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Long-Term Performance of Track Transition Solutions in Revenue Service

Charity Duran Sasaoka and David D. Davis

Summary

In the spring of 2005, the Transportation Technology Center, Inc. (TTCI) evaluated track transition problems and solutions in revenue service. This work, sponsored by the Association of American Railroads (AAR) and the Federal Railroad Administration, is part of an effort to develop effective and economic designs for track transitions.

Concrete span ballasted deck bridges in revenue service were monitored to document the long term performance of different tie materials used to address the track stiffness differential. Measurements were taken to document track stiffness and track damping characteristics for each of the test sites. The following observations were made after approximately 270 million gross tons:

Track stiffness characterization:

- Plastic ties installed on concrete span ballasted deck bridges effectively eliminated the track stiffness differential. There was no statistical difference between the approach track dynamic modulus and the bridge track dynamic modulus.
- Concrete ties with rubber pads were installed on both a concrete span bridge and a steel beam span bridge. The modified concrete ties decreased the modulus of the bridge track below that of the approach. The first iteration of these pads reduced the modulus below the desired value, but can be engineered to the desired value. Long-term performance indicates the pads are durable enough to withstand the harsh service environment they are subjected to.

The following observations were reconfirmed with the accumulation of tonnage:

- Track modulus is variable over a short distance. Several measurements are needed on a short bridge or approach to adequately characterize a site.
- Track on ballasted deck bridges is typically stiffer than the approach track.
- Several different tie materials were used to address track stiffness differential problems from the approach to the bridge structure. Different tie materials can provide effective improvements. Replacing ties on existing bridge track can be cost-effective in comparison to modifying the subgrade or bridge structure.

Track damping characterization:

- Track damping properties are affected by factors such as ballast quality, tie type, and rail temperature:
  - The mechanism for damping the ballast layer is structural damping. The energy from the impact is dissipated as the ballast pieces move relative to one another.
  - The mechanism for damping in the ties is internal damping. The energy is dissipated due to the material properties of the tie.
- It is important to measure damping at different layers in the structure to accurately characterize the entire system.
- Each layer of the track structure dissipates different frequency vibrations:
  - High frequency vibration is typically dissipated at the superstructure level. The rail, fasteners, and platework are damaged by these high frequency vibrations resulting from impact loads.
  - The lower frequency, higher energy vibrations travel into the substructure. These vibrations contribute to tie, ballast, and subgrade degradation.
- Different tie materials can add a significant amount of damping to overall track structure. Damping at this layer in the structure allows more of the higher energy vibrations to be attenuated before they reach the bridge structure:
  - Concrete ties with rubber pads increased the damping by approximately 50 percent. This allows the energy from the impact to dissipate twice as fast as conventional concrete ties.

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

INTRODUCTION

Track transitions at the bridge to bridge approach are a significant maintenance problem in mainline track. 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. Dynamic loading in this area can be as high three times the static wheel load. Track transition problems can be divided into three categories and are illustrated in Figure 1:

- Differential Settlement – Bridge and approach structures settle at different rates. Railroad bridges are built on deep foundations and are relatively immune to subgrade settlement. In contrast, the approach consists of fill and has a large amount of settlement. This is commonly referred to as the “dipped approach.”
- Track Stiffness Case – An abrupt stiffness change occurs between the bridge structure and the approach. For example, a concrete span ballasted deck bridge with concrete ties can have a track modulus that is very high compared with the surrounding track.
- Damping Case – Track damping is the energy dissipation of the dynamic loads generated due to track transition problems. For example on a bridge approach energy is dissipated through the track structure, subgrade, and surrounding ground. On a bridge structure some energy is dissipated in the ballast layer, but a large amount of damaging vibrations can reach the bridge structure.

Track transition issues for both ballasted deck bridges and open deck bridges have been documented.

Several different tie materials have been installed and monitored to determine the effect on minimizing the track stiffness differential and adding damping to the track structure.

FIELD MONITORING

Ballasted Deck Bridges

Several test sites on a western coal route in revenue service have been monitored for approximately 270 million gross tons (MGT) to determine the effect of different tie material on the track stiffness transition issue and the long term performance. Table 1 summarizes the test locations and test variable of each location.

