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Evaluation of Tangent Distance between Reverse Curves in Yard Crossovers

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Key Findings:

- The new proposed AREMA recommendations for minimum tangent lengths between reverse curves result in wheel-rail forces that are unlikely to cause flange climb, but may cause rail rollover under unfavorable conditions (high in-train forces and high track curvature).
- For coupled cars with dissimilar lengths, lateral coupler angle limits are reached at higher track curvatures — even when the recommended tangent distances are present between the curves.
- Results are based on computer simulations of two combinations of coupled railcars with different lengths under 0- and 100-kip buff loads negotiating reverse curves up to 12.75 degrees with nominal track geometry.
- The simulations predict higher L/V ratios than a 1976 AAR study[1] that used a simpler quasi-static model simulated under similar conditions.

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Transportation Technology Center, Inc. (TTCI) conducted a study involving a series of Multi-Body Dynamics (MBD) simulations in NUCARS®* to evaluate the proposed new recommendations on minimum tangent distances between reverse curves for low-speed operation currently being considered by the American Railway Engineering and Maintenance-of-Way Association (AREMA).

Depending on the degrees of curvature and railcar dimensions, buff and draft forces may be transmitted through the wheel-rail interface, causing higher than normal lateral-to-vertical (L/V) force ratios. This presents a special challenge in rail yards, where sharp reverse curves are common due to space limitations. The problem is exacerbated if the coupled cars have dissimilar lengths, short couplers, and long overhangs.

As shown in Figure 1, a common mitigation method is the insertion of short tangent track sections in between the reverse curves to reduce coupler angles and lateral wheel forces.

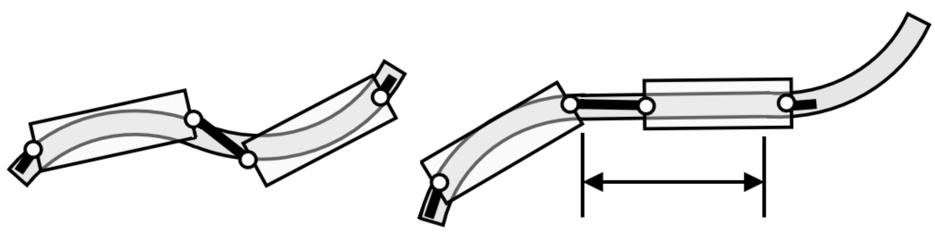

Figure 1. Coupler angularity in reverse curves (left), mitigation by adding a tangent section (right)

In 1976, the Association of American Railroads (AAR) conducted a study to determine the minimum recommended tangent length between reverse curves from 6 to 16 degrees with no spiral and no superelevation.[1] The study used a computer program called the Quasi-Static Lateral Train Stability Model (QLTS) to estimate maximum L/V ratios and coupler angles.

Recently, AREMA has been re-visiting its recommendations on minimum reverse curves in yard operations.[2] The AREMA Committee 5 Subcommittee on Design Geometry asked TTCI to conduct a study on this subject using up-to-date computer simulation methods.

OBJECTIVES

The objectives of this study were to: 1) revisit the 1976 AAR study by simulating several test cases using modern MBD methods and compare the results with those obtained using QLTS in 1976; and 2) evaluate AREMA's proposed new recommendations on minimum tangent length distances between reverse curves for yard operations (Table 1) using modern MBD methods.

Table 1. AREMA Committee on Track Design's proposed recommendations on minimum tangent lengths[3]

Degree of Reverse Curves		Recommended Min. Tangent Length (ft.)
Greater than	Equal to	
0°	1° 30′	0
1° 30′	3°	10
3°	4° 30′	20
4° 30′	6°	30
6°	7° 30′	40
7° 30′	9°	50
9°	10° 30′	60
10° 30′	12°	70
12°		75

PROCEDURES

Comparison of QLTS and NUCARS® Results

NUCARS® was used to set up a simulation environment with inputs similar to one of the test cases from the 1976 study: an empty, 44-foot boxcar (33-inch coupler, 22 tons light weight) coupled in between two empty, 95-foot boxcars (60-inch couplers, 65 tons light weight) subjected to a 30-kip buff load, negotiating 9-degree reverse curves at 22 mph. The length of a tangent between the reverse curves was varied from zero to 100 feet. The simulated wheel-rail contact conditions included AAR-1B wheel profiles, AREMA 136 rail profiles, and dry rail conditions (friction coefficient of 0.5).

