Field Results of a Modified Turnout Designed to Increase Diverging Route Speeds without Increasing Lead Length

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ABSTRACT

This paper presents the results of five years of service testing of a new design turnout designed to increase diverging route speeds without increasing lead length. The turnout was developed under a Federal Railroad Administration sponsored study looking at low-cost means to increase speeds through turnouts. The resulting design optimized traditional AREMA geometry by reducing the switch angle, incorporating a new diverging switch rail, and reshaping both the curved stock and closure rails, while maintaining the original lead length of the turnout. Dynamic simulations showed that higher speeds could be achieved over the optimized geometry without increasing peak wheel/rail forces experienced over the traditional geometry.

Two new design turnouts were installed on a crossover in Ridgewood, NJ on New Jersey Transit in 2004. Initial testing was conducted in 2004 and 2005 and included comparison with a standard AREMA #20 based on lateral and vertical wheel/rail forces and lateral car body accelerations. The turnouts remained in service and were monitored on a semi-annual basis through 2009. Additional dynamic and ride quality testing was performed in the fall of 2009 and compared to both conventional turnouts and to the original test results obtained in 2004/2005.

This paper presents the results of five years of field experience and follow up dynamic performance testing of the turnouts. The observations and results show that the turnout design meets the goal of providing a low-cost means to increase the speeds through existing turnouts with improved ride quality and decreased wheel/rail forces.
INTRODUCTION AND OVERVIEW

Turnouts are discontinuities in the track structure that are needed to move a rail vehicle from one track to another. These discontinuities can cause derailments due to abrupt or non-uniform changes in track geometry, which can produce excessive force levels. In the diverging route, these discontinuities frequently create a need for speed restrictions. The highest diverging speed permitted on number 20 turnouts of conventional design in North America is generally 45 miles per hour. To obtain a higher diverging speed, it is usually necessary to completely replace an existing turnout with a longer and more costly one.

There have been many attempts at improving turnout design [1-12]. However, new designs (such as tangential geometry points or swing-nose frogs) are generally incompatible with conventional American Railway Engineering and Maintenance of Way Association (AREMA) designs, and require a substantial investment of time and money to achieve optimal performance. This is especially significant since many turnouts are never completely replaced.

For these reasons, interest has grown in finding a low-cost means of increasing permissible speeds through turnouts that are compatible with the conventional AREMA standard designs. As part of a Federal Railroad Administration (FRA) sponsored study, a new turnout was designed to increase diverging route speeds without increasing lead length. The low-cost design modifications were limited to the area between the switch points and the toe of frog due to the high cost of relocating the frog or head block ties (and switching equipment). The resulting design optimized traditional AREMA geometry by reducing the switch angle, incorporating a new diverging switch rail, and reshaping the curved stock and closure rails, while maintaining the original lead length of the turnout.

As discussed in Reference 13, the approach taken was to design the turnout so that the vehicle turning force is uniformly distributed throughout the entire length of the turnout. The
resulting uniform distribution would result in the highest possible speed limit. Since, the largest force occurs at the switch point due to the turning of the train though the switch angle, reducing the switch entry angle was part of this design. Design constraints included no change in the overall length of the turnout as well as insuring that the design modifications were relatively low-cost and easy to implement.

The #20 AREMA turnout with straight switch points was selected as the focus for the geometry optimization. Since it is the “curvature” associated with the switch angle that limits the speed through the turnout, in order to increase the allowable speed it is necessary to reduce this representative curvature. However, since the train must still be turned by an angle equal to the frog angle for a #20 frog (2.864 degrees), any decrease in the amount of turning through the switch rails must result in an increase in the turning accomplished during the curved closure rail. Thus an optimum curvature throughout the turnout is achieved when the “representative degree of curvature” of the switch points is lowered to the point where it becomes equal to the degree of curvature of the curved closure rail (which must be increased as a result of the modifications to improve the switch angle). This must be combined with the need to make no modification to the actual lead length of the turnout.

The actual design process then generated the geometrical equations describing the layout of the diverging route of a turnout [13], which were then used to optimize the turnout geometry. This optimum solution (angle, curved section, tangent section) is shown in Figure 1 as compared to the gauge lines from the AREMA #20 with straight switch points. Note: The switch point angle is decreased by nearly 100%. Also note that the two gauge lines start at the same location and end at the same location and angle. This angle at the end is, of course, equal to the frog angle and the endpoint itself is at the meeting with the toe of frog. This clearly shows that the new design can be created by reshaping an existing AREMA #20 with straight switch points.
The new turnout design was validated by dynamic simulations which showed that higher speeds could be achieved over the optimized geometry without increasing peak wheel/rail forces experienced over the traditional geometry. Dynamic simulations were performed using NUCARS, a widely accepted rail vehicle dynamic simulation model [14]. References 13, 15 and 16 present the design approach and process, the details of the final design and the simulation testing and evaluation of the alternate and final designs.

