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Diamond Crossing Foundation Design

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Summary

A significant maintenance issue in mainline track is the performance of track transitions such as those found at bridge approaches, road crossings, and special trackwork. In 2005, the Transportation Technology Center, Inc. evaluated track transitions at special trackwork; in particular, diamond crossings. This evaluation, sponsored by the Association of American Railroads (AAR), is part of an effort to develop effective and economic designs for track transitions.

Diamond crossings are an area where high impact loads are generated due to the wheel traversing the crossing frog flangeway gap. Compared to surrounding track, this is an area of the track structure that experiences both mainline and branch line traffic. There is also an abrupt stiffness change in this area due to the platework and structure of the diamond crossing.

Several measurements where taken at the Facility for Accelerated Service Testing to determine the load environment and to characterize the track structure. Based on this testing at FAST and modeling of track transitions, improved diamond crossing foundation designs were developed.

TTCI's recommended diamond crossing foundation design has damping added to two layers of the track structure. The hot mix asphalt subgrade with a ballast mat adds strength to the subgrade and damping to help dissipate low frequency vibrations. Damping material will be installed under the platework to dissipate energy higher in the structure to minimize component damage. The optimal foundation diamond crossing prototype will be built and tested at FAST in 2006. In addition, the following observations were made:

- The track acts as an energy distributing structure. Energy dissipation is a function of track damping.
    - Structural damping is the main mechanism in the ballast layer.
    - Internal damping is the mechanism for energy dissipation in the ties and platework. This type of damping is inherent to the material properties used in the construction of the ties and platework.
- High frequency, low energy vibrations resulting from the wheel flangeway corner impact are dissipated high in the structure and contribute to broken fasteners and platework and damage to the running surface. The dominant frequencies measured from wheel impacts in track were at 55, 280, and 550 Hertz.
- Low frequency, high energy vibrations resulting from wheel bounce tend to travel farther into the track structure contributing to tie, ballast, and subgrade degradation.

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Introduction

A significant maintenance issue in mainline track is the performance of track transitions such as those found at bridge approaches, road crossings, and special trackwork. In these locations, the track structure, and often the load environment, changes significantly over a very short distance. This can result in increased dynamic loading and track maintenance.

Problems at a track transition can be divided into three categories: 1) Differential settlement, 2) Track stiffness issues, and 3) Damping issues.

Differential settlement is where two segments of track settle at different rates. Figure 1 shows how diamond crossings can be lower in relation to the surrounding track. The factors that contribute to this are the high impacts generated and large amount of tonnage compared to the surrounding track. High vertical impacts are generated as the wheel traverses the flangeway gap at the corners. These high impacts result in vibrations that travel to the subgrade and contribute to its breakdown. Both of these factors contribute to the high settlement that occurs in this area.

Figure 1. Track Transition at a Diamond Crossing

Track stiffness issues result from the abrupt stiffness change that occurs in the track transition areas. The diamond crossing structure is inherently stiffer than the surrounding track. It consists of the supporting platework and guardrails that contribute to stiffness. The abrupt stiffness change by itself contributes only slightly to higher dynamic loads, but coupled with a running surface deviation can induce high impact loads. Impact loads at diamond crossing corners can be as high as three times static wheel load.[1,2] Figure 2 shows a comparison of the diamond crossing load environment and open track.

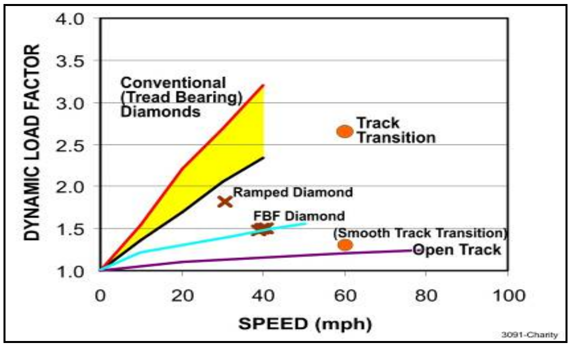

Figure 2. Load Environment at Track Transitions and Diamond Crossings Compared to Open Track

