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Examining Rail Cant Angle with WRTOL™

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Summary

The effects of initial rail cant on wheel/rail interaction were investigated using WRTOL™*, a wheel/rail profile assessment software package developed by Transportation Technology Center, Inc. Three effects of rail cant were investigated: (1) contact stress level and pattern, (2) effective conicity, and (3) wheel/rail conformality. Significant findings were:

- An initial cant angle of 1:40 for new rail produces conicities indicative of good vehicle lateral stability and conformality for the greatest number of wheels in the measured wheel profile databases used. The analysis indicated no compelling reason to recommend changing this practice.
- Selection of initial cant angle for a particular route should consider the particular worn wheels, vehicle types, and range of curves expected for that route.
- Cants of 1:40 and 1:50 produced the best overall conformality for the greatest number of wheels in the measured wheelset databases used, potentially leading to reduced risk of rolling contact fatigue and high-speed instability.
- Cants of 1:40 and 1:30 produce similar wheel/rail contact features.
- There is little difference in contact stress level or pattern on the rail crown for cant angles ranging from 1:40 to 1:20, and, except for a small number of outlier wheels, all show similar distributions of effective conicity.
- A 1:10 cant produces undesirable effects on vehicle curving, such as widely-separated and concentrated points of contact.

Three commonly used new rail profiles and two standard wheel design profiles were chosen for the study:

- Rail profiles: 115-, 132-, and 136-pound RE rail
- Wheel profiles: standard AAR1B, wide flange, and narrow flange

Two databases of measured wheel profiles were used, one containing 82 pairs of representative North American wheel profiles, and a second containing 112 pairs of measured wheel profiles obtained from a Norfolk Southern revenue freight service line. Nominal wheel radius and flange-back spacing were used in modeling the wheelsets. Contact stress levels and patterns, effective conicities, and wheel/rail gap values were computed for each wheel/rail combination at cant ratios of zero, 1:50, 1:40, 1:30, 1:20, and 1:10.

The effects of initial rail cant angle on wheel/rail contact were studied to determine if use of alternate cant angles can reduce the risk of rolling contact fatigue, improve vehicle lateral stability, and vehicle curving.

This work was performed under the AAR Wheel/Rail Profile Design and Maintenance Strategic Research Initiative.

*WRTOL™ is software that calculates the geometric interactions between a measured pair of rails and any number of wheel profiles. WRTOL™ is a trademark of Transportation Technology Center, Inc.

INTRODUCTION

Cant is the angle formed between the base of the rail and the crosstie. It is a design parameter of the tie plates used with wooden ties, and the angle of the rail seat in concrete ties. Cant is commonly expressed as a ratio. Typical values of cant used on North American freight railroads are 1:40 (1.43°), which is the most common, and 1:20 (2.86°). Figure 1 shows an illustration of rail cant.

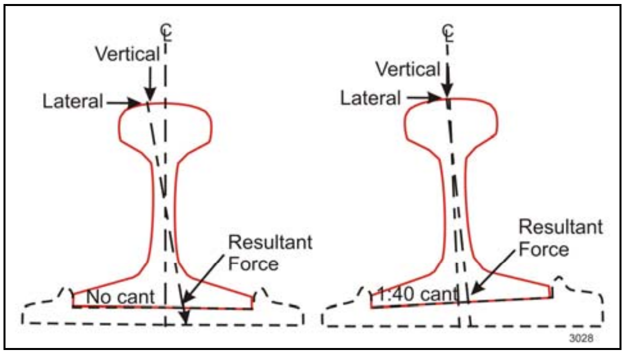

Figure 1. Uncanted and Canted Rail

Cant was introduced to mitigate gage widening and tie plate cutting. The lateral force exerted by the wheels causes the load to be applied eccentrically to the rail. The resultant force crosses the centerline of the rail at an angle, with the lateral component forming an overturning moment about the field-side corner of the rail base. Tilting the rail inward brings this force closer to the centerline of the rail, thus reducing gage widening and tie-plate cutting.[1]

The AAR1B wheel profile has tread taper of 1:20. This taper is beneficial for producing a rolling-radius difference for steering in curving. On canted rail, this taper causes a greater area of wheel tread to contact the railhead, lowering contact stress; in revenue service, however, this taper gradually wears away, so a 1:40 cant was selected to compensate. Cant also assists in truck curving by allowing symmetric rail profiles to produce asymmetric contact patterns on the high and low rails in curves.[1]

TTCI studied the effects of rail cant to determine if an optimal cant angle exists that will reduce the risk of rolling contact fatigue, and improve vehicle lateral stability and curving performance.

