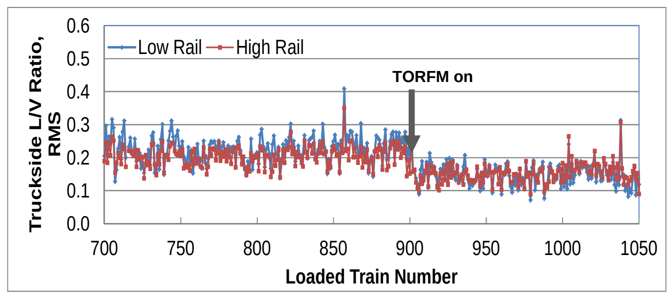


Figure 3. Truck Side L/V Ratio

ONE RAIL APPLICATION TEST

The one rail application test was conducted in April 2013 to understand the effect on wheel/rail lateral forces when one of the applicators fails. The TORFM test in this curve included the following four sequential scenarios:

- Both TORFM applicators on
- Apply TORFM to high rail only (low rail application off)
- Apply TORFM to low rail only (high rail applicator off)
- Both TORFM applicators off

Track conditions at this curve were improved in February 2013, when a rail gang replaced the worn tie plates under low rail. A second rail spike was also added at each tie plate on the high rail.

Figure 4a shows a working TORFM applicator; Figure 4b shows how the supply hose was routed back into the tank for one rail application. For making a valid comparison of lateral forces, only the data from eastbound loaded coal trains, generally containing 120 to 160 hoppers weighing 286,000 pounds, was counted as the valid test data. Table 1 describes the number of cars and operating speeds for the trains involved in the test. The balance speed on this curve is 29.8 mph, and the track chart speed is 35 mph. Due to the limited number of loaded coal trains passing, the test data was collected during two days.

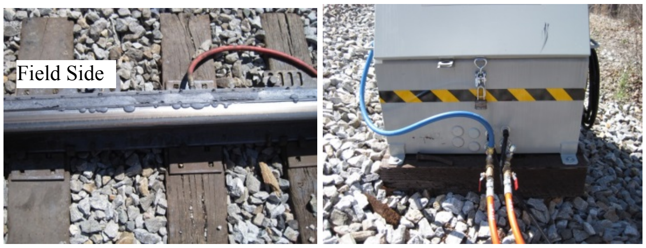


Figure 4. (a)TORFM Applicator, (b) Rerouted Hose for One Rail Application Test

Table 1. Number of Cars and Speed

	Loaded Train	Number of Cars	Speed (mph)	Test Scenario
Day 1	1	160	27.2	Both TOR on
	2	150	27.5	Both TOR on
	3	140	23.5	Apply to high rail only
	4	121	25.1	Apply to high rail only, Snow
Day 2	5	154	26	Apply to high rail only
	6	140	25	Apply to low rail only
	7	135	25	Apply to low rail only
	8	150	25.9	Both TOR off
	9	159	25.4	Both TOR off

The two trains for the *Both TOR on* condition listed in Table 1 were the last two loaded coal trains before the low rail applicator was disconnected (resulting in TORFM applied to high rail only). The low rail applicator was turned back on at the end of the first day of testing for safety reasons.

On the second day of testing, the first test run was conducted with *Apply to high rail only* for train 5. Application was then switched to *Apply to low rail only* for trains 6 and 7. Once these runs were completed, both applicators were turned off. The data from the next two trains (8 and 9), with *Both TOR off* conditions were also included in the analysis.

TEST RESULTS

Figure 5 compares the lateral force distributions on leading wheels of four loaded coal trains under the four TORFM application scenarios. The data includes every leading wheel in a counted train. For comparison, the data was sorted and normalized based on the numbers of cars. Table 2 further summarizes the results.

Results indicate the lateral force distributions on leading wheels are strongly dependent on the TORFM application scenarios. The scenario of *Apply to high rail only* produces the highest lateral forces with 92 and 78 percent of the leading wheels producing lateral forces above 7.5 kips on the low and high rails, respectively. The *Apply to high rail only* condition generates higher lateral forces than without TORFM application on both rails, where about 50 percent of leading wheels produced lateral forces above 7.5 kips on both high and low rails. The lateral force of 7.5 kips is the median level measured in this test.

