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Contact **Charity Sasaoka**, **(719) 584-7176** with questions or concerns regarding this *Technology Digest.* E-mail: charity_sasaoka@ttci.aar.com.

# Preliminary Analysis of Guardrail Entry Geometry

### by Charity Sasaoka, David Davis, Don Guillen, and Satya Singh

## Summary

Transportation Technology Center, Inc., using its vehicle dynamics model NUCARS™, completed the first phase of a study to determine if varying the entry geometry of a guardrail would improve dynamic performance under heavy axle load traffic. A typical coal hopper with nominal performance characteristics and wheel profiles was used in the completed simulations.

## Conclusions

A guardrail design with a curved entry (convex) had the best dynamic performance for nominal car conditions. At 40 mph, the convex entry decreased the maximum lateral load by approximately half of the standard two-angle entry.

Impacts from a nominal car occur close to where the guardrail becomes full section. Designs that minimize the entry angle at this location are better. The following are ways to reduce the entry angle:

- Longer flare: Higher up-front manufacturing costs, but good for all wheels
- Curved flare: Lower up-front costs, but the lateral position of the wheel flange in flangeway must be known (efforts are underway to determine the distribution of wheels across the flangeway)

The length of the entry of the guardrail determines where the lateral impact load will occur.

The magnitude of the lateral impact load is directly related to the entry angle of the guardrail. The smaller the entry angle, the less severe the impact load for nominal car conditions.

Changing the flangeway from a 1 7/8-inch to a 1 3/4-inch width had minimal effect on the maximum impact load for nominal car conditions.

The typical guardrail has a two-angle entry design and a 1 7/8-inch flangeway. Variations of this design were modeled to identify potential design improvements. This analysis determined the effects of varying guardrail design parameters on nominal car behavior. Additional work will be conducted to determine the effects on poor performing cars.

**Suggested Distribution:**
☐ Maintenance-of-Way
☐ Planning & Analysis
☐ Track Maintenance
☐ Safety

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## INTRODUCTION

A guardrail's primary function is to guide the wheel through the frog by pulling the wheelset to the field side, thus preventing the wheel flange from striking the frog point. Guardrail designs used today have evolved from the earlier days of railroading. Early practice was to use a rail section fastened to the running rail as a guardrail at frogs. The ends of the guardrail were cut at an angle to allow for guiding wayward wheel flanges back toward the running rail with minimal impacts. Use of a rail section guardrail generally limited the flare opening of the guardrail to 3 1/2 to 4 inches without bending the rail. A straight cut flare entry was used to narrow the flangeway from 3 1/2 to the 1 7/8 inches needed at the point of frog.

With experience, designers learned that most wheels struck the guardrail near the narrow end of the flangeway flare. However, the 3 1/2-inch opening was also needed to account for wheel back-to-back spacing variances, track gage variances, and component wear. Designers adopted a two-angle flare to reduce the entry angle over this portion of the flare. This was done by raising the entry angle in the first foot of the flare.

Guardrails vary in design, components, and performance. The most common designs used in heavy axle load applications are independent guardrails. The guardrail is independent from the running rail and its position can be adjusted to compensate for wear. The guardrail sits on plates in common with the running rail. Figure 1 shows an independent guardrail. Other types of guardrails attach to the running rail, such as hook flange or bolted rail section guards.

**Figure 1. Independent Guardrail**

Several parameters that can be varied in guardrail design are the length, height, flangeway width, and entry design of the guardrail. The minimum length of a guardrail is dictated by the need to cover the length of the frog where the gage line deviates from the nominal track alignment. The height of the guardrail can vary from 1 to 2 inches above the top of the rail. A raised guardrail increases the contact area between wheel and rail, lowering stresses on the guardrail. Flangeway width depends on many factors, including frog design, inspection and maintenance policy. Placement and flangeway width of guardrails are limited to compliance with FRA *Track Safety Standard* (CFR 49 Part 213.143). The typical guardrail has a two-angle entry design. The entry design of the guardrail in this study was varied to determine if improvement in dynamic performance could be achieved by steering the wheel through the frog.

## MODELING AND RESULTS

### Model

The effect of the entry geometry of the guardrail was modeled using NUCARS™. Five different entry geometries were modeled to determine if the lateral impact load could be minimized. Figure 2 illustrates the entry geometries evaluated.

1. Standard 2-angle entry: This is the typical guardrail. It consists of two slopes, the first a 12-inch, 4.17-degree angle entry, and a 3-foot, 1.79-degree angle entry.
2. One-angle entry, 4-foot: One slope 4 feet long with a 2.38-degree angle entry.
3. One-angle entry, 8-foot: One slope 8 feet long with a 1.19-degree angle entry.
4. Convex entry: Circular entry with a radius of 59 feet. Center of circle to gage side of running rail. The entry angle decreases throughout the length of the entry.
5. Concave entry: Circular entry with a radius of 59 feet, opposite of the convex. Center of circle to field side of running rail. The entry angle increases throughout the length of the entry to the guardrail.