Cant is of greatest importance when new rail is laid because it affects the orientation in space of the rail profiles prior to traffic and grinding. Once exposed to sufficient traffic, the rail will acquire a worn profile shape with an orientation that is dependent on the predominant wheel profile shapes running on the rail. Under load, the rail cant may remain fixed or may vary significantly depending on the lateral force exerted by wheels, wheel shape, the strength of rail fasteners, and the condition of the ties and ballast. TTCI has measured the rotation angle of worn rail at several locations on heavy haul lines exposed to various vehicle and track conditions. Measured rotation angles ranged from near zero to over 1.2 degrees.

A proper initial cant angle can provide a desirable initial wheel/rail contact pattern. After rail is laid, the effective cant is influenced by wheel/rail forces and track maintenance practices. For this reason, only AREMA rail design profiles for 115-, 132-, and 136-pound rail were used in this study. These are the most commonly used rail profiles in revenue freight service. The effects of initial rail cant on wheel/rail interaction were investigated using WRTOL™, a wheel/rail profile assessment software package developed by TTCI.

METHODOLOGY

Rail cant was studied using six cant ratios: zero (no cant), 1:50, 1:40, 1:30, 1:20, and 1:10. An analysis was conducted for each combination of rail design profile and cant angle, using standard AAR1BWF and AAR1BNF *wheel design profiles* with nominal values of radii (18 inches) and back-to-back flange spacing (53.156 inches). To investigate new rail contacting worn wheels, a second analysis was carried out using two *measured wheel profile* databases, consisting of (1) 82 measured North American representative freight wheel profiles (NA82) and (2) 112 measured wheel profiles from freight vehicles in use on a Norfolk Southern (NS) revenue service line (NS112).[2] Three wheel/rail contact characteristics were investigated: (1) contact stress levels and patterns, (2) effective conicity and its distribution, and (3) conformality. These indicate, respectively, the risk of rolling contact fatigue, vehicle lateral stability, and curving performance.

RESULTS

Contact Stress Levels and Patterns

Results of the analysis using wheel *design* profiles on 136-pound rail design profiles are shown in Figure 2. The rail profiles are shown at their actual cant angle. Each point in the figure represents a point of contact between wheel and rail. The solid and dashed horizontal lines indicate unacceptably high stress levels. Stress levels and patterns produced on 115- and 132-pound rail profiles are very similar to those shown in the figure. As cant is increased, the contact pattern changes from broadly distributed contact across the rail at 1:40 to separate regions of contact at the gage corner and on the field side of the rail.

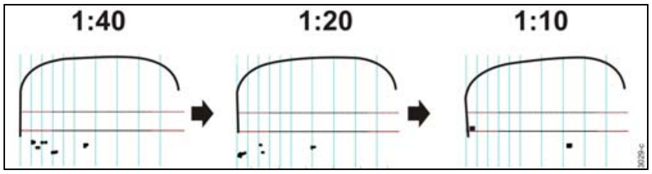

Figure 2. Contact Stress Levels and Patterns for AAR Design Wheels on New 136-lb Rail, with Lateral Shift Values of Approximately -6.5 to +6.5 mm

Figure 3 shows results obtained using the NA82 database on 136-pound rail. The more numerous points of wheel/rail contact form the clouds visible in this figure.

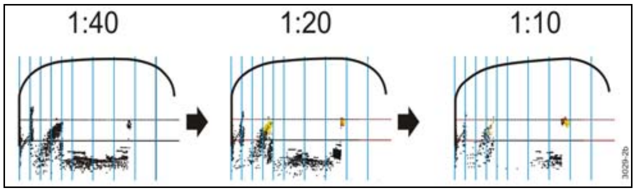

Figure 3. Contact Stress Patterns for NA82 Wheels on 136-lb Rail at Various Cant Angles

Figures 2 and 3 show results for the right rail. Those for the left rail are identical in the case of design wheels and nearly identical for measured wheels. In both cases, 33 kips of vertical force and 10 kips of lateral force were used in the simulations. Lateral shift typically ranged from –6.5 to +6.5 millimeters to include all possible contact scenarios of the wheel and rail combinations; however, unrealistic contact (i.e., flange climb) situations were not considered.