Two new design #20 turnouts were fabricated and installed on a crossover in Ridgewood, NJ on New Jersey Transit in 2004. Initial testing was conducted in 2004 and 2005 and included comparison with a standard AREMA #20 based on lateral and vertical wheel/rail forces and lateral car body accelerations. The turnouts remained in service and were monitored on a semi-annual basis through 2009. Additional dynamic and ride quality testing was performed in the fall of 2009 and compared to both conventional turnouts and to the original test results obtained in 2004/2005.
This paper presents the results of five years of field experience and follow up dynamic performance testing of the turnouts. This activity included the monitoring of the condition and degradation of new turnouts in comparison to conventional turnouts, the performance of ride quality measurements and an economic benefit analysis. For a review of the initial simulation and field testing of these turnouts refer to References 15 and 16.

MONITORING OF THE CONDITION AND DEGRADATION OF THE NEW TURNOUTS AND COMPARISON WITH CONVENTIONAL TURNOUTS

The new design No. 20 turnouts 5A and 5B were installed by New Jersey (NJ) Transit on May 15, 2004, and December 8, 2004 respectively at Ridgewood, NJ. Cleveland Track Materials manufactured and supplied the modified point rails and plates. Turnout #5A is shown in Figure 2A. ZETA-TECH performed detailed turnout inspections of these two turnouts installed in a crossover (numbered 5A and 5B) in the Ridgewood interlocking south of the Ridgewood Station in northern New Jersey. Concurrently, ZETA-TECH selected two conventional AREMA No. 20 turnouts (numbered 1A and 1B), within a common crossover, operating under conditions similar to those of the new design turnouts at Ridgewood. The conventional turnout #1A is shown in Figure 2B. An identical detailed inspection of these two conventional turnouts was performed in order to compare with new design turnouts.

FIGURE 2A: New Design Turnout # 5A showing Right Point
Inspections of turnouts included detailed measurements of key turnout components to include:

- Switch point wear and/or batter
- Frog wear and/or batter
- Wear of the closure rails
- Track geometry; particularly degradation of the lateral and vertical geometry
- Comprehensive monitoring of key turnout components and measurement parameters.

The inspection data was recorded in electronic form and then used to analyze rate of degradation of the turnout and its key components. This rate of degradation, and the corresponding projected maintenance/replacement requirements was determined for all four turnouts (two new designs and two conventional) and used as the basis for comparison between these two turnout designs.

All NJ Transit maintenance activities on these turnouts were likewise recorded. The crossover 1A-1B was surfaced one time and both frogs were welded twice during this period. The crossover 5A-5B received no surfacing or lining during this period. It should be noted that the
right-hand point of 5B broke off along the top of the point rail twice, however this was not due to the design of the point, but rather to the angle of the stock rail undercut not fitting properly with the angle of the point rail cut. Using a proper undercut to insure a good fit of the point against the stock rail will avoid this problem.

Traffic over these crossovers has remained constant for the entire duration of the project. The traffic characteristics are listed below.

- The 1A-1B crossover has experienced 15 trains per day travelling in the 1B to 1A direction through the crossover (right-hand turnouts).
- The 5A-5B crossover has experienced 27 trains per day travelling in the 5A to 5B direction (left-hand turnouts).
- Based on the direction of traffic flow, turnouts 5B and 1A receive trailing traffic and turnout 5A and 1B receive facing traffic. Analysis of metal removal and wear was performed comparing turnouts 5A with 1B and 5B with 1A. It should be noted that since 5A and 5B are left-hand turnouts whereas 1A and 1B are right hand turnouts, the right hand point of 5A and the left hand point of 1B are curved points and the left hand point of 5A and the right hand point of 1B are straight points.

A sample of measured wear values comparing turnouts 5A (right point) and 1B (left point) are presented in Figures 3 through 6. Figure 3 presents Switch Point width measurements comparing the width of the conventional 1B point with the new design 5A point over a period of approximately three years. As can be seen in this figure, the width of the conventional 1B decreases at a very high rate, corresponding to the traditional high rate of side wear of this type of switch point. In comparison, the new design 5A point shows significantly less wear, with the increased width corresponding to the vertical wear (see Figure 4) and the resulting measurement at a wider (flatter) part of the point.
Figure 4 presents Switch Point height measurements and shows comparable wear measurements after an initial break in period for the 5A point.