Damping issues arise from energy dissipation of high dynamic loads. Track damping differs between different track structures at a track transition. It is important to understand the types of impacts and design damping into the track structure to alleviate the potential damage. Two types of impacts are generated at track transitions with running surface defects. For the purpose of this discussion, flangeway gaps are considered as if they were running surface defects:

- Wheel impact is a high frequency impact due the wheel traversing a running surface deviation. The high frequency content results from the vibration of the wheel set on the wheel/rail contact surface. This type of impact loading can be responsible for damage high in the structure such as cracked castings and braces, broken bolts, and cracked concrete ties. These vibrations can be minimized by enhancing damping high in the structure.
- Wheel bounce is a low frequency secondary impact. The distance these transient vibrations can travel into the track structure is highly influenced by track stiffness. Vibrations may resonate with the movement of rails and ties on the ballast elasticity and contribute to surface/alignment degradation and ballast/subgrade deterioration. These vibrations can be minimized by enhancing damping lower in the structure.

DIAMOND CROSSING FOUNDATIONS

Background

A significant issue at diamond crossing transitions, result from the high impact loads that are generated at the flangeway gaps. Impact size is directly related to the size of the effective gap. The effective gap is the distance the wheel must traverse unsupported at the diamond crossing corner. This impact is impossible to eliminate but it may be possible to minimize its potential damage. To lower the impact load, different methods have been studied, including ramped corners and flange bearing. Another potential way to minimize impact load effects and resulting damage is to add damping to the structure.

Track acts as an energy distributing structure. Energy dissipation is a function of track damping. Track damping properties are affected by a number of factors such as ballast quality, tie type, platework, and rail temperature. There are several mechanisms in which energy is dissipated in the track structure. Structural damping is the main mechanism in the ballast layer. Energy is dissipated as the ballast pieces move relative to one another. It is important to maintain good ballast quality to effectively dissipate the energy before it reaches the subgrade layer of track. This is especially important for diamond crossing structures to help minimize differential settlement. Minimizing differential settlement helps to eliminate running surface deviations that can develop at track transitions.

Internal damping is the mechanism for energy dissipation in the ties and platework. This type of damping is inherent in the material properties used in their construction. Adding materials with good damping properties higher in the diamond structure will help dissipate energy from high impact loads, minimizing broken bolts and cracked platework.

Dynamic Track Response Field Measurements

Impact testing was done during an Instrumented Wheel Set test to properly document the track characteristics (set-up shown in Figure 3). Accelerometers were placed at subgrade, tie, and rail layers of the track structure. The damping characteristics of each layer were determined by the acceleration decay rate and the response frequency. Impacts were generated by installing a track panel that simulated diamond crossing flangeway gaps of 1.88 inches.