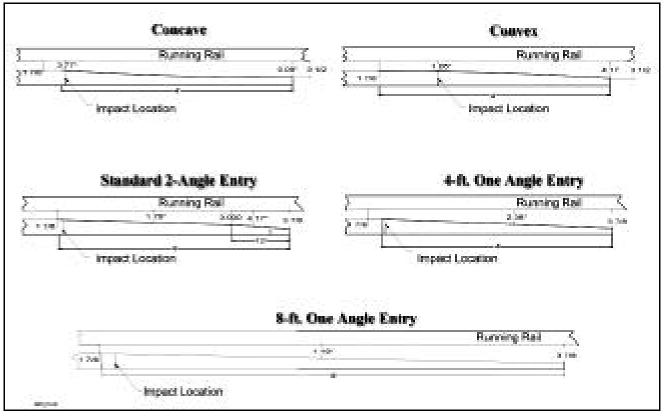

**Figure 2. Illustration of Guardrail Entry Designs**

The following parameters were used in the model:

- 100-ton hopper, nominal suspension and wheel profiles
- AREMA No. 20 turnout with a No. 20 railbound manganese frog
- Flangeway width of the guardrail 1 3/4 inch and 1 7/8 inch
- Speed 10 mph to 60 mph
- Guardrail 26 feet long, 1 inch above top of rail
- Facing point, diverging move

Currently NUCARS™ is not capable of modeling the guardrail independently from the running rail; therefore, this model is representative of an attached guardrail, such as a hook flange guardrail.

The model results are limited because the car used represents only nominal conditions. The wheels on the car are newly equipped with AAR-1B profiles with a minimum angle of attack as the wheelset enters the guardrail. This analysis is good for optimal running conditions and is representative for most of the fleet in revenue service. It is also recognized that bad actor cars (e.g., worn wheels and warped truck) may cause extensive damage to turnouts. For example, a warped truck may cause a wheelset to enter into a guardrail with a high angle of attack. This condition may increase the lateral impact load on the guardrail and move the location of the impact. This preliminary analysis will help determine the best performing guardrail for nominal conditions and will help lead to further research to determine the best guardrail geometry for situations near allowable limits. Future work will include modeling of worn wheel, warped truck conditions, and independent guardrails.

## RESULTS

The magnitude of the lateral impact load is dependent on the size of the effective entry angle. The effective entry angle is determined by the location of the impact load. The concave entry has the highest effective entry angle of 3.51 degrees and the highest lateral load of approximately 37,000 pounds at 40 mph. Table 1 is a comparison of entry angles and maximum lateral loads at 40 mph.

**Table 1. Comparison of Lateral Impact Loads and Effective Entry Angle at 40 mph**

| Entry Design | Maximum Entry Angle | Effective Entry Angle | Max. Lateral Load (lb) @ 40mph | Percent of Standard |
|---|---|---|---|---|
| 8 ft, 1-angle entry | 1.12 | 1.12 | 7291 | 41% |
| 4 ft convex | 4.43 | 0.98 | 8495 | 48% |
| 4 ft, Standard 2-angle entry | 4.17 | 1.59 | 17839 | 100% |
| 4 ft, 1-angle entry | 2.24 | 2.24 | 24129 | 135% |
| 4 ft concave | 4.43 | 3.51 | 36854 | 207% |

Figure 3 shows the maximum lateral loads for all five-entry geometries from 10 mph to 60 mph. The 8-foot one-angle entry and the convex entry lateral loads are half of the standard 2-angle entry. Both the 8-foot one-angle entry and the convex entry design have similar dynamic impact loads, but the main difference is the location of the impact. Figure 4 shows the location of the impacts for all entry designs.

