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Turnout Alignments for Heavy Axle Load Mainline Traffic

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Summary

Transportation Technology Center, Inc. reviewed turnout alignment designs to develop strategies to improve turnout performance for capacity constrained mainline operations with heavy axle load traffic. Improved performance turnout alignments will benefit the railway with lower safety risks, lower forces, and reduced maintenance. The project is funded under the Strategic Research Initiatives Program for the Association of American Railroads.

The large entry angle in AREMA switches generates high lateral forces in switch entry. The increased maintenance requirement resulting from this is one reason why most railways limit speeds below those allowed under Federal Railroad Administration (FRA) track safety standards. The high lateral to vertical (L/V) ratio also increases the safety risk for wheel climb derailment at these locations.

Better designs can significantly lower maximum lateral forces and L/V ratio for the same size turnout. This is done by reducing the entry angle and also by reducing the closure curve radius that follows, but with the drawback of reducing the maximum speed allowed under FRA rules (the maximum cant deficiency rule).

Theoretically, one could reduce entry angle and keep the same closure curve radius (i.e., lengthen the turnout) to achieve better performance, but it is often not practical for existing lines where interlocking layouts define the turnout lengths.

Under current regulations, the turnout designer is faced with the dilemma that lowering maximum lateral forces also lowers allowable speeds (for the same length turnout). In terms of forces and accelerations, optimal designs will have lower entry angles than AREMA style turnouts. This will balance lateral forces throughout the turnout. The designer must select the entry angle and closure curve radius that will produce an optimal balance of allowable speed and turnout component durability/maintainability.

Further capacity improvements may be possible by operating the lower entry angle turnouts at speeds that produce the same lateral forces as the currently used turnouts. This would allow speed increases of 10 or more mph. However, this option is limited under the current track safety standards.

INTRODUCTION

Transportation Technology Center, Inc. evaluated turnout alignments for performance using analytical tools and full-scale testing. The objectives of the evaluation were to improve the technical performance of the turnouts and improve the operating performance of the railways. Turnouts are key control points of the railway network. Improvements in turnout capabilities can improve railway safety, efficiency, and reliability, and they provide additional capacity with little additional capital cost.

Background

The results of several heavy axle load (HAL) studies showed that turnout performance has improved significantly over the past 30 years.[1,2] This was achieved, despite increases in wheel loads, by a strong partnership between railroad track engineers, trackwork suppliers, and researchers. The improvements came largely through improved quality, improved materials, and by making designs maintainable.

These improvements have given the industry durable designs that are reliable; however, turnouts are still major bottlenecks, requiring speed restrictions for diverging traffic.

North American turnouts evolved from designs intended for a single track railway. These designs favor the mainline route (which is straight through the turnout) over the diverging route. This type of turnout requires lower speeds and generates higher forces for the diverging route. The left-/right-handed turnout designs used were influenced by the track safety rules that typically govern allowable speed on the diverging route. The allowable speed in curves is governed by the cant deficiency. Turnouts are built without superelevation to simplify crosstie, platework, and frog designs at the expense of greater cant deficiency.

Figure 1 shows the plan view of a split switch turnout typical for HAL service. The turnout shown is a left-handed AREMA style turnout. The turnout mainline alignment is tangent (straight). The diverging route alignment is composed of two circular curve segments, tangential to each other, and a tangent segment at the frog. The first circular curve segment is not tangent to the mainline route. Rather, it is tangent to a line parallel to and outside (below in Figure 1) of the mainline. This alignment creates a kink or entry angle at the point of switch. It also shortens the turnout, as compared to a tangential design.

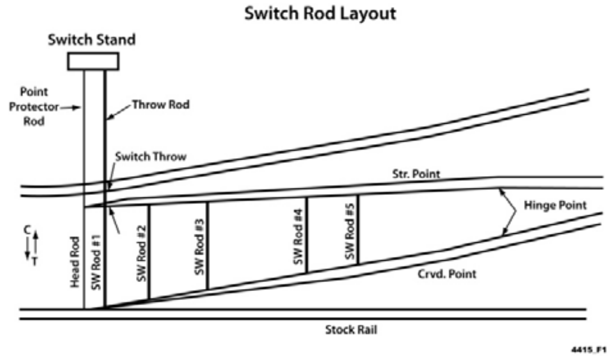

Figure 1. Turnout Plan View

On a practical basis, some entry angle is inevitable even with tangential alignments. A minimum thickness switch point is required for durability.