The measures of performance were maximum lateral coupler-to-car angle, 50-millisecond maximum single-wheel L/V ratios (a measure of flange climb derailment risk), and 6-foot maximum truck side L/V ratios (a measure of rail rollover risk).

Evaluation of Proposed Tangent Lengths

Generally, coupling cars with long overhangs, differing lengths, and/or short couplers causes the largest coupler angles and wheel lateral forces in reverse curves. The 1976 study modeled several potential worst-case combinations of coupled empty boxcars: 95′+89′ cars, 95′+44′ cars, and 95′+32′ cars. The current study focused on the first two combinations, since the 32-foot cars described in the 1976 report (19-foot truck centers, 29-inch couplers) are uncommon. Analysis of data from the Umler® system shows that cars with similar combinations of outside length and truck centers comprise less than 0.2 percent of existing cars with 29-inch couplers.

For each recommended tangent length in Table 1 (e.g., 0, 10, 20 feet), the simulation environment included the curvature in the middle of the corresponding range (0°45′, 2°15′, 3°45′, respectively). Two combinations of car lengths (95′+89′+95′ and 95′+44′+95′) and two buff loads (0 and 100 kips) were simulated. All simulations were conducted at 10 mph, with unworn AAR-1B profiles on all wheels, AREMA 136 rail profiles, and under dry rail conditions (friction coefficient of 0.5). A total of 36 cases were simulated.

RESULTS

Comparison of QLTS and NUCARS® Results

Figures 2 and 3 show the maximum lateral angles between the coupler and the middle (44-foot or 89-foot) car and maximum L/V ratios from one of the simulated cases.

Although QLTS predicted larger coupler angles than NUCARS® (Figure 2), the NUCARS® predictions of L/V ratios were more conservative (Figure 3).

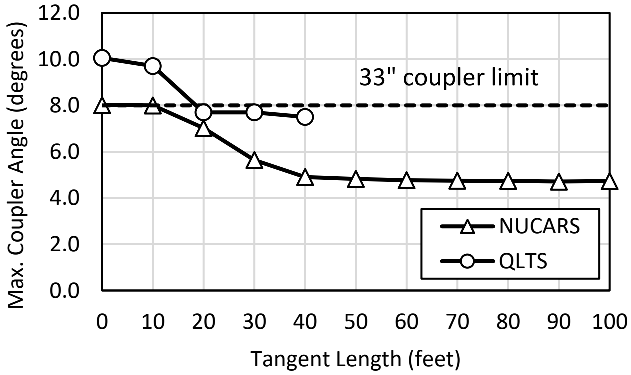

Figure 2. Comparison of NUCARS® and QLTS results: maximum lateral coupler-to-car angles