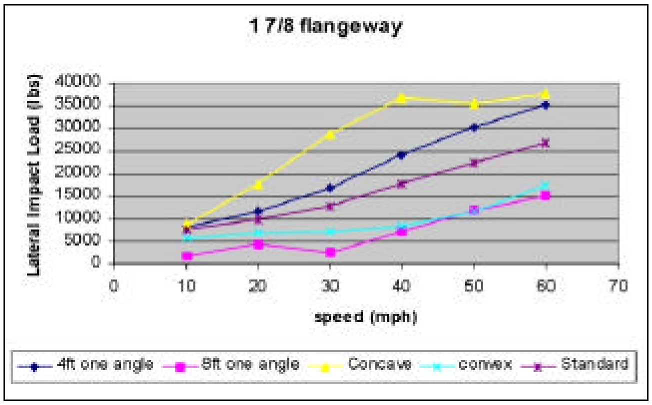

**Figure 3. Comparison of Lateral Impact Loads for All Entry Geometries from 10 mph to 60 mph**

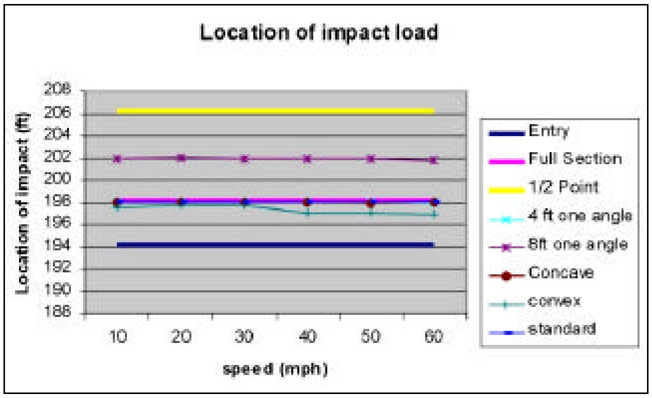

**Figure 4. Location of Lateral Impact Load on the Guardrail**

The length of the entry determines where the impact load will occur. One of the most important functions of the guardrail is to protect the point of the frog. It is imperative to keep the location of the impact load away from the point. As Figure 3 shows, the longer the entry angle, the closer the impact load moves to the point. The 8-foot one-angle entry actually had the lowest lateral impact loads, but the location of the impact is closer to the point of the frog. The convex entry had lower lateral impact loads and the location of the impact was approximately 8 feet from the frog point.

It is important to lower the loads on the guardrail but not at the expense of increasing the load on the frog. The main function of the guardrail is to protect the frog. Figure 5 shows the lateral impact loads on the frog. The convex entry lowered the loads on the frog by approximately 1.5 times in comparison with the standard two-angle entry.

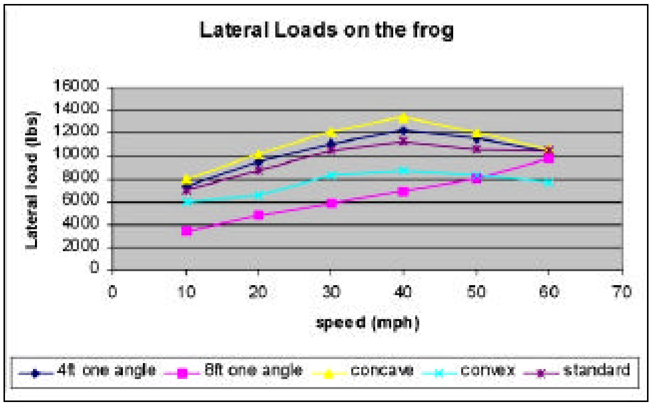

**Figure 5. Comparison of Maximum Lateral Impact Loads on the Frog from 10 to 60 mph**

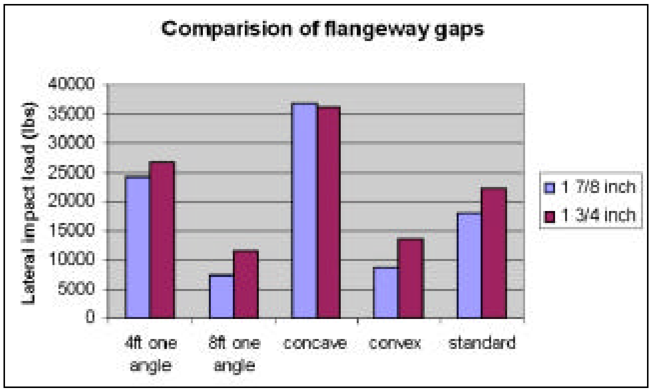

**Figure 6. Maximum Lateral Impact Loads for 1 7/8-inch and 1 3/4-inch Flangeway Width at 40 mph**

Optimal flangeway width is a function of track gage tolerance and the tolerance of the back-to-back wheel spacing. A tight flangeway width may increase the wear and the lateral load on the guardrail. Figure 6 shows a comparison of lateral loads for 1 7/8-inch and 1 3/4-inch flangeways at 40 mph. For nominal car conditions, the difference in lateral impact loads for flangeway gaps of 1 7/8 inch and 1 3/4 inch is minimal.

## FUTURE WORK

TTCI will model a greater range of car conditions, such as worn wheels, followed by field-testing on the best design determined from the NUCARS™ modeling. Implicit in the selection of a non-linear (i.e., curved) guardrail entry flare is the assumption that the distribution of wheel flange positions across the flangeway is known. In actuality, the details of typical revenue service distribution of wheel flange lateral position within the allowable limits has not been formally studied.

A high-speed camera will be used to film wheels as they traverse through a guardrail and frog at FAST. The footage from the high-speed camera will be used to determine the location of the lateral impact on the frog and the guardrail. Once the wheel path through the frog and guardrail has been accurately mapped, changes in the design can be made to help "steer" the wheel through special track work minimizing component wear and damage.

## Bibliography

Davis, D., Guillen, D., and Sasaoka, C., "A Review of Turnout Current Design Practices," Research Report R-961, Association of American Railroads (AAR), Washington, D.C., December 2002.