TORFM application to the *low rail only* and to *both rails* generated similar lateral force distributions. Only about 20 percent of leading wheels produced lateral force above 7.5 kips.

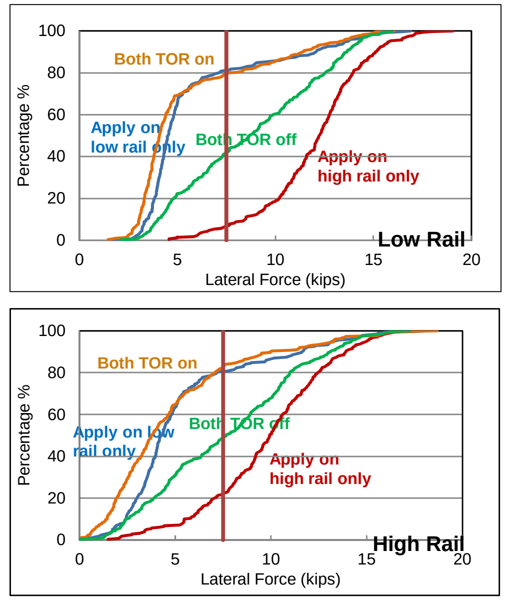


Figure 5. Lateral Force Distribution of Leading Wheels

Table 2. TORFM Application Scenarios and Lateral Forces

	Test Scenario	% of Wheels Lateral Force Below 7.5 kips	% of Wheels Lateral Force Above 7.5 kips
Low Rail	Both TORFM on	80	20
	Apply to high rail only	8	92
	Apply to low rail only	80	20
	Both TORFM off	44	56
High Rail	Both TORFM on	82	18
	Apply to high rail only	22	78
	Apply to low rail only	80	20
	Both TORFM off	50	50

Figure 6 shows the RMS lateral force values for four application scenarios (8 loaded trains), which follow the same TORFM application trends shown in Figure 5.

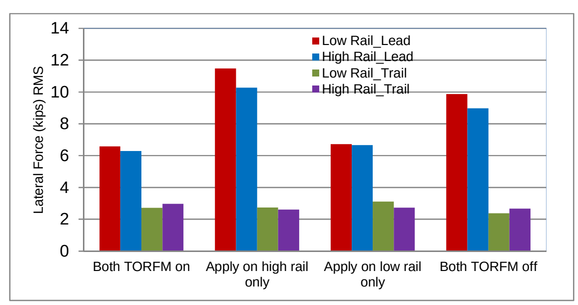


Figure 6. Lateral Forces (RMS) of Lead and Trail Wheels

The trends of the lateral force variations for the cases tested were consistent. Figure 7 displays the low rail lateral force data of two loaded trains for *Apply to high rail only*. After the first loaded train (train 3, colored blue in Figure 7) passed, heavy snow quickly developed (Figure 8), which appeared to have a significant impact on lateral forces under the first half of train 4, (colored red in Figure 7) — where low rail forces were much lower than under any of the TORFM scenarios. But once snow was removed by the first 60 cars (120 leading axles), lateral forces quickly climbed back to levels similar to those under train 3.

The test data also showed that the variations of TORFM application scenarios had a small effect on the lateral forces on trailing wheels (Figure 6).

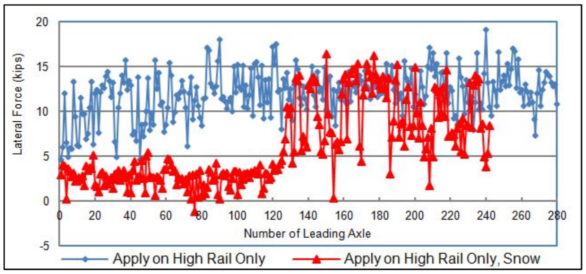


Figure 7. Effect of Snow on the Lateral Forces, Leading Wheels, Low Rail

Figure 8. Snow Started after the First Loaded Train with *Apply to High Rail Only*

