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Crossing Diamond Dynamic Performance Study

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Summary

In 2004, the Transportation Technology Center, Inc. (TTCI), Pueblo, Colorado, conducted a parametric study using the NUCARS™ track model to quantify the crossing diamond dynamic load environment.

Crossing diamonds are an area that can generate high impact loads. These impact loads cause damage to both track and vehicle components. As the wheel traverses the gap at the crossing diamond corner, it moves from a level running surface into the gap leaving the wheel unsupported as it crosses the gap. The wheel then falls and strikes the corner on the opposite side. The resulting impact can generate high forces which contribute to broken components such as plate work, bolts, and damage to vehicle components. A secondary impact is also generated from wheel bounce. The loading from this second impact tends to be of low frequency and contribute to ballast breakdown and surface misalignments.

An estimated $150 million is spent annually on maintenance of crossing diamonds in North America. Service delays can easily exceed the amount of actual maintenance costs and frequently cause bottlenecks on high tonnage lines, which in turn often require slow orders, causing disruptions to train services.

This study examined the relationship between crossing diamond frog angle, speed, condition of running surface, and the resulting impact load generated. The following results were determined from the study:

1. The effective gap is the distance the wheel must traverse at the diamond crossing corner unsupported. Lower angle crossing diamonds (less than 40 degrees) with good running surface conditions do not have an effective gap. As with turnout frogs, the wheel is wide enough to span the flangeway gap. Thus, it is always in contact with one or both sides of the frog. As the diamond crossing angle increases, the effective gap also increases.
2. Worn diamond crossings can have large effective gaps due to the flow of metal at the corners. In revenue service, effective gaps as large as 4 inches have been measured.
3. Impacts at diamond crossing corners are generated as the wheel lands on the opposite corner. The maximum vertical load in these areas at 40 mph can be as high as 3.6 times the static wheel load with nominal conditions and ten times the static wheel load with worn conditions.
4. The size of the effective gap influences the magnitude of the impact load. Lower angle crossing diamonds with no effective gap have no impact load as the wheel traverses the corner. However, as the effective gap increase, the impact load increases linearly.
5. Vehicle speed also influences the magnitude of wheel impact. For a 90-degree crossing diamond with new running surface conditions, an increase in speed of 10 mph will increase the wheel impact magnitude by about 20 kips.

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TTCI Transportation Technology Center, Inc.

Introduction

Crossing diamonds are an important part of the track subjected to high impact loads. These impact loads cause damage to track and vehicle components requiring frequent maintenance costing an estimated $150 million for North American Railroads. These service maintenance delays also cause bottle necks in service that can easily exceed the amount of the actual maintenance costs.

In 2004, the Transportation Technology Center, Inc. (TTCI), conducted a parametric study using NUCARS™ track modeling software to quantify the crossing diamond dynamic load environment.

Parametric Study

The objective of the parametric study was to quantify the relationship between the impact loading at the crossing diamond corners, angle, and operation speed. The model parameters are listed:

- Vehicle
  - Loaded hopper (263,000 GRL)
  - Unloaded hopper car
  - Wheel Profile (new AAR1B and hollow worn profile 4mm)
- Crossing Diamond
  - Angle: 20 to 90 degrees (varied in 10 degree increments)
  - Running Surface Condition (new rail profiles and worn rail profile
- Speed
  - 10 to 60 mph (varied in 10 mph increments)

Effective Gap

The effective gap is the size of the gap the wheel must traverse from one running surface to other at the crossing diamond corner. The effective gap is not the width of the flangeway, but depends on flangeway geometry. Size of the effective gap is determined by these parameters; crossing diamond angle (θ), wheel tread width (W_w), width of the flangeway (W_f), and condition of running surface at flangeway corners, shown in Figure 1.

