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## **An Assessment of the Effects of Speed and Running Surface Condition on Wheel Impacts at Crossing Diamonds**

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### **Summary**

Transportation Technology Center, Inc., (TTCI) is tasked by the Heavy Axle Load and Engineering Research Committee (HALERC) of the Association of American Railroads to investigate the flangeway corner degradation of high angle conventional (tread bearing) crossing diamonds and develop a methodology for allowable speed guidelines based on the condition and geometry.

Conventional crossing diamond flangeway corners are exposed to excessive dynamic impact loads. These impact loads result in low cycle fatigue on flangeway corners along with degradations in crossing diamond structure and its fastening system due to low frequency vibrations, and subgrade degradation due to high frequency vibrations. This turns out as frequent inspection, maintenance, replacement and high costs associated with labor, material and train delay along with safety concerns. Several different improvements and crossing diamond designs have been introduced to mitigate impact load effects, such as flange bearing frogs, ramped, and One Way Low Speed flange bearing crossing diamonds. Even though these designs provide significant benefits, applications may be limited and conventional designs are still commonly used.

TTCI has developed a tool to measure effective gap (i.e., the distance that wheels traverse unsupported) and drop of the traversing wheel on worn crossing diamonds in revenue service. These measurements were used as an input to NUCARS®\* double rail model, a special methodology that enables wheel contact on several surfaces to model special trackwork. Impact loads on a new (unworn) diamond were modeled and verified with load measuring wheelsets.

Measurements and modeling results showed the following;

- In general, the impact load affected zone on a high angle crossing diamond frog is approximately 4 inches by 4 inches on a high angle flangeway corner.
- Impact loads can double at low speeds and triple at higher speeds due to a 0.5 inch wheel drop (i.e., flangeway corner batter). Thus, degradation is expected to accelerate rapidly as well as flangeway corner batter.
- The relationship between speed and resulting impact loading is presented. Using an example of 100 kips, the analysis suggests that new crossing diamonds can be operated at 45 mph with this limit. However, worn crossing diamonds that cause wheels to drop 0.5 inch at the frogs can be operated at only ~12 mph without exceeding 100 kips of vertical wheel force. The methodology used can be applied to any wheel impact limit.

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\*NUCARS® is a registered trademark of Transportation Technology Center, Inc., Pueblo, Colorado



**INTRODUCTION**

Development of a rational, engineering-based guideline for speeds at crossing diamonds is a long sought goal of the track standards engineers. Recent improvements in running surface characterization and vehicle-track dynamics simulation<sup>1-4</sup> allow track engineers to explore the effects of train speed, crossing angle, and running surface condition.

Impact loads result in low cycle fatigue on conventional crossing diamond flangeway corners, because there is an appreciable amount of plastic deformation before degradation. Material flows significantly in the lateral and longitudinal directions, and running surface profile vertical drop occurs with accumulated tonnage, as Figure 1 shows.



Figure 1. Longitudinal Profile of a Worn Flangeway Corner

**EFFECTIVE GAP MEASUREMENT**

The running surface profile at the flangeway corners is critical to impact load generation. After an extensive investigation of typical worn shapes in revenue service crossing diamonds, the following two parameters were determined to be important for predicting wheel impact loads:

- Unsupported flangeway gap—the distance a wheel travels unsupported across the flangeway gap
- Wheel drop—the change in elevation (i.e., wheel drop) in traveling across a flangeway gap

These two measures are usually related, but the relationship varies depending on the frog material and the wheel loads of traffic on the crossing diamond.

Figures 2 and 3 show the gauges developed to measure effective gap and wheel drop, respectively. Effective gap is measured by noting where contact occurs when placing a wheel-shaped gauge on the frog.



Figure 2. Gap Measurement Tool – Effective Gap

Figure 4 shows wheel drop is measured relative to the nominal rail running surface elevation by comparing the height

of the level arm shown in Figure 3 when the wheel is on the frog versus when it is away from the frog.



Figure 3. Gap Measurement Tool – Wheel Drop



Figure 4. High Angle Crossing Diamond Flangeway Corner Impact Load Affected Zone (0.5-inch Wheel Drop)

**IMPACT LOAD MODEL**

Figure 5 shows a NUCARS<sup>®</sup> model with a rigid gap on the rail for simulating a wheel passing over the flangeway of a cast frog in a crossing diamond. The NUCARS track model simulates the rail as an Euler-Bernoulli flexible beam with spring and damper connections between the rail and the ground. The relative movement between the two edges of the flangeway is negligible (rigid).