EXPLANATION OF TEST RESULTS

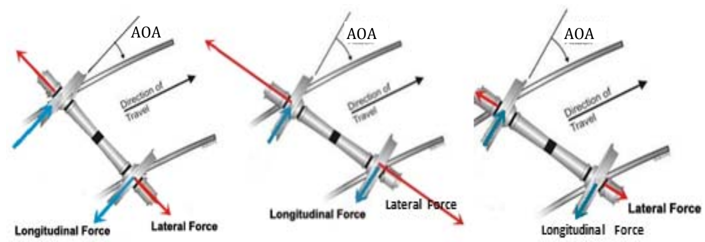
Under given vehicle and track conditions, the lateral force level depends primarily on the wheelset steering ability and the friction conditions at the wheel/rail interface of low rail.

The rolling radius difference between high and low rail wheels on the lead axles will be very similar for all four scenarios, because the high rail wheels are in flange contact. The steering moments resulting from the longitudinal forces are limited by the friction conditions at wheel/rail interfaces. For 3-piece freight trucks under steady state curving conditions, the longitudinal forces on the left and right wheels must be equal amplitude but in opposite directions, because the wheels are rigidly mounted on a common axle. Therefore, the longitudinal steering force is limited by the rail with the lowest friction coefficient.

The longitudinal forces act to steer the axles in the curve. Higher friction conditions normally result in lower angles-of-attack (AOA) for the lead axles of each truck. The dry rail (without lubrication or TORFM on either rail, Figure 9a) would be expected to generate higher longitudinal axle steering forces and lower AOA than the *Apply to high rail only* (Figure 9b) and *Apply to low rail only* (Figure 9c) conditions.

For the curvatures present at the test site, the lead axle AOAs cause saturation of creep forces at the wheel/rail interface. This results in a maximum lateral gage spreading force of μV on the low rail, where V is vertical wheel load and μ is the low rail friction coefficient. The magnitude of the gage spreading force is controlled by the AOA and the friction conditions on the low rail.

Therefore, the *Apply to high rail only*, which has a dry condition on the head of the low rail ($\mu \approx 0.5$, Figure 9b), results in higher AOAs due to lower longitudinal forces, and higher lateral forces. The *Apply to low rail only* friction condition ($\mu \approx 0.3$, Figure 9c) produced lower longitudinal and lower lateral forces. *Apply to both rails* is a similar force situation as *Apply to low rail only*.



(a) (b) (c)

Figure 9. Longitudinal Forces, Lateral Forces, and Wheelset AOA (a) Without TORFM Application, (b) Apply to High Rail Only, (c) Apply to Low Rail Only (and Apply to Both Rails)

CONCLUSIONS

Controlled TORFM application can considerably reduce lateral forces, resulting in reduced risk of rail roll. However, failed TORFM application on low rail, such as that caused by a broken hose or clogged ports, can cause considerably higher lateral forces. Under weak rail restraint conditions, the risk of rail roll would be even higher than with no TORFM applied.

TORFM applied to low rail only can result in lower lateral forces similar to TORFM applied on both rails. Making equal application of TORFM to both rails is strongly recommended to prevent an undesirable condition from occurring; i.e., TORFM applied to the high rail only.

Application to low rail only should be tested on track with a single curve or a single direction of curves within one TORFM effective distance range. Rail lateral forces, wear, and surface conditions should be monitored to compare with both rail applications. The TORFM application cost can be reduced if the test provides positive results. TORFM must be applied to both rails on track containing both left hand and right hand curves in the effective distance range.

References

1. Wu, H. and B. Kerchof. February 2013. "Management of Wheel/Rail Interface to Prevent Rail Rollover Derailments." *Proc. 10th International Heavy Haul Conference*, Delhi, India.
2. Reiff, R. June 2005. "Implementing Top of Rail Friction Control North American Freight Railroad Experience." *8th International Heavy Haul Conference*, Rio de Janeiro, Brazil.