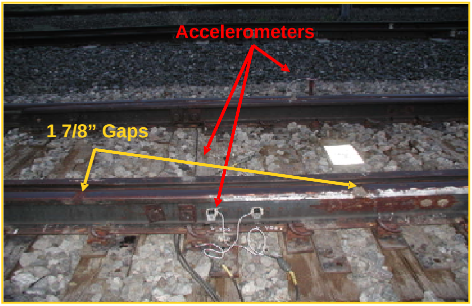

Figure 3. Impact Test Set-Up

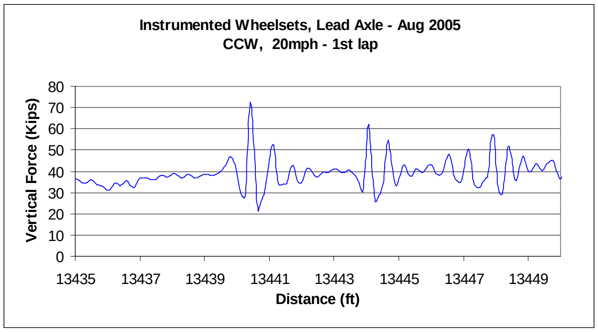

Figure 4. Vertical Impact Load Magnitude Measured by IWS

Figure 4 shows the magnitude of the impact at 20 mph, measured by instrumented wheelsets, was approximately 72 kips. Figure 5 shows the response frequency of each layer of track. The dominant frequencies that occurred are at 55, 280, and 550 Hz. As the energy travels through the structure, the magnitude of the vibrations is dissipated. The high frequency, low energy vibrations are completely dissipated in the rail and tie layer. The low frequency, high energy vibrations were able to propagate to the subgrade.

Track conditions at diamond crossing locations often show signs of an overloaded substructure. Diamond crossings can be lower than the adjacent track and there can be mud pumping and general ballast and subgrade degradation. The breakdown of the ballast and subgrade layer can be contributed to low frequency, high energy vibration that propagates into the subgrade layer. Attenuating this vibration before it can travel into the subgrade can help prolong the life of the track structure in these areas.

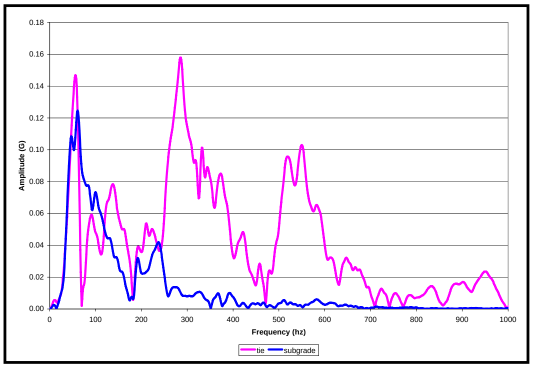

Figure 5. Frequency Response of the Track Structure

Foundation Design

It is important to understand what the frequencies are in each layer in order to design an effective foundation. Figure 6 shows the theoretical response of the track structure. Each frequency is a function of movement of different components in the track structure.

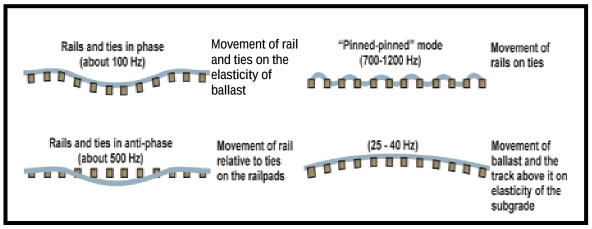

Figure 6. Theoretical Response of Track Structure

The measured response frequencies corresponded to the movement of the ballast and the track above it on the elasticity of the subgrade (55 Hz), the movement of the rail and ties on the ballast (280 Hz), and the rail and ties moving out of phase (500 Hz).

An effective design can enhance the track damping at different layers within the structure to attenuate the amplitude of vibrations at different frequencies. Figure 7 shows possible locations where damping could be added within the track structure.[3] The design lower in the structure must enhance the strength of the subgrade.

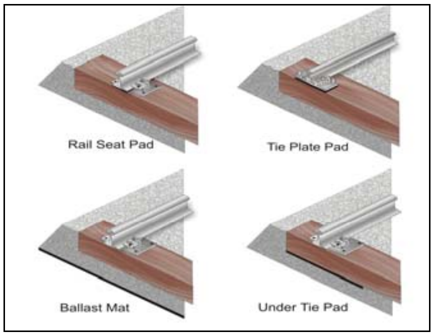

Figure 7. Possible Track Structure Damping Placement

Subgrade treatments such as hot mix asphalt (HMA), concrete, and cellular confinement layers are successful at strengthening the track structure.[4] Figure 8 shows a comparison of track modulus between these treatments and conventional track structure. The HMA subgrade displaced the biggest increase in track modulus. An issue with increasing the track stiffness is increasing the distance the low frequency vibrations travel into the substructure. It is, therefore, also important to enhance the damping.

