



U.S. Department  
Of Transportation

**Federal Railroad  
Administration**

# Research Results

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## Improved Spiral Geometry for High Speed Rail

### SUMMARY

A different shape of spiral section for transitioning from tangent to curved track was tested on the Northeast Corridor in a 0.925-degree curve (Figure 1) near Guilford, CT, where typical operating speed for Amtrak's Acela trains is 125 mph. The modified spiral geometry was intended to reduce lateral forces and improve ride quality for high speed trains when entering and exiting curves. The modified design causes a train to rotate around its center of gravity as it leans into a curve, rather than centering rotation at the top-of-rail as does a conventional railroad spiral.

Ride quality and force measurements were made before and shortly after spiral modification, and 1 year later. Compared to conventional geometry, initial and final measurements showed that the modified spirals reduced peak-to-peak lateral accelerations in the car body by 41 percent. Lateral wheel-rail force measurements from two instrumented wheelsets of an Acela power car showed a reduction in root-mean-square (RMS) net axle lateral forces of about 33 percent. Initially, truck lateral peak-to-peak acceleration dropped by 38 percent, but after 1 year, these accelerations returned to the pre-modification levels.

At the test site, the modified spiral geometry was applied without the need to change rail length. The resulting shape and rate of superelevation change also fall within existing Federal Railroad Administration (FRA) track safety standard allowances. Amtrak plans to continue this study by installing the modified spiral geometry on at least two additional curves for further evaluation.



Figure 1. Curve with modified spiral, near Guilford, CT



## BACKGROUND

The practice of placing a spiral transition between tangent and curved track is well established. However, the traditional linear spiral typically used in North America has limitations that have become more pronounced as speeds and loads have increased. The changes in superelevation and curvature produced in a linear spiral can seem somewhat abrupt in higher speed operation, especially when high cant deficiencies are also present.

To address these limitations, FRA sponsored a test of a modified spiral shape that computer modeling indicated could reduce lateral forces and improve ride quality. The intent of the investigation was to apply this modified spiral to both ends of a curve in a higher speed section of the Northeast Corridor and measure its actual effect on Amtrak's Acela trains. Ride quality and force measurements were made before and shortly after spiral modification, and 1 year later to provide an indication of the long term stability of the modified spiral alignment.

LTK Engineering conducted the study in cooperation with Amtrak's Engineering Department and the Volpe National Transportation System Center (Volpe), technical advisors to FRA. Vampire<sup>®</sup> dynamic simulation software was used with input data representing Amtrak's Acela trains to predict responses to the modified spiral geometry. The modeling results were used to develop the final modified spiral alignment and to estimate the force reduction and ride quality improvement.

After reviewing model results for several candidate curves, Curve 128 of Track 1, a 0.925-degree curve with 4 inches of superelevation, at Guilford, CT was selected as the test curve.

An additional task was to develop an interface with the tamper's software so the machine could convert the existing spirals to the proper modified alignment. The new alignment was also checked to assure required vertical and horizontal clearances would be achieved.

## IMPROVED SPIRAL DESIGN

The modified design is based on choosing a track alignment and rate of change in superelevation, from zero at the tangent to the full amount at the curve, to minimize lateral acceleration and rate of change in lateral acceleration of the car body as it gradually leans into the curve—to offset the overturning moment from the natural centrifugal forces. This is generally achieved by causing the car body to rotate around its center of gravity, rather than centering rotation at the top-of-rail as does a conventional railroad spiral. The resulting horizontal alignment is slightly S-shaped.

The applied rate of superelevation is similar to that in a conventional spiral, as indicated in Figure 2 by comparing the heavier purple line (at the top of the left spiral data) with the other thinner, colored lines which represent data for the modified spiral taken at different time periods. The main difference is illustrated in Figure 3, which shows a more gradual change in superelevation for the modified spiral where it meets tangent track (at the left) and the full curve (at the right).