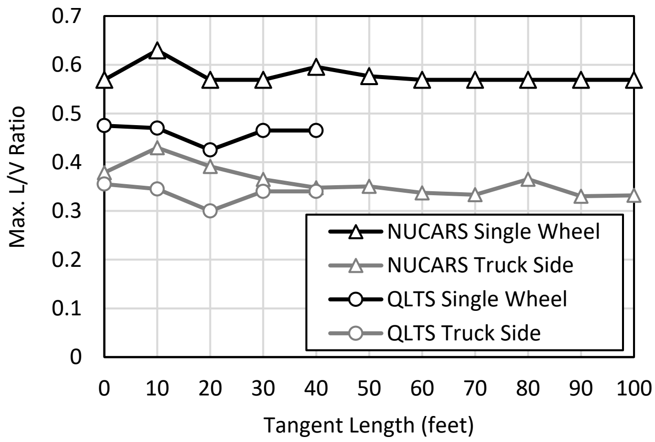

Figure 3. Comparison of NUCARS® and QLTS results: maximum L/V ratios

The differences between QLTS and NUCARS® results are caused by the latter's higher level of detail in modeling of coupler motion, wheel-rail contact, mechanical clearances (e.g., wheelset-to-rail, bolster-to-side frame), and other effects. For example, a more detailed coupler model prevents the coupler angle from exceeding its mechanical limit in NUCARS® but not in QLTS (Figure 2). Accounting for dynamic effects and a detailed wheel-rail contact model in NUCARS® leads to higher maximum forces than those predicted by QLTS, which works under quasi-static assumptions.

Evaluation of Proposed Tangent Lengths

Figures 4 through 6 show the NUCARS® outputs of the 36 simulated cases. The outputs are only shown for the middle car, since it experienced higher L/V ratios than the end cars in nearly all cases.