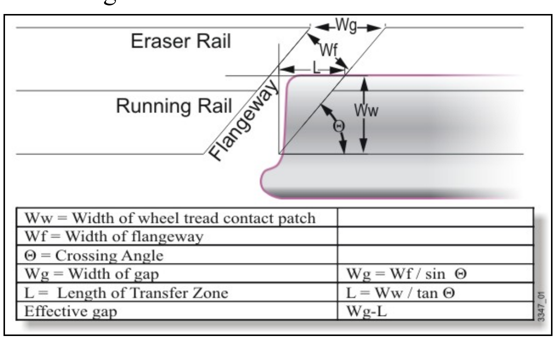

Figure 1. Diamond Crossing Corner Geometry

The above parameters, with the exception of the condition of the running surface, are related by Equation 1.

$$\text{Effective gap} = (Wf / \sin \theta) - (Ww / \tan \theta) \qquad (1)$$

Lower angle crossing diamonds (less than 40 degrees) allow the wheel to be supported all the way through the track transition zone. In contrast, at higher angle crossing diamonds, the wheel must "jump" the gap. This jump causes the wheel to fall bluntly on the opposite corner of the crossing diamond, generating high impact loads. Figure 2 shows the relationship between diamond crossing angle and the effective gap for a diamond crossing with a 1.875 inch flangeway and new running surface profiles.

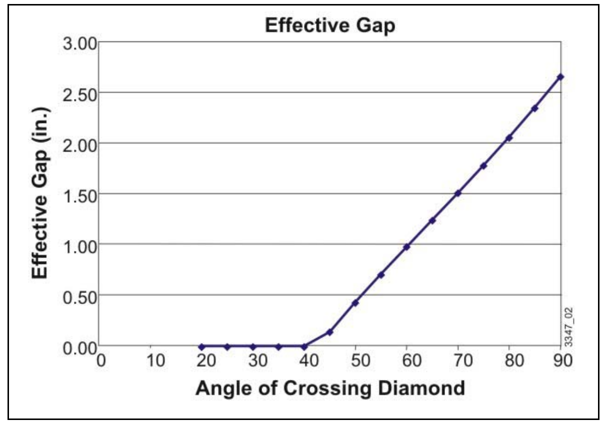

Figure 2. Crossing Diamond Angle and Effective Gap Relationship

The condition of the running surface affects the size of the effective gap. Figures 3a and 3b show a crossing diamond corner with new running surfaces and worn running surfaces for a 90-degree crossing diamond with a 1.875 inch flangeway. The worn crossing diamond measured in revenue service had an effective gap of 3.78 inches. As the crossing diamond wears and the effective gap increases the impact loads increase perpetuating the degradation at the diamond crossing corners.

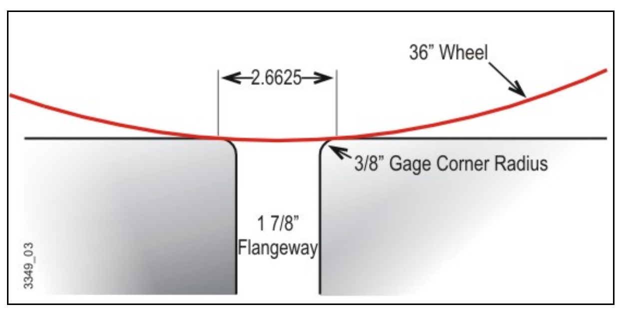

Figure 3a. New Condition Effective Gap

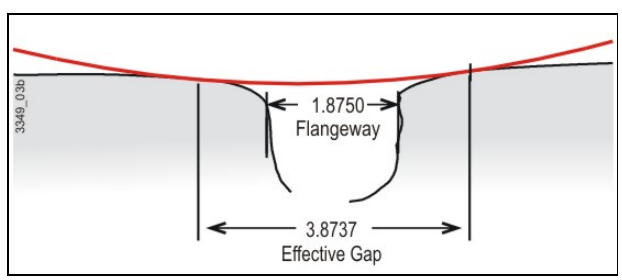

Figure 3b. Worn Condition Effective Gap

Load Environment

The magnitude of the vertical impact load at a crossing diamond corner is determined by the size of the effective gap, condition of the running surface (traverse and longitudinal profiles), speed, and condition of the car.