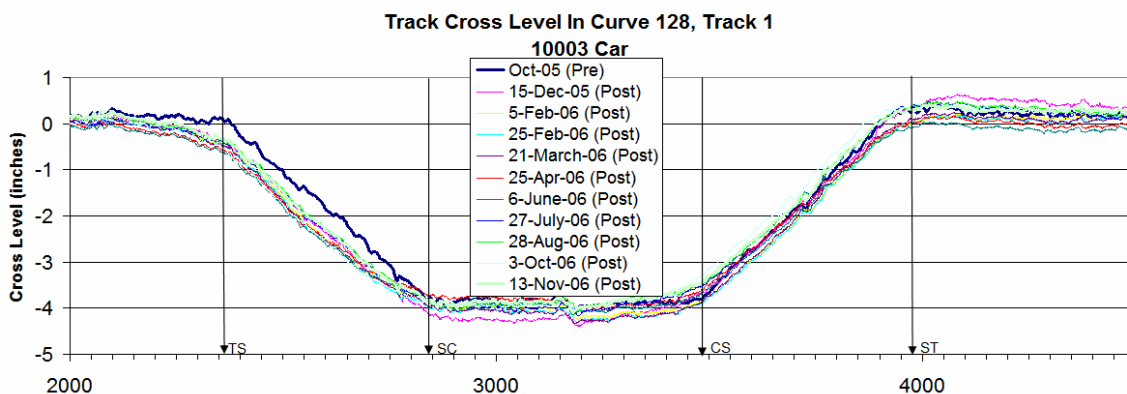
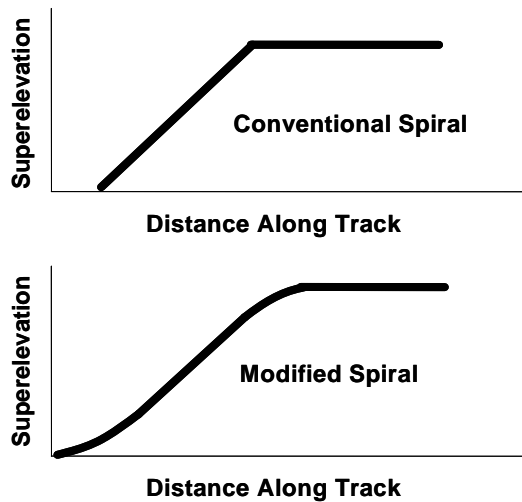


Figure 2. Track crosslevel in Curve 128, Track 1



**Figure 3. Comparison of change in superelevation in the conventional and modified spirals**

**DATA ANALYSIS**

Ride quality and force measurements were made using Amtrak’s track geometry car 10003 (a specially equipped Acela coach) in April of 2005 and then twice a month during routine inspection trips for 10 data sets.

Measurements were taken over a 1-year period to evaluate how stable the modified spiral shape might remain in the long term. The closely-grouped traces in Figure 2 indicate that track surface remained stable during this period. Alignment measurements also showed minimal change.

Table 1 shows the RMS values of net axle load (NAL) force fluctuation for Axles 3 and 4 (the trailing truck) of the Acela power car. The listed values are 101-point moving averages from data recorded every foot.

**COMPARISON OF VEHICLE DYNAMIC MODELING AND TEST RESULTS**

Although the waveform of the predicted lateral acceleration does not exactly match that measured in the car body, the overall trend, relative magnitudes, and variation are similar.

**Table 1. Comparison of lateral forces before and after spiral modification**

Net Axle- to-Track Lateral Forces From Acela Power Car Trailing Truck (100-ft moving averages)	Axle 3	Axle 4
Before Modification - April 2005	1,729 lbs	1,171 lbs
After Modification - December 2005	1,136 lbs	796 lbs
Percent Reduction	34%	32%

The reason for the difference is not clear. The wheel forces predicted by the model were close to the measured values in RMS trend, relative magnitude, and variability.

The improvement predicted by the model analysis for power car lateral axle forces (Axle 4) and coach car body lateral acceleration is shown in Table 2.

**Table 2. Comparison of Predicted and Measured Vehicle Dynamic Response**

Fluctuations About Running Averages	Coach Body Lateral Acc.	Coach Truck Lateral Acc.	Power Car NAL Load
Before Modification – Predicted	0.0135 g (RMS)	N/A	1029 lbs (RMS)
After Modification – Predicted	0.0091 g (RMS)	N/A	861 lbs (RMS)
Percent Improvement – Predicted	33%	N/A	16%
Percent Improvement – Measured	41%	38%	32% - 34%



The values in Table 2 are based on the calculated RMS variation. The results show a predicted 16 percent and 33 percent improvement for NAL loads and coach car body lateral accelerations, respectively. The predicted reduction in coach car body lateral RMS acceleration compares well with the actual measured reduction. No predicted values for coach truck accelerations are shown due to questionable results.

With the linear spirals (pre-modification), the measured variation in lateral axle load was significantly greater than predicted by the model.

## CONCLUSIONS

Conclusions from the study are:

- With normal tamping methods, conventional spirals can be modified to an alignment which results in reduced lateral forces and accelerations.
- Improved spirals can be fitted to existing curves, provided the curves are not too short. Most railroad curves have adequate length to accommodate the tested alignment.
- With accurate vehicle input data, dynamic modeling software can adequately predict vehicle performance on modified spiral geometry and can verify compliance with safety parameters prior to altering the track.
- The track geometry in the modified spirals and in the curve remained relatively stable with a very slow degradation rate.
- A substantial and lasting decrease in car body lateral accelerations (i.e., an improvement in ride quality) was measured following installation of the modified spirals. Significant reductions in lateral truck accelerations and wheel-rail forces also were observed although these improvements were not as long lasting.
- The reason for truck accelerations returning to pre-modification levels, despite the improved and very stable track geometry, should be investigated.

## ACKNOWLEDGMENTS

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## REFERENCE

Chrismer, S. and Klauder, L. (2007). Improved Spiral Geometry for High Speed Rail and Vehicle Response. Washington, DC: Federal Railroad Administration. Expected to be published in 2008.

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