Figure 2 shows data taken with the TLV on a concrete span ballasted deck bridge with typical concrete ties. The plot indicated that track modulus is highly variable over a short distance. The track modulus abruptly increases from the approach track to the bridge track. In order to accurately document this change and understand the track characteristics it is important to take many measurements in a short distance.

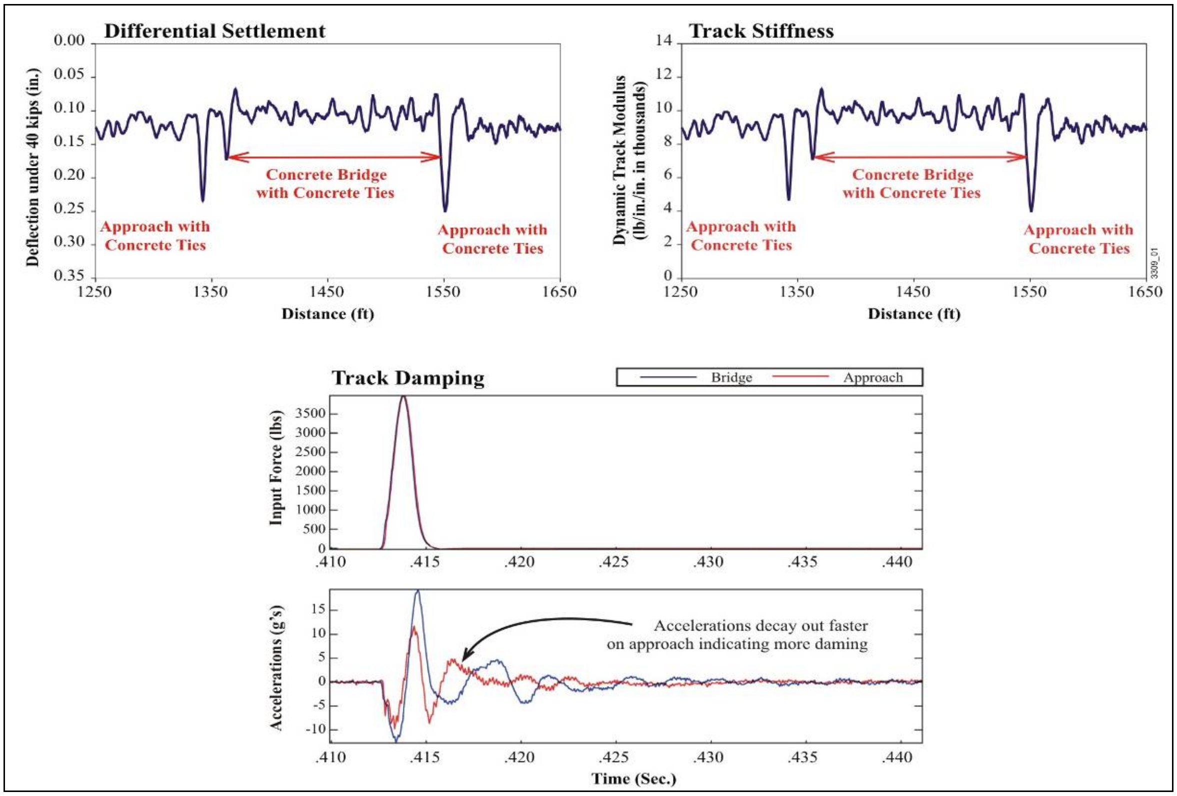

Figure1. Illustration of Track Transition Cases

Table 1. Description of Test Sites in Marysville, KS

Date	MGT	Tie Type on Bridge	Tie Type on Approach	Bridge Type
11/7/03	5	Plastic	Concrete	Concrete Span
5/25/04	85			
4/18/05	230			
11/7/03	40	Concrete	Concrete	Concrete Span
5/25/04	120			
4/18/05	270			
11/7/03	40	Concrete with Rubber Pad B	Concrete	Steel Beam Span
4/18/05	270			
11/7/03	40	Concrete with Rubber Pad A	Concrete	Concrete Span
5/25/04	120			
4/18/05	270			