As the cant is increased, contact becomes more concentrated on the field side of the rail profile. Cant angles of 1:40, 1:30, and 1:20 all yield similar contact stress patterns on the rail crown.

Effective Conicity

Effective conicity is commonly used to evaluate the potential for a wheel/rail profile pair to cause vehicle lateral instability (hunting). WRTOL™ was used to investigate effective conicities of the rail design profiles at various cants. Wheel design profiles and measured wheel profiles were considered separately.

Effective conicity was calculated for each combination of wheel and rail profile. In the case of the *design* wheel profiles, the conicities were very similar for all cants because of the 1:20 taper on the AAR design profiles. For the *measured* wheel profiles, the conicities varied considerably. Their rank-order plots for 136-pound rail are shown in Figures 4 and 5 using the NA82 and NS112 wheelset databases, respectively. Note that the rank-order is different for each cant. Results for 115- and 132-pound rail are not shown, as they are very similar, although 115-pound rail produced maximum effective conicitities approaching 0.75, considerably higher than the maximums produced by 132- and 136-pound rail.

Conicity tends to decrease with increasing cant angle because at low cant angles contact occurs during wheel flanging mainly between the gage shoulder of the rail and the wheel flange root. At higher cant angles, contact moves farther out on the rail crown and the wheel tread. For 1:10 cant, contact occurs on the field side of the rail crown.

A minority of wheels caused negative conicities, which are apparent on the left of the rank-order plots in Figures 4 and 5, and are especially prominent in Figure 4 at cants of 1:10 and 1:20. Negative conicities are caused by hollow wheels making contact on the field side of highly canted rail. While not hunting in the ordinary sense, this negative conicity can cause vehicle lateral oscillation and flange contact on tangent track.[3] Results obtained using the NS 112 database indicated fewer negative conicities.

At all cant ratios, a minority of wheelsets generate high conicities. The highest values of these outliers are associated with cants of 1:30, 1:20, and 1:10, while the lowest are associated with zero and 1:40.

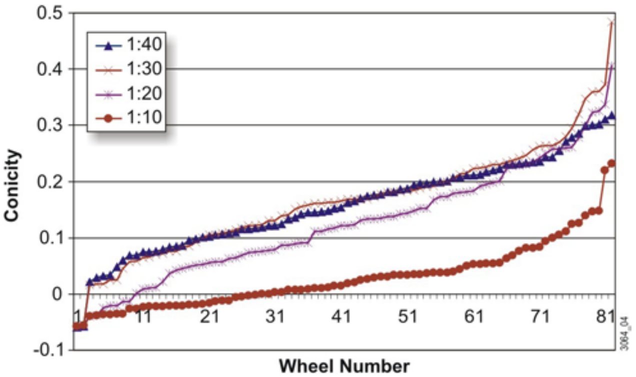

Figure 4. Rank-Order Effective Conicities for 136RE Rail using NA82 Wheelset Database

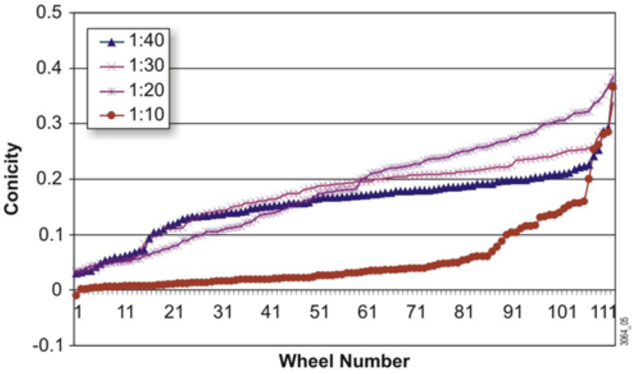

Figure 5. Rank-Order Effective Conicities for 136-lb rail using NS112 Wheelset Database

Conformality

Conformality was evaluated by calculating the width of the gap between the wheel flange root and rail gage corner at its greatest point. This is illustrated in the inset in Figure 6. The distribution of gap values provides an overall measure of wheel/rail conformality. Results for 136-pound rail, using NA82 wheel profiles, are shown in Figure 6, while Figure 7 shows the distribution of gap values using the NS112 database. Extreme gap values can be observed in both figures at 1:10 cant, indicating two-point contact; this indicates poor steering in curves. Both figures show that conformality increases (i.e., the size of gap decreases) with decreasing cant angle. Cants of 1:40 and 1:50 (1:50 is not shown in the figures) produced the best overall conformality for the greatest number of wheels.