The typical AREMA design, however, uses alignments with an entry angle of about ½ degree (for a No. 20 turnout, for example). This “secant” alignment has the following features (as compared to a tangential design):

- Shortens the turnout length
- Eliminates the thinnest portion of the diverging route switch point
- Allows a larger radius curve for the diverging route

The third feature is important, because it helps determine the allowable speed for the diverging route. The mainline route speed in not limited by the alignment, but the diverging route is limited by its curvature.

As with the rest of the track, the allowable speed in the turnout curve is governed by the maximum cant deficiency limit in the FRA track safety standards.[3] Recent studies have questioned the applicability of this rule to turnouts.[4] The effect of this rule has been to inhibit use of better designs. Since North American turnouts do not have superelevation, the radius of the curve directly determines the allowable speed. Thus, making this radius larger allows higher speeds in the turnout. Since there is no penalty in allowable speed for a switch entry angle, the penalty for a large entry angle is nil, but there are physical drawbacks. The secant turnout alignment produces a lateral force profile with a large, short duration spike near switch entry, as the wheels strike the diverging switch point. This is followed by a rebound and a relatively low steady state curving force (due to the closure curve) in the remainder of the turnout. Figure 2 shows predicted forces in an AREMA style turnout.

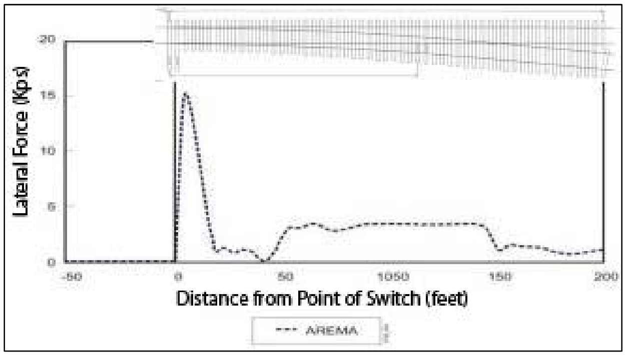

Figure 2. Turnout Lateral Forces

The consequences of this entry spike are seen in increased alignment degradation, increased lateral accelerations, reduced ride quality, and increased maintenance. Therefore, most No. 20 turnouts of this design are limited to 40 mph diverging speeds, even though FRA track safety standards allow 50 mph speeds. A typical alignment defect for an AREMA style turnout is a panel shift outward (to the diverging switch point side) near the point of switch. The effective entry angle increases as the alignment degrades, creating a higher risk of wheel climb by increasing the lateral forces and/or spreading the distance with high L/V ratios.

Capacity Issues

Turnouts are control points for the mainline railway network. These locations control the fluidity of the railway, greatly affecting the efficiency and capacity of the network. Thus, the decision to optimize allowable speed for AREMA style turnouts is understandable. It allows the railway to maximize line capacity with a low first cost, but high maintenance turnout design. Equilateral alignments, which would allow higher diverging route speeds for the same turnout length, are not popular because they must be replaced if the second track is extended beyond the turnout.

Railroads are also reluctant to use longer length replacement turnouts because of the placement of associated signal infrastructure, such as switch machines and line side signals. These locations are expensive to move. They are also difficult to move in multiple track interlockings, where there is limited space between adjacent turnouts.

The effect of higher diverging speed turnouts on line capacity will be line specific. For single track lines with short passing sidings, the effect may be small. Most trains using the diverging route will be stopping in the sidings. For lines with longer sidings and segments of double track, higher diverging speed turnouts will allow running meets of trains. For these cases, the effect on capacity can be significant.

In addition, the better designs should reduce the occurrences of condition related speed restrictions in the turnouts, which should also increase capacity and reliability.

Turnout Performance

The existing AREMA style designs work well for cases where most diverging traffic is relatively low speed. The most frequent causes of mainline turnout accidents are related to switch entry forces. Typical degradation modes are:

- Gapped or chipped switch points
- Dragging equipment derailments
- Track surface and alignment defects
- Worn switc
- Split switches

Distance from Point of Switch (feet)
--- AREMA — Pseudo-tangential

In particular, track surface and alignment defects are affected by the high forces developed from large entry angle switch alignments. The alignment degradation has the effect of reducing diverging route entry angle while creating a mainline route entry angle. This mainline deviation will affect more trains if a speed restriction is placed on the mainline route.