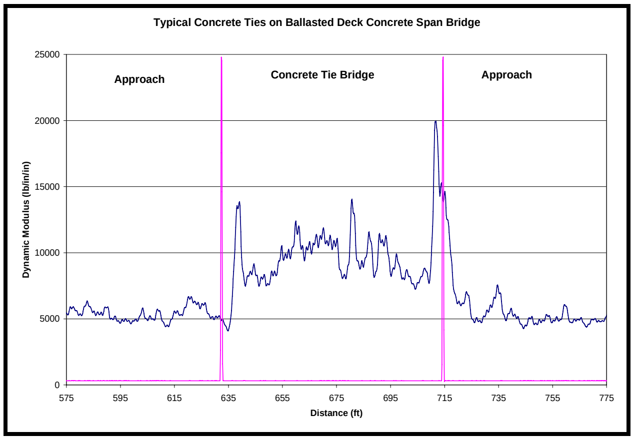

Figure 2. Dynamic Modulus Data Taken at Union Pacific's (UP) Marysville, KS Subdivision

The track on a concrete span ballasted deck bridge with typical concrete ties has a very high modulus compared with the approach track. The modulus on the bridge is approximately one and a half times higher than that of the approach. The track stiffness differential contributes to track degradation and tie cracking.

Different tie materials were installed on several bridges at UP's Marysville, KS Subdivison. The intent was to select tie materials to minimize the track stiffness differential. Two different types of concrete ties with rubber pads, and plastic ties were used in the tests. Figure 3 is a summary of the test results over 270 MGT. The plastic ties on the concrete span ballasted deck bridge minimized the track stiffness differential with the approach. The average modulus on the bridge and the approach, have no statistical difference. Plastic ties may be a good match for concrete tie territory.

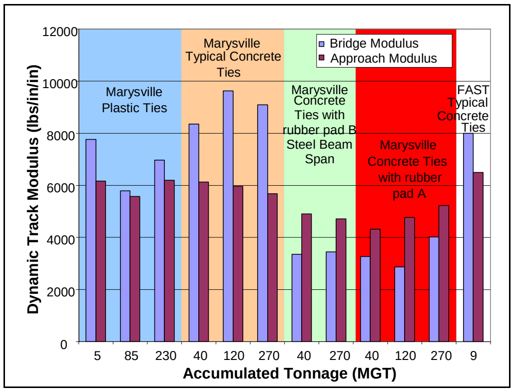

Figure 3. Summary of Test Result at 270 MGT

The rubber pads were adhered to the bottom of concrete ties and installed on both a concrete span bridge and a steel beam span bridge. Both types of rubber pads were successful at lowering the bridge modulus below that of the approach track. This method of addressing the track stiffness transition issue is promising because the desired properties can be designed into the pad. Another benefit of the rubber pads is that they provide damping for the bridge structure.

The long term performance of both the concrete ties with rubber pads and plastic ties is promising. Over 270 MGT was accumulated during this test. The rubber pads held up well in the harsh service environment. The plastic ties also performed well. On all three bridges there was no indication of cracked ties or track degradation.

Track Damping

The track acts as an energy distributing structure. Energy dissipation is a function of track damping. Track damping should be carefully considered when seeking ways to reduce damaging vibrations.

Track damping properties are affected by a number of factors such as ballast quality, tie type, and rail temperature. There are several mechanisms in which energy is dissipated within the track structure. Structural damping is the main mechanism in the ballast layer. Energy is dissipated in this layer by the ballast pieces moving relative to one another. The quality of the ballast is a factor of the damping characteristic. Good, clean ballast tends to have higher damping values due to the bigger particles. When fouled, the ballast behaves like a soil rather than discrete particles minimizing the damping. Minimizing differential settlement and tamping cycles is an effective way to increase the ballast life and maintain the good damping properties inherent to good, clean ballast.

Internal damping is the mechanism for energy dissipation in the ties and is inherent to the material properties of the tie. The tie may be the most efficient way to add damping to an already existing structure.

It is important to measure damping at different layers in the track structure to accurately characterize the entire system. Each layer of track dissipates different frequency vibrations. Higher frequency, lower energy vibrations resulting from impact loading are dissipated higher in the track structure. The rail, fasteners, and platework can be damaged from this type of impact. The lower frequency, higher energy vibrations tend to travel farther into the structure before the energy is dissipated. This type of vibration contributes to tie, ballast, and subgrade degradation.

The method used to characterize track structure in terms of track damping is a hammer test (Figure 4). An instrumented hammer is used to excite the track, and accelerometers that are placed on different areas of the track structure are used to measure the track structure response. The damping characteristics can be determined from the acceleration, decay rate, and the response frequencies. The damping ratio is calculated from the decay rate. This ratio is an important tool because it takes into account the magnitude of the impact and the time it takes for the energy to dissipate. Damping ratios from different track structures can be compared to determine if there was an improvement in the damping characteristics.