Figure 5 presents Closure Rail width measurements which shows a widening (flattening) of the conventional 1B closure rail due to the higher rate of vertical wear (see Figure 6) as compared to new design 5A.
FIGURE 5: Closure Rail Wear-Width measurements - #5A Right Rail vs. #1B Right Rail
Figure 6 compares vertical wear of the closure rail by showing comparative height measurements with the 1B closure rail showing a high initial vertical wear break in period.

![Graph showing closure rail wear-height measurements]

**FIGURE 6: Closure Rail Wear-Height Measurements - #5A Left Rail vs. #1B Left Rail**

As can be seen in these figures, the overall wear performance of the new design switch was superior to the conventional #20 switch rail.

**RIDE QUALITY MEASUREMENTS**

Ride quality measurements were recorded using ZETA-TECH’s accelerometer based Ridemeter/Accelerometer unit mounted on a New Jersey Transit passenger car on both the new design test turnouts and on conventional turnouts with similar train operations. These measurements were similar to the initial measurements taken after installation of the turnouts as reported in References 15 and 16. Two full sets of ride quality measurements were obtained to provide statistically reliable data and to allow for comparison with the multiple runs made immediately after turnout installation. The results of these measurements were also compared to the previous measurements to evaluate rate of degradation of the ride quality.

Measurements of car body lateral acceleration were obtained while traversing both the standard AREMA and the new design turnouts. More specifically, the ridemeter was used on passenger trains traversing the following crossovers on New Jersey Transit:
1) Crossover #5 in the Fall of 2003 before modification (i.e. AREMA Standard #20 with curved switch points)

2) Crossover #1 in the Fall of 2003 (another nearby AREMA Standard #20 with curved switch points)

3) Crossover #5 in the Spring of 2005 after installation of the modified geometry switch point

4) Crossover #5 in the Fall of 2009 after four years of service

A key parameter in the lateral acceleration data was the maximum acceleration (“g”) value experienced; i.e. the maximum absolute (positive or negative) value. Another important indicator of lateral acceleration behavior is to the peak to peak acceleration (P2P). This is the difference between the maximum (+) and minimum (-) values observed over a one second interval. Maximum values of the P2P lateral acceleration were found for each pass through a crossover.

Table 1 presents a summary of the each run’s average maximum lateral acceleration, and average maximum peak to peak lateral acceleration. The average maximum acceleration over the new design switch, shortly after installation, was 0.166 g\(^1\). The average maximum over the AREMA standard design switch (all runs) was 0.285 gs. Thus, the new design switch showed a reduction of approximately 42% in the maximum lateral acceleration when newly installed. After approximately four years of service (2009) the measured average of the acceleration maximums for the new design switch was 0.191 gs, a 15% increase over the maximum acceleration measured in 2005 immediately after installation. This, however, was still a 33% reduction in maximum lateral acceleration when compared with the conventional AREMA #20 turnouts, after four years of service.

\(^{11}\text{g or gravity units} = 32.174\text{ feet per second}^2\)
TABLE 1: Summary of Passenger Train Car Body Accelerations

<table>
<thead>
<tr>
<th>Crossover(s)</th>
<th>Time Frame</th>
<th>Average of Lateral Acceleration Maximums (g)</th>
<th>Average of Peak to Peak Lateral Acceleration Maximums (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREMA Standard Crossover #1</td>
<td>Fall 2003 Before Modification</td>
<td>0.270</td>
<td>0.392</td>
</tr>
<tr>
<td>AREMA Standard Crossover #5</td>
<td>Fall 2003 Before Modification</td>
<td>0.307</td>
<td>0.465</td>
</tr>
<tr>
<td>Both AREMA Standards (#1 and #5)</td>
<td>Fall 2003 Before Modification</td>
<td>0.285</td>
<td>0.422</td>
</tr>
<tr>
<td>Modified Crossover #5</td>
<td>Spring 2005 After Modification</td>
<td>0.166</td>
<td>0.240</td>
</tr>
<tr>
<td>Modified Crossover #5</td>
<td>Fall 2009</td>
<td>0.191</td>
<td>0.262</td>
</tr>
</tbody>
</table>

The average maximum peak to peak acceleration (P2P) values showed a similar behavior. The 2005 peak to peak measurements on the new design turnout was 0.240 gs, as compared to the AREMA standard design values of 0.422g, a reduction of 43%. In 2009, the average maximum for peak to peak acceleration on the new design switch was found to be 0.262, which still represented a 38% reduction over the standard AREMA turnout in spite of the 9% increase over the 2005 readings.