Improved Performance Designs

Improved performance designs have been developed that have lower maximum lateral forces and lower wheel climb risk. These designs are not commonly used in North America for several reasons. Perhaps the biggest reason is the lower allowable speed for such designs (as compared to the AREMA alignment). Figure 3 shows two examples of alignments used in HAL applications. It shows the entry angle is decreased by decreasing the radius of the curve in the body of the switch.

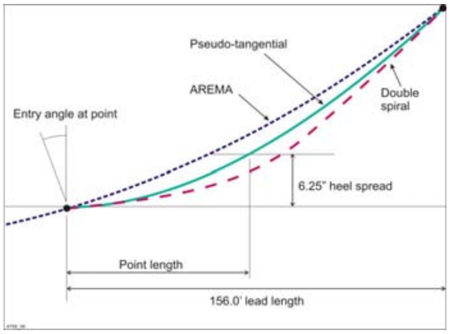

Figure 3. Turnout Alignment Options

The pseudo-tangential alignment follows a tangential alignment, except for a short tangent section at the point of switch.[2] This short segment truncates the point, keeping it within the length of an AREMA alignment turnout. The double spiral alignment is also tangential. It uses spirals to keep the turnout length the same as an AREMA alignment turnout. Figure 4 shows the predicted lateral wheel force for the AREMA and pseudo-tangential alignments. Note that the lower entry angle of the pseudo-tangential design greatly reduces the maximum lateral wheel load in switch entry. The work done by both alignments is the same in turning the train. The tangential, spiral design performs even better, because it levels the lateral force throughout the switch.

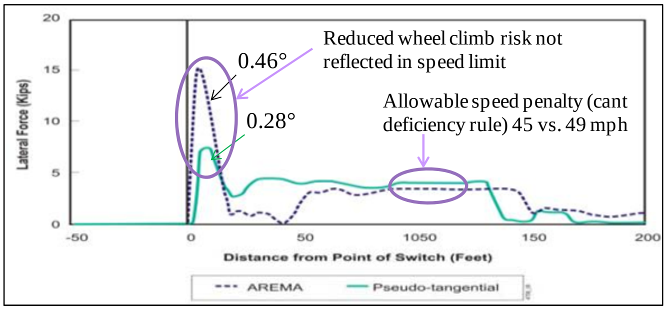

Figure 4. Predicted Lateral Forces for Various Turnout Alignments (loaded hopper)

Table 1 shows a comparison of the properties and the predicted performance of the designs shown in Figure 4. This table shows that the lower entry angle designs will generate lower forces and have a lower risk of wheel climb. However, the three alignments are rated at 49, 45, and 42 mph maximum speed under the track safety standards cant deficiency rule.

Table 1. Properties and Predicted Turnout Performance at 40 mph

Design	Entry Angle (Degree)	Min. Curve Radius (Degree)	Max. Lateral Force (KIPS)	Max. L/V Ratio (Loaded)	Max. L/V Ratio (Empty)
AREMA	0.46	3200	14.5	0.62	0.72
Pseudo-Tangential	0.28	2733	7.5	0.20	0.32
Tangential, Spiral	0.11	2400	5.8	0.11	0,17

Figures 5 and 6 show L/V ratios versus distance measured from a loaded 315,000-pound hopper car for an AREMA style and a tangential, spiral turnout in facing point moves at 40 mph at the Facility for Accelerated Service Testing (FAST). Note that the higher entry angle alignment, shown in Figure 5, generates a maximum L/V ratio of 0.67. This compares well with the predicted value of 0.62 for a loaded car.

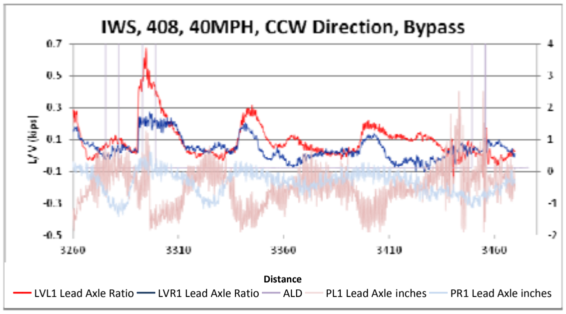

Figure 5. AREMA Style Turnout Performance

Figure 6 shows the performance of the tangential spiral turnout as measured with a 315,000-pound hopper car. The switch entry maximum L/V ratio is 0.37. The predicted value for this alignment is 0.11. The predictions are for nominal alignment. This difference emphasizes how the influence of geometry perturbations increase as the nominal alignment degrades.