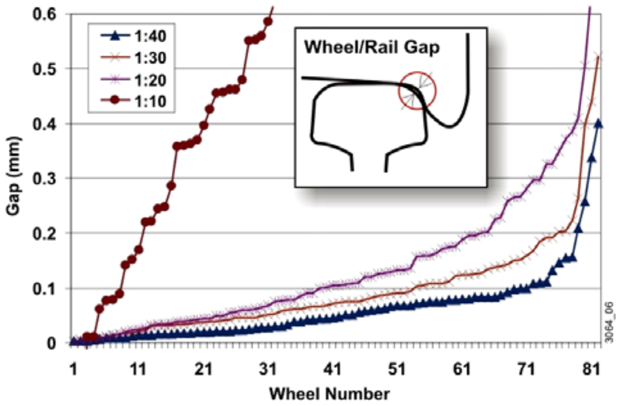

Figure 6. Gap Distribution for 136RE Rail Using NA82 Wheels; Inset Shows Wheel/Rail Gap

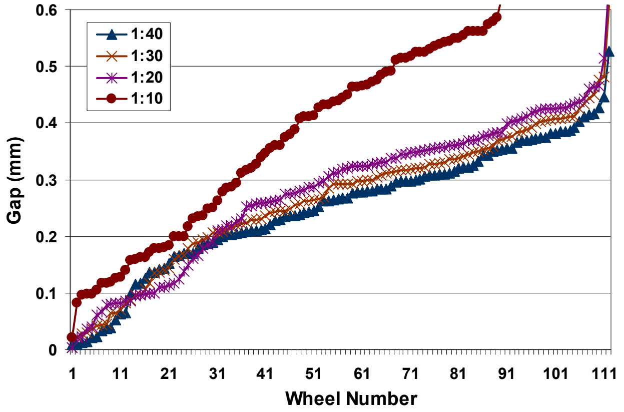

Figure 7. Gap Distribution for 136RE Rail Using NS112 Wheels

Choice of Wheel Database

These results indicate that the choice of initial rail cant should be dependent on the population of wheels expected to run on the rails. A 1:40 cant produces higher conicities and smaller gaps than a 1:20 cant when used with the NA82 wheel database. A 1:20 cant produces higher conicities than the 1:40, and very similar gaps when used with the NS112 wheel database. The NA82 database contains wheels measured from a wide range of vehicles and routes and therefore represents expected performance on lines where traffic is mixed, whereas the NS112 database is likely somewhat biased toward heavy-haul coal traffic and sharper curves, resulting in different wear patterns and correspondingly different conicity and conformality. The choice of initial cant angle therefore should be highly dependent on wheel shape.

CONCLUSIONS

- An initial cant angle of 1:40 for new rail produces conicities indicative of good vehicle lateral stability and conformality for the greatest number of wheels in the in the NA82 and NS112 measured wheel profile databases used. The analysis indicated no compelling reason to recommend changing this practice.
- Selection of initial cant angle for a particular route should consider the particular worn wheels, vehicle types, and range of curves expected for that route.
- Cants of 1:40 and 1:50 produced the best overall conformality for the greatest number of wheels in the NA82 and NS112 measured wheelset databases.
- Cants of 1:40 and 1:30 produce very similar wheel/rail contact features.
- There is little difference in contact stress level or pattern on the rail crown for cant angles ranging from 1:40 to 1:20, and, except for a small number of outlier wheels, all show similar distributions of effective conicity.
- A 1:10 cant produces undesirable effects on vehicle curving and lateral stability, including widely-separated regions of contact.

FUTURE WORK

It would be desirable to examine the dynamic forces generated in rail at various cants and under various conditions, as well as the corresponding contact patterns in the wheels used in this study. It would also be informative to investigate how stress levels and patterns in the base and web of standard rail design profiles change as cant angle cant angle is varied.

The two databases of measured wheel profiles used in this study were obtained from North American railroads where a 1:40 cant predominates. As wheels and rail that have experienced heavy traffic tend to reinforce each other's worn shapes, it is conceivable that these results may have a bias. It would be desirable to repeat this analysis using wheel profiles obtained from a railroad having a captive fleet of rolling stock and which uses a different cant in standard practice.

ACKNOWLEDGEMENT

TTCI Engineer Matthew Forister contributed significantly to this project.

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