The results of the comparative tests, as presented in Table 1, show a clear reduction in both maximum and peak to peak acceleration while traveling over the new design #20 turnouts, which is comparable to the results presented previously in References 15 and 16. These results are likewise supported by the acceleration data taken from accelerometers mounted on the NJ Transit Track Geometry Vehicle (TGV) presented as a function of speed in Figures 7 and 8. In both sets of data, the reduction in accelerations levels (both maximum and peak to peak) are well defined and increase with speed. In fact, lateral and peak to peak accelerations experienced at 55 mph on the new design were equal to or lower than those at 45 miles per hour on the conventional AREMA design.
Similarly, lateral and vertical wheel/rail force measurements, as measured using track mounted strain gages [15, 16] and presented in Table 2, showed measurable reduction in vertical and lateral forces, and L/V ratios after the installation of new design turnouts. Measured lateral force levels on the new design were less than half of those measured at the convention AREMA turnout, and maximum L/V ratio was reduced by 30%.
TABLE 2: Summary of Passenger Train Wheel Force Measurements

<table>
<thead>
<tr>
<th>Data Description</th>
<th>Before Modification</th>
<th>After Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Measurements/Trains</td>
<td>288/9</td>
<td>437/13</td>
</tr>
<tr>
<td>Train Speed Range (mph)</td>
<td>19 to 44</td>
<td>28 to 43</td>
</tr>
<tr>
<td>Average Train Speed (mph)</td>
<td>36.1</td>
<td>38.6</td>
</tr>
<tr>
<td>Maximum Vertical Force (lbs)</td>
<td>21,120</td>
<td>18,885</td>
</tr>
<tr>
<td>Minimum Vertical Force (lbs)</td>
<td>10,660</td>
<td>7,110</td>
</tr>
<tr>
<td>Average Vertical Force (lbs)</td>
<td>15,016</td>
<td>11,943</td>
</tr>
<tr>
<td>Maximum Lateral Force (lbs)</td>
<td>7,608</td>
<td>3,435</td>
</tr>
<tr>
<td>Average Lateral Force (lbs)</td>
<td>2,202</td>
<td>890</td>
</tr>
<tr>
<td>Maximum L/V Ratio</td>
<td>0.40</td>
<td>0.28</td>
</tr>
<tr>
<td>Minimum L/V Ratio</td>
<td>0.15</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Finally, this data further supports the observations made by train crews [15, 16] that the NJ Transit passenger trains experienced a substantially smoother ride over the new design for the range of speeds currently allowed by the AREMA standards.

DEGRADATION ANALYSIS

As part of the ongoing monitoring of the new design and conventional turnouts, regular semi-annual measurements were taken of the key switch degradation parameters to include vertical and lateral wear on the point. These measurements were analyzed and compared with the results taken from adjacent (comparable) turnouts and combined with traffic data and actual NJ Transit maintenance records for all relevant turnouts to determine the rate of turnout component degradation, and in particular switch point and closure rail wear.

Figures 9 through 12 present the results of the turnout component wear measurements and are shown for the 5A (new design) and 1B (conventional) turnouts since these points receive the majority of facing point traffic. Similar results were obtained for the trailing point turnouts (5B and 1A). These wear measurements include switch point wear-- both lateral (width) and vertical (height)-- for both the right and left (curved and straight) switch points. They also include closure rail wear both lateral (width) and vertical (height) for both the right and left (curved and straight) closure rails.
Figures 9 and 10 show the relative wear of these switch points taken at their corresponding switch rod locations over time. It should be noted that turnout 5A has 7 switch rods and turnout 1B has 6 switch rods. It can be observed in both figures that the wear rate on the modified turnout is significantly less than the conventional turnout. This reduction in wear rate of the modified switch points will result in increase life expectancy of the modified turnout points over a conventional number 20 turnout.

**FIGURE 9: Switch Point Width Wear for Turnout #5A vs. Turnout #1B**

**FIGURE 10: Switch Point Height Wear for Turnout #5A vs. Turnout #1B**

In comparing the closure rail wear between 5A and 1B (Figures 11-12), it should be noted that the 5A right closure and 1B left closure rails are the curved closure rails whereas the 5A left
and 1B right are the straight closures. The closure rail wear rate (both width and height) comparison for turnouts 5A and 1B (Figures 11 and 12) likewise show measurably reduced wear for the modified turnout (5A) closure rails than for the conventional (1B) turnout.