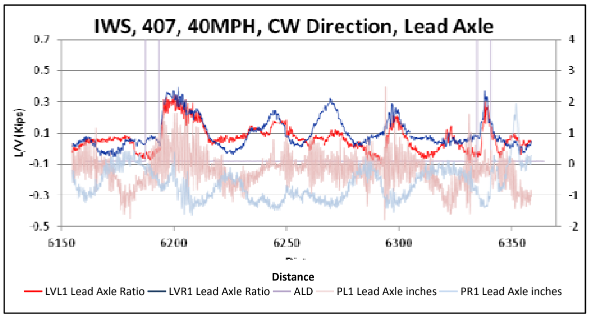

Figure 6. Tangential, Spiral Turnout Performance

The effect of speed on L/V ratios was determined for a speed range of 20 to 60 mph on the two turnouts. Figure 7 shows the maximum L/V ratios predicted for a loaded and an empty car at this range of speeds on the diverging route of each turnout. Also shown are the measured L/V ratios for a loaded car. Although the loaded car L/V ratios are not of particular concern for wheel climb risk, they confirm the predictions from the empty car models, which suggest the better alignment in the tangential, spiral turnout will reduce wheel climb risk at any given speed.

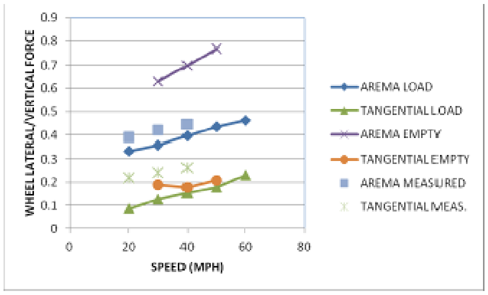

Figure 7. Predicted and Measured Lateral and Vertical Force Ratios for FAST Turnouts (loaded 315,000-pound hopper)

Note that measured L/V ratios on the service worn turnout are somewhat higher than predicted for an idealized alignment, which must be considered when determining maintenance and speed policies for turnouts. Also, note that the improved alignment switch has predicted and measured L/V ratios that are lower than those of the AREMA switch at all speeds.

Figure 8 shows the relationship of switch entry angle and maximum L/V ratio, which is a key factor in determining a speed policy for turnouts. Predicted L/V ratios for both a loaded and an empty coal hopper are shown.

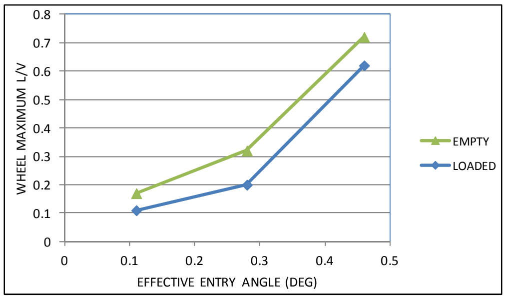

Figure 8. Predicted L/V versus Switch Entry Angle

Conclusions

The large entry angle in AREMA switches generates high lateral forces in switch entry. The resulting maintenance required is one reason why most railways limit speeds below those allowed under FRA track safety standards. The high L/V ratio also increases the safety risk for wheel climb derailment at these locations. Better designs can significantly lower maximum lateral forces and L/V ratios for the same size turnout. This is done by reducing the entry angle and also by reducing the closure curve radius that follows, but it has the drawback of reducing the maximum speed allowed under FRA rules (the maximum cant deficiency rule). Theoretically, one could reduce entry angle and keep the same closure curve radius (i.e., lengthen the turnout) to achieve better performance, but it is often not practical for existing lines where interlocking layouts define the turnout lengths.

Under current regulations, the turnout designer is faced with the dilemma that lowering maximum lateral forces also lowers allowable speeds. In terms of forces and accelerations, optimal designs will have lower entry angles than AREMA style turnouts. This will balance lateral forces throughout the turnout. Further capacity improvements may be possible by operating the lower entry angle turnouts at speeds that produce the same lateral forces as the currently used turnouts. This would allow speed increases of 10 mph or more for typical No. 20 turnouts.

References

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