As the wheel traverses the gap, it unloads briefly before dropping onto the opposite running rail, generating a large and high frequency impacts (less than 0.01 seconds), which is responsible for damage to track and vehicle components. Wheel bounce, a secondary impact longer than 0.01 seconds, contributes to ballast breakdown and surface deviations.

Figure 4 shows the results of two NUCARS™ simulations of a loaded hopper car traveling at 40 mph over a crossing diamond with a 2 and 4 inch effective gap. The vertical force magnitude for the 4 inch effective gap was approximately 60 percent larger than the 2 inch gap demonstrating that the larger gap affects wheel unloading, impact load, and wheel bounce magnitude.

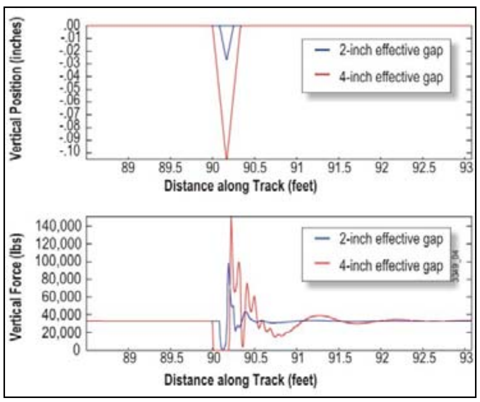

Figure 4. Loaded Hopper Car – NUCARS™ Simulation

The crossing diamond angle determines the size of the effective gap for new running surfaces. Figure 5 shows the range of crossing diamond angles and speeds and the resulting vertical impact.

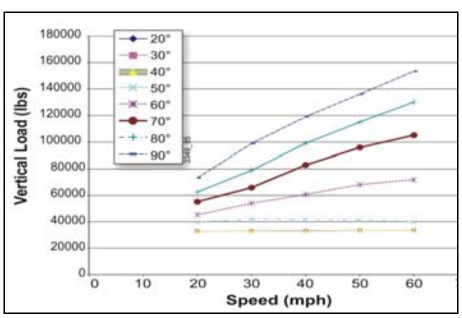

Figure 5. New Crossing Diamond Impact Loads

The flangeway is 1.875-inches, but the size of the effective gap varies according to the angle of the crossing diamond. The lower angle crossing diamonds, 20 to 40 degrees, in good condition, allow the wheel to be supported throughout the entire transition at the corner. This corresponds to the absence of the high impact loads at these corners. As the crossing diamond angle increases the effective gap increases, increasing the impact load generated.

A crossing diamond with worn running surfaces can have a large effective gap. The increase in the size of the effective gap is due to the metal flow and change in running surface profile as a result of the large impact loads at the corners. A low angle crossing diamond with no effective gap in new condition can have a large effective gap in the worn condition, shown in Figure 6. The common corner shows the most deformation because it receives impacts in both directions. The mainline corner typically has less wear. The height mismatch between the two corners requires the wheel to span a much larger distance than the flangeway gap; therefore, the larger effective gap induces larger impact loads.

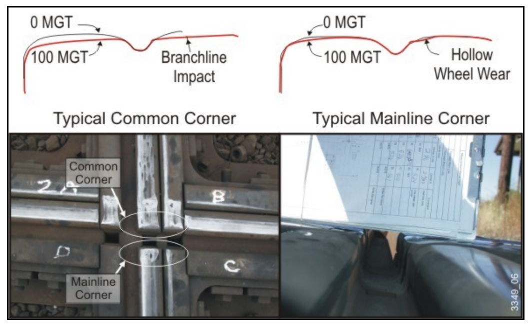

Figure 6. Worn Diamond Crossing Corner

Figure 7 shows the impact loads for a loaded hopper car traversing a range of crossing diamonds in worn and new condition over a range of speeds.