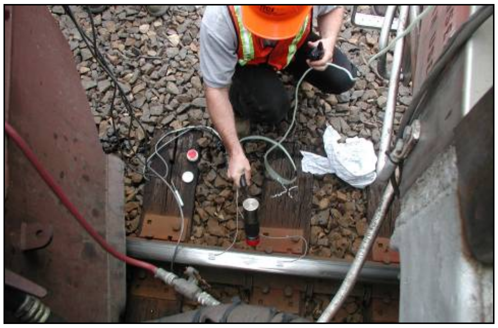

Figure 4. Hammer Test

The test bridges were characterized for track damping. Figure 5 shows the result from the hammer test on the bridges with concrete ties, plastic ties, and concrete ties with rubber pads. The response accelerations were monitored on the ties to determine which tie material effectively added damping to the structure. The concrete ties with rubber pads and the plastic ties had similar damping properties. In the decay plot, the accelerations at the plastic tie and the concrete ties with rubber pads were attenuated better than the typical concrete ties. Figure 6 shows a comparison of the damping ratios. The concrete ties with rubber pads have a damping ratio of 0.15, while typical concrete ties have a damping ratio 0.10. The 50 percent increase in damping provided by the rubber pads is valuable improvement. The energy from the impact loads will be dissipated twice as fast with the concrete ties with rubber pads than typical concrete ties. Good attenuation properties are essential for the ties on the bridge. Minimizing the damaging vibrations at the tie level of the structure will help prolong ballast and bridge structure life.

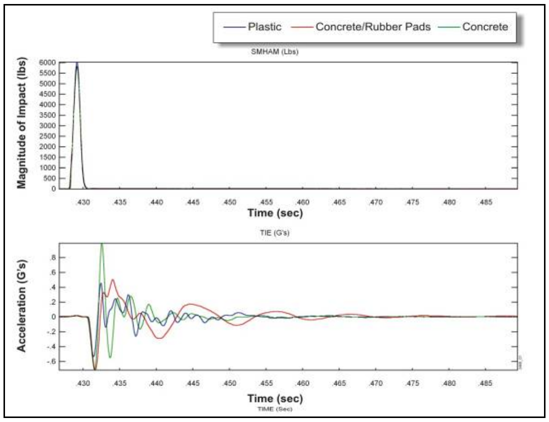

Figure 5. Hammer Test Data for Test Ties

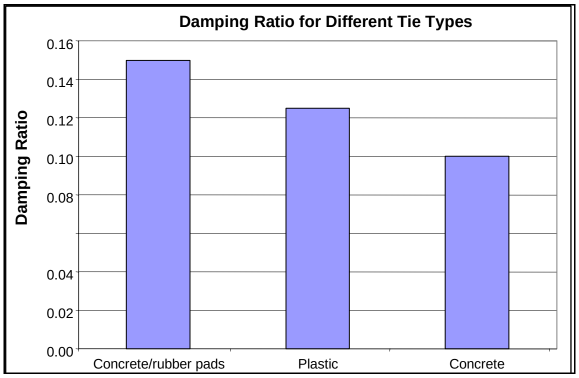

Figure 6. Damping Ratios for Test Ties

Conclusion

Plastic ties and concrete ties with rubber pads are an effective way to minimize the track stiffness differential and have performed well in the harsh railroad environment. Over 270 MGT were accumulated on the test bridges, the ties showed no signs of cracking, and the overall unloaded track structure required less maintenance. Another important property is the tie damping characteristic. The ties are an effective way to increase the damping in an already existing structure.

Future Work

The work done to date has mainly focused on the track transition issues at the bridge approach and ballasted deck bridge transition area. Open deck bridges are currently being monitored to document and understand the modes of degradation. Track structure that is effective at minimizing track transition issues in these areas will be designed. Special trackwork and road crossings have similar track transitions issues. Crossing frogs tend to have high impacts at the transition zone. Modeling suggests there is an optimal damping value to minimize the vertical impacts. A diamond crossing foundation is being designed to effectively attenuate the impacts and strengthen the subgrade to minimize the differential settlement in these areas.