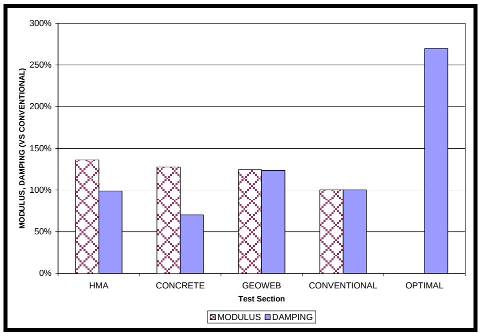

Figure 8. Subgrade Testing at FAST[1]

Dynamic modeling indicates there is an optimal amount of damping that decreases vertical impact loads by up to 30 percent.[4] Figure 9 shows the range of optimal damping. Figure 8 indicated that conventional track has about 40 percent of the optimal damping value. The subgrade treatments did not provide the needed increase in damping to reach optimal levels.

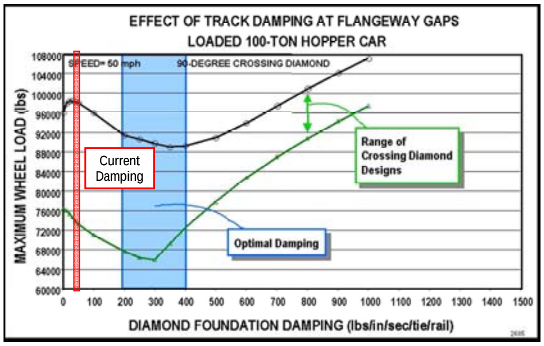

Figure 9. Diamond Damping on Vertical Dynamic Forces

In the diamond crossing foundation design it is important to add damping to reach the optimal value. The concept for the TTCI design is illustrated in Figure 10. Damping is placed in two different layers of the track structure. The goal is to cumulatively reach the optimal damping value to provide maximum impact attenuation.

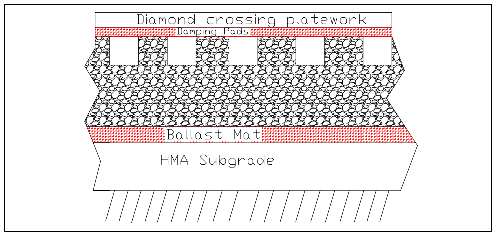

Figure 10. Preliminary Diamond Crossing Foundation Design

Damping higher in the structure is important to help dissipate the energy from high frequency impacts. It is also effective at dissipating energy from low frequency, high energy impacts. The preliminary design has damping material placed under the platework of the diamond crossing, which must withstand the harsh environment.

Additional design considerations include:

- Controlling settlement – Tonnage is higher on diamond crossings and the dynamic load environment is more severe. Thus, foundations more efficient at load distribution ensure that settlement is similar to open track. Diamond crossing settlement is minimized if they are not in low spots and are well drained.
- Smooth transitions back to conventional open track – Abrupt transitions in track structure lead to track geometry defects that generate high dynamic loads. This can be avoided by allowing for gradual transitions back to conventional track structure.

Preliminary diamond crossing foundation work has begun at the Facility for Accelerated Testing (FAST). A ballast mat has been installed over an existing HMA subgrade to provide increased damping in the lower foundation. A modified HMA, such as a rubberized HMA, is believed to offer the best combination of track strengthening and increased damping. HMA has also been effective at reducing settlement and gross failures on weaker subgrades.

An impact test will be performed on the HMA subgrade with the ballast mat to determine the amount of track damping that was added. The design of damping material for higher in the track structure will then be designed so that the diamond foundation is in the optimal damping range (i.e., 200 to 400 lbs/in/sec/tie/rail).

Future Work

The optimal foundation diamond crossing prototype will be built and tested at FAST in 2006.

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