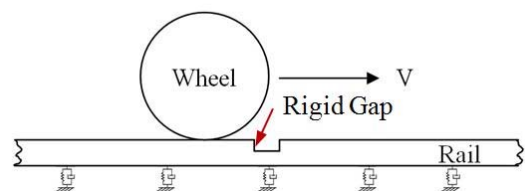


Figure 5. NUCARS Rail Model with Rigid (Cast Crossing) Flangeway Gap

The wheel-rail contact on the two edges of the flangeway is a typical three-dimensional case, which cannot be simulated accurately by using a traditional wheel-rail contact model. Wheel and rail profiles are described in the cross section plan; the flangeway gap discontinuities, which lie in the longitudinal

direction, were the root cause of wheel-rail impacts. The shape of the flangeway gap and rail surface around the gap, which has significant effects on the impact, was modeled as an input for accurate simulation. For this purpose, a special methodology was adopted in the modeling to simulate a three-dimensional flangeway contact with a two-dimensional wheel-rail contact model.

A circular wheel and flat rail with flangeway gap profiles, which were different from the traditional wheel and rail profiles, as Figure 6 shows, were used for these two crossing diamond simulations. Due to limitations of the simulation model, operations over frogs must be modelled as a lateral perturbation in the track. From the vertical vehicle dynamics point of view, excitations on wheels from longitudinal or lateral rail surface discontinuities have the same effect. This special methodology captures the moment when the wheel contacts the two edges of the flangeway gap (i.e., the flangeway corners) and the transition from one edge to another.

Wheel-rail impacts are simulated by the wheels sliding laterally (at train speed) into the flangeway gaps. In other words, this methodology uses the lateral vehicle sliding movement and wheel-rail contacts to simulate the vertical impacts caused by longitudinal rail surface discontinuities.

The rail roll degree-of-freedom was turned off and the wheel-rail friction coefficient was set to 0.001 to eliminate these effects on wheel vertical movements. The NUCARS double rail model and this special modeling methodology thus improved the simulation accuracy of the high frequency wheel-rail impacts on crossing diamond and turnout flangeway gaps by simulating the simultaneous wheel contacts and transitions on the two sides of the flangeway gap, as Figure 6 shows.



Figure 6. Modeling Impact on Flangeway Corner

Figure 7 compares the models of new and worn crossing diamond profile shapes with various wear depths on the flangeway corner and the longitudinal slope on the track. The worn crossing diamond profile shapes were generated based on the measurements in the field using the gap measurement tool. These simplified cases have symmetrical and fairly uniform shapes. They are likely more conservative than revenue service cases, because they maximize wheel drop for a given amount of corner deformation. In revenue service, deformation from crossing traffic may wear the flangeway corner narrowly and allow wheels to span across the worn area without as much wheel drop.

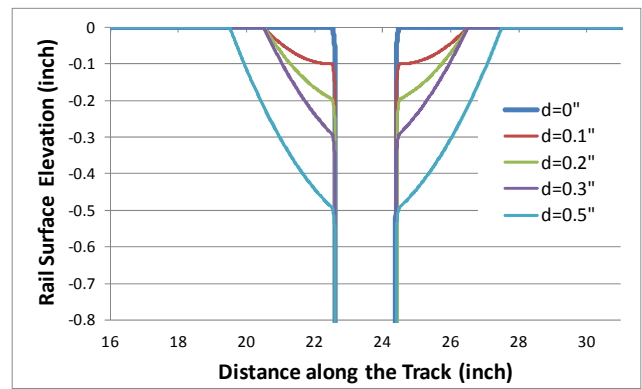


Figure 7. New and Worn Crossing Diamond Shapes with Various Wear Depths (d) on Flangeway Corner

Figure 8 shows the measured relationship between effective flangeway gap and wheel drop for three high angle crossing diamonds on one heavy haul mainline route. One can surmise from this relationship that small changes in flangeway gap result in significant changes in wheel drop (and resultant forces).

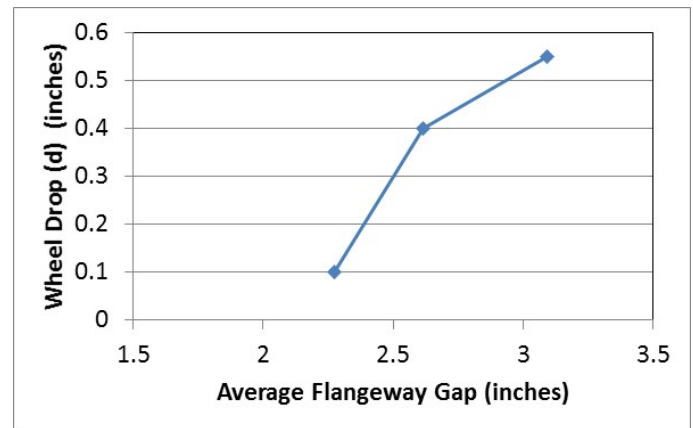


Figure 8. Measured Flangeway Gap vs. Wheel Drop

### MODELING RESULTS

Figure 9 shows the modeling results for new and worn crossing diamonds.