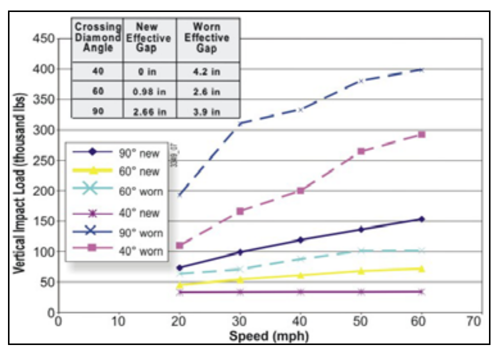

Figure 7. New and Worn Running Surface Impact Loads

The worn conditions were modeled from crossing diamonds measured in revenue service. The impact generated at a worn crossing diamond corner can be very severe. For example, a 90-degree crossing diamond with worn running surfaces at 40 mph can have an impact of 2.75 times greater than new running surface conditions. As diamond crossing condition degrades, impacts increase dramatically and the rate of degradation increases, not only at the corners but for the whole track structure in these areas. Figure 8 shows typical diamond crossing degradation.

Figure 8. Typical Diamond Crossing Track Degradation

Figure 9 shows an unloaded hopper car over the same set of diamonds. It is important to note that unloaded cars can generate high impacts. The trends are similar between the loaded and unloaded vehicle.

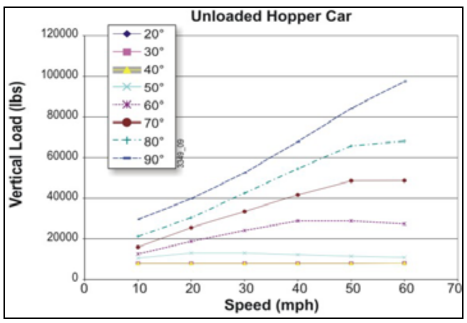

Figure 9. Unloaded Hopper Car Impacts

The duration of the unloading is influenced by the size of the effective gap, speed, and the condition of the vehicle. Figure 10 shows NUCARS™ output for a loaded and unloaded hopper traversing a 90-degree crossing diamond with new running surface profiles.

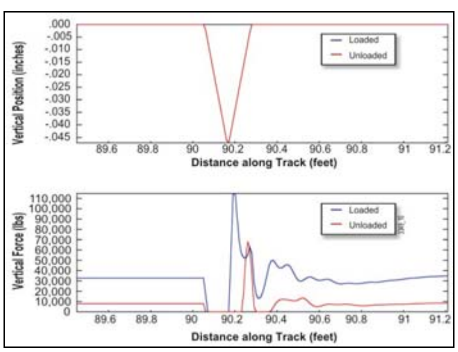

Figure 10. Comparison of Loaded and Unloaded Hopper Car Wheel Unloading

High Impact Considerations

High impacts generated at crossing diamonds can cause damage to both track and vehicle components. Resulting damage includes broken welds, broken bolts, cracked plates, ballast breakdown, and alignment deviations. Higher angle crossing diamonds have severe load environments. Typical high angle crossing diamonds in revenue service last approximately 200 MGT.

Another variable to consider is the damage caused to vehicle components by large impact loads. Undesirable results of high dynamic loads generated at the diamond crossing corner may be spring bottoming. Spring bottoming allows high vertical forces to be transmitted to the carbody, truck, and track. This occurs when the dynamic displacement of a carbody is large enough to cause the coils of the spring to go solid. The dynamic capacity of a spring is a measure of the displacement from the loaded car to the solid spring condition.

The impacts at diamond crossings are typically a high frequency event where spring bottoming generally does not occur. Yet, spring bottoming may occur where there are multiple crossing diamonds that a vehicle must traverse in a short distance, Figure 11.

Figure 11. Multiple Crossing Diamonds

Conclusion

Diamond crossings have a severe load environment due to the gap in the running surface that the wheel must traverse. Several factors affect the severity of the impact load. The effective gap and travel speed are the two main determinant generators of impacts. The effective gap is a function of the crossing angle and condition of the running surface. As the diamond crossing wears, impacts increase, promoting degradation.

Speed is the other main factor in the size of the impact generated at diamond crossings. As speed increases the impact load increases linearly. In effect, high angle crossing diamonds with speeds in excess of 40 mph generate impact loads that can be as high as 10 times the static wheel load.

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