FIGURE 11: Closure Rail Width Wear for Turnout #5A vs. Turnout #1B

FIGURE 12: Closure Rail Height Wear for Turnout #5A vs. Turnout #1B

**BENEFIT ANALYSIS**

Using the results of the degradation analyses and the costs of installation of the new design turnouts and conventional turnouts (to include both material costs and New Jersey Transit labor and equipment costs), a benefit analysis was performed for the new turnout design. The benefits identified in this study included:
a). Savings due to increased component (points and closure rails) life²

b). Savings due to longer surfacing cycles on the new design turnout in comparison to the conventional turnout, associated with the reduced dynamic forces²

c). Improved ride quality over the new design turnout²
d). Increased train operating speeds through the diverging leg of the turnout
e). The ability to convert a conventional turnout into a higher speed turnout without having to increase the lead length of the original design. This was identified as the largest benefit since it provided the capability to increase speed without the added cost of signal modifications that can cost in excess of $75,000.00 per turnout.

CONCLUSIONS

A new turnout was designed to increase diverging route speeds without increasing lead length. The resulting design optimized traditional AREMA geometry by reducing the switch angle, incorporating a new diverging switch rail, and reshaping both the curved stock and closure rails, while maintaining the original lead length of the turnout. Two new design #20 turnouts were fabricated and installed on a crossover in Ridgewood NJ on New Jersey Transit in 2004. Initial testing was conducted in 2004 and 2005 and included comparison with a standard AREMA #20 based on lateral and vertical wheel/rail forces and lateral car body accelerations. The turnouts remained in service and were monitored on a semi-annual basis through 2009.

The five years of field observations and follow up dynamic test results show that the new turnout design meets the goal of providing a low-cost means to increase the speeds through existing turnouts with improved ride quality and decreased car dynamic forces.

² At same operating speed
Ride quality and wheel/rail force measurements showed measurable benefits from the new design. Track mounted strain gauges showed a significant reduction in lateral forces and in L/V ratios for revenue trains on the new design geometry when compared to the AREMA standard geometry. For example, the peak L/V ratio observed was reduced from 0.4 to 0.28. The average L/V ratio observed was reduced from 0.15 to 0.07. Similar reductions were also found for maximum and average lateral forces.

Ride quality data from passenger trains also showed a significant reduction in lateral acceleration and peak to peak lateral acceleration for the new geometry design. In 2009, after four years of service, the modified turnout still showed a 33% reduction in maximum lateral accelerations and a 38% reduction in the peak to peak acceleration over the standard AREMA turnout. These acceleration reductions demonstrate a substantially smoother ride by passenger trains which was confirmed by discussions with train operating personnel.

Wear measurements on the new design and conventional turnouts over a four year period likewise showed reduced rate of wear for the new switch geometry to include reduced lateral and vertical wear on both the switch point and closure rails.

An economic benefit analysis of the new geometry turnout was performed looking at the effect of reduced maintenance and longer component lives as compared to an estimated increased initial cost of $5,000 per turnout. The largest benefit achieved was determined to be the ability to convert a conventional turnout into a higher speed turnout without having to increase the lead length of the original design and without the added cost of signal modifications.

Thus, based on over four years of field testing and measurements, it was determined that a low-cost modified design of the diverging route geometry of a conventional #20 turnout generates reduced levels of forces and accelerations\(^3\), and based on model results and previously

\(^3\) At the same operating speed
reported field tests [13, 15, 16] can achieve higher speeds without any increase in lateral wheel forces, L/V ratios, or lateral accelerations above that of a conventional turnout. Incorporation of a superior geometry within the same dimensions as the AREMA standard will allow railroads to achieve higher diverging route speeds safely, at low-cost, and without the need of additional space. This design approach, which is applicable to the majority of existing turnouts, has been shown to result in reduced levels of force and acceleration, enhanced ride quality and reduced component wear, thus leading to longer service life and reduced maintenance costs.
ACKNOWLEDGEMENTS

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REFERENCES


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TABLE 2: Summary of Passenger Train Wheel Force Measurements

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FIGURE 2A: New Design Turnout # 5A showing Right Point

FIGURE 2B: Conventional AREMA #20 Turnout # 1A showing Left Point

FIGURE 3: Switch Point Wear-Width Measurement - #5A Right Point vs. #1B Left Point

FIGURE 4: Switch Point Wear-Height Measurement- #5A Right Point vs. #1B Left Point

FIGURE 5: Closure Rail Wear-Width measurements - #5A Right Rail vs. #1B Right Rail

FIGURE 6: Closure Rail Wear - Height Measurements - #5A Left Rail vs. #1B Left Rail

FIGURE 7: Maximum Lateral Accelerations of Each TGV Pass

FIGURE 8: Maximum Peak to Peak Lateral Accelerations of Each TGV Pass

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