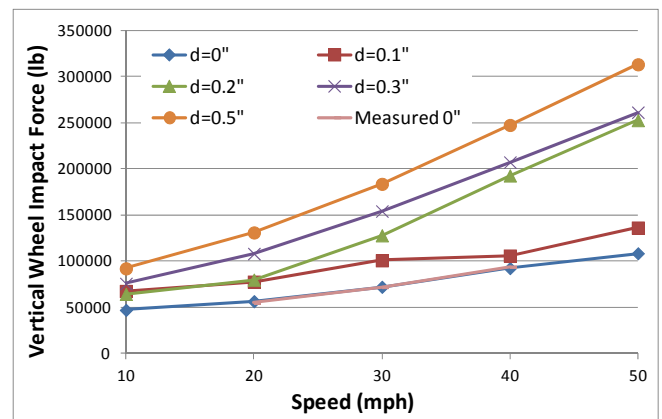


Figure 9. Impact Forces on a 90-degree Crossing Diamond Flangeway Corner with Various Vertical Wheel Drops (d)

- The maximum vertical impact forces generally increase with running speeds and the crossing diamond flangeway corner vertical height loss.
- The maximum vertical impact force depends on the running speed and landing locations on the rails after the wheel passes the flangeway gap.
- The predicted maximum vertical impact forces on a new crossing diamond match the test results measured from an instrumented wheelset (IWS).

## SPEED GUIDELINES

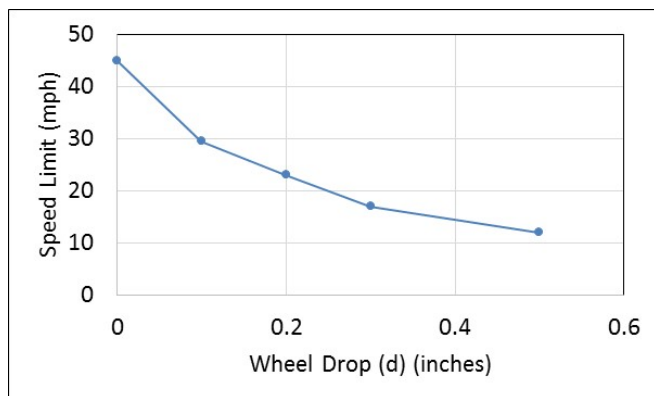
With the measurement and analytical tools described in this *Technology Digest*, a track engineer can assess the effects of speed and crossing diamond running surface condition on wheel impact forces. Thus, an engineering-based speed guideline can be developed for railway freight operations to help optimize life cycle costs (including train delay).

To demonstrate the development of a speed guideline, the wheel-rail impact force limit was set to 100 kips. While rail and wheel steels are similar in properties, most crossing diamonds use high alloy content steels that are more impact resistant. The rule may be somewhat conservative for optimizing crossing diamond life cycle costs, but it serves as a good starting point for developing an engineering-based guideline for crossing diamond speeds.

In revenue service, wheel impact loads are measured using a strain gaged based wheel impact load detector (WILD) to measure vertical loads. WILD and IWS may measure different magnitudes for the same event in a reasonable range due to the following:

- The rail and track structures have more flexibility and damping than wheelsets
- The IWS filtering frequency was 240 Hz, which is higher than most of the rail-based strain gage measurement systems

To perform an example calculation, the wheel-rail impact force limit was set to 100 kips as a criterion. Figure 10 shows the predicted speed limits on crossing diamonds with different wear conditions.



**Figure 10. Example Speed Guideline (to limit predicted wheel-rail forces to 100 kips) for a 90-degree Crossing Diamond at Various Wear Conditions**

Values for other wheel-rail impact force limits can be determined from Figure 9 by noting at what speed the predicted force exceeds the designated limit value at each running surface condition.

## CONCLUSION

For mainline operations, the optimum crossing diamond speed is typically the one that minimizes train delays. On the other hand, increasing speed from 40 mph to 60 mph is calculated to reduce the life of the crossing diamond by 56 percent.<sup>5</sup> Based on the measurements, observations, and modeling results, flangeway corner vertical drop and speed were found to be the most critical contributors to impact load generation. Per the example of allowing no more than a 100 kip high impact load, 45 mph (or lower if the mainline operating speed is lower than 45 mph) is estimated as the optimum speed for levelled corners. Recommended speed reduces significantly as a function of vertical profile change. Thus, flangeway corners should be maintained to minimize the drop even before degradation is observed. Keeping corners levelled may result in minimal acceleration of degradation.

## ACKNOWLEDGEMENTS

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