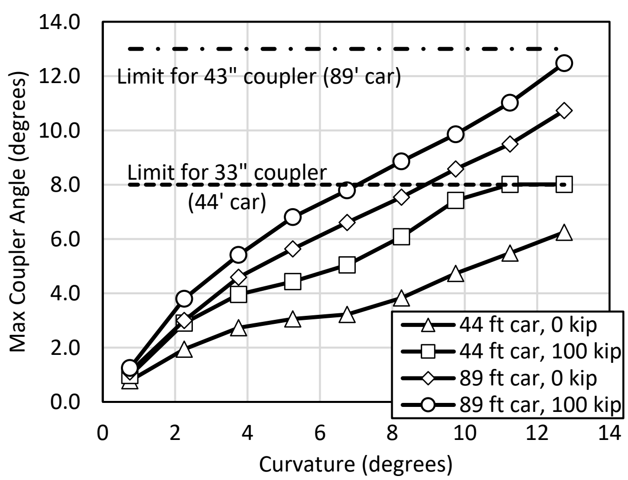

Figure 4. Maximum lateral coupler angles

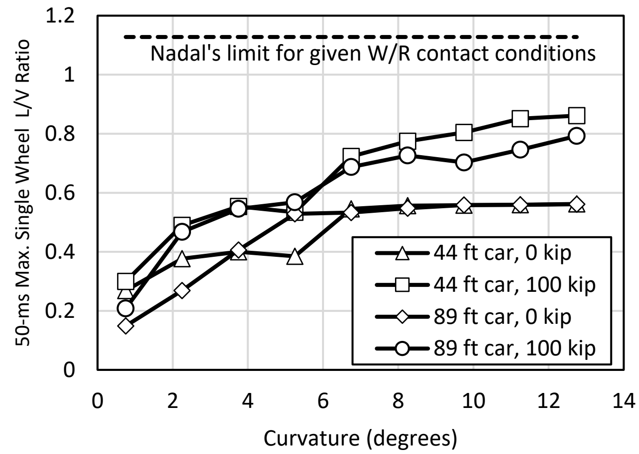

Figure 5. Maximum single wheel L/V ratios

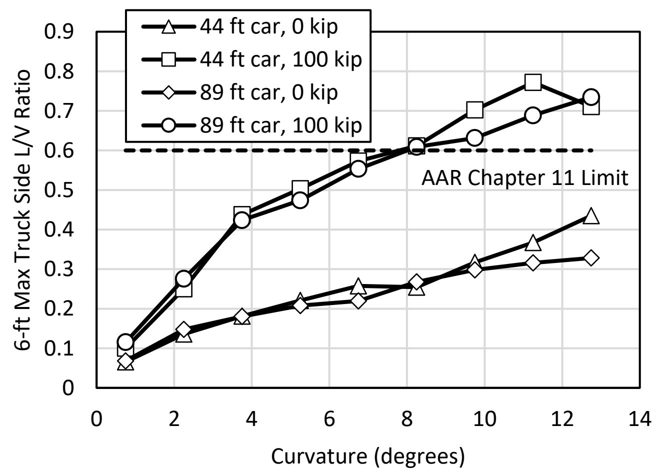

Figure 6. Maximum truck side L/V ratios

Lateral coupler angle limits were reached for a 95′+44′+95′ car combination under a 100-kip buff load for curves over 10 degrees (Figure 4), but even in those cases single wheel L/V ratios did not reach Nadal's limit[4] (Figure 5). However, in curves over 8 degrees (corresponding to AREMA turnouts No. 9 and smaller) the truck side L/V ratios for either of two car combinations exceeded the 0.6 limit[5,6] under a 100-kip buff force (Figure 6). This indicates a potential for rail rollover.

DISCUSSION

Coupler angles in reverse curves depend on the curvature, car lengths, coupler lengths, truck center distances, and the tangent length in between the reverse curves. The relationship between each of these variables and the coupler angle is complex, even when simplified geometrical models are used (such as the standard formulae for curve negotiation[7]).

Therefore, even though the combinations of cars and curve geometry used in this study are among some of the worst realistic cases, identifying the worst possible scenario would require analysis of hundreds more different combinations of car and track geometry parameters.

Additionally, negotiating reverse curves is slightly different from negotiating a crossover with the same degree of curvature and same tangent length (example shown in Figure 7). Crossovers have additional design variables (i.e., switch entry angles, straight versus curved switch point) which were not included in this study.

Factors such as decreasing car weights, increasing buff loads, adding track geometry irregularities, modeling wheel and rail wear, frog and switch profiles, guardrails may further increase L/V ratios above those shown in Figures 5 and 6.

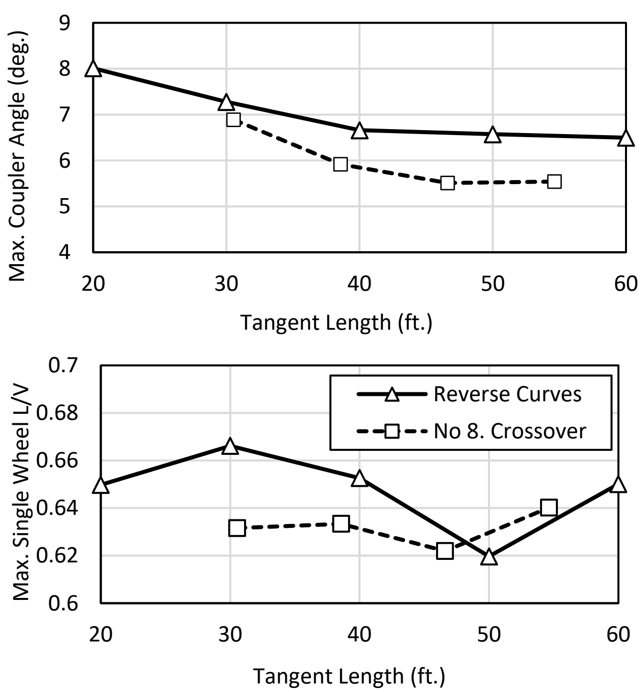

Figure 7. Maximum coupler angles and single wheel L/V ratios in reverse curves vs. in a crossover with similar curvature

CONCLUSIONS AND RECOMMENDATIONS

Under the nominal conditions simulated in this study, the recommended minimum tangent lengths being considered by AREMA result in wheel-rail forces that do not show a high risk of flange climb derailment but indicate a possibility of rail rollover for certain car length combinations under high buff loads.

Because of the limitations discussed here, the coupler angles and L/V ratios calculated in this study should be treated as first-order estimates of actual worst-case conditions.

ACKNOWLEDGEMENTS

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