Implementing Track Transition Solutions for Heavy Axle Load Service

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ABSTRACT

Track transition areas such as bridge approaches, road crossings, and special trackwork can become significant maintenance problems under heavy axle load traffic and can generate impacts that contribute to accelerated degradation and shortened component life resulting in service disruptions. An estimated $200 million is spent annually on track transition maintenance. The Transportation Technology Center, Inc., (TTCI), Pueblo, Colorado, a subsidiary of the Association of American Railroads (AAR), evaluated the effectiveness of currently accepted track transition designs and several prototypes as part of an effort to develop effective and economic designs for track transitions. Observations were made from theoretical work and field testing on the Union Pacific Railroad (UP) and at the FRA’s Facility for Accelerated Service Testing (FAST), Pueblo, Colorado.

Key Words: Bridge approach, road crossing, and special trackwork
BACKGROUND

One of the most significant maintenance problems 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 needed track maintenance (Figure 1).

Problems at a track transition are can be divided into three categories:

- **Differential Settlement**
- **Track Stiffness Case**
- **Track Damping Case**

Differential settlement is where two segments of track settle at different rates, such as the bridge to bridge approach track transition. 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 compared with the bridge structure. This common bridge to bridge approach construction method can result in what is commonly known as a “dipped approach.” The running surface deviation that develops in a dipped approach area can contribute to high dynamic loads as high as three times the static wheel load.

The track stiffness case is the abrupt stiffness change that occurs in the track transition areas. A concrete span ballasted deck bridge with concrete ties can have a very high track modulus compared with the surrounding track. The abrupt stiffness change by
itself does not contribute to higher dynamic loads, but coupled with a running surface deviation can induce high impact loads. The abrupt stiffness change does contribute to the degradation cycle promoting differential settlement at track transitions. This case has the more fundamental problem of a significant mismatch in track stiffness. Open deck bridges lack the ballast and subgrade layers found in conventional track. However, the problem also exists on ballasted deck bridges. Here, relatively short and stiff concrete spans can produce track with stiffness about double that of open track. This can result in poor ride quality and additional stress on track components on the bridge and its approaches, as well as higher dynamic loading on the bridge.

The track damping case addresses energy dissipation of high dynamic loads. Track damping differs between different track structures at a track transition. 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 much of the energy can reach the bridge structure. It is important to understand the types of impacts and design damping into the track structure to alleviate potential damage. There are two types of impacts generated at track transitions with running surface defects, wheel impact and wheel bounce:

- **Wheel Impact** is a high frequency impact due the wheel traversing a running surface deviation. The higher 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 broken components, cracked concrete ties, and damage higher in the structure. These vibrations can be minimized by enhancing damping higher in the structure.
• **Wheel Bounce** is a low frequency secondary impact. These transient vibrations are highly influenced by track stiffness. They may resonate with the movement of rails and ties on the ballast elasticity and contribute to surface and alignment degradation and ballast and subgrade deterioration. These vibrations can be minimized by enhancing damping lower in the structure.

TTCI is addressing all three of the settlement, stiffness, and dampening track transition cases mentioned earlier. Predictive tools are being developed to aid in designing effective track transitions. Field evaluations are being conducted to monitor the effectiveness of track transitions in place.

**THEORETICAL WORK**

Predictive tools are being developed to aid in designing track transitions solutions. Parametric studies have been done using NUCARSTM and Geotrack™ software to look at the effects of track damping and stiffness. A differential settlement model has been developed to help predict settlement for different track structures.

**Geotrack™ Study**

A parametric study of track designs for the approach to bridge transition problem was done using Geotrack™. Typical track structures were modeled for the bridge approach and ballasted deck bridge. For this study, a base case track structure was selected as 136 RE rail, wood ties on 19 inch spacing, 18-inches of ballast and subballast, and a medium strength subgrade. Foundation properties for the track on bridge foundation were derived
from track modulus measurements made on ballasted deck bridges at FAST and in revenue service.

Table 1 lists the base case track parameters used in the study. Predicted track modulus values for the base cases indicate future track transition problems. For example, the change in modulus from concrete tie track on a bridge approach to concrete tie track on a ballasted deck concrete bridge is about 4,000 lbs/in/in (or about double the approach value).

Figure 2 shows the results of the parametric study of track stiffness, using the wood tie track as the base case. This study concludes that stiffening the subgrade is the most effective way to increase track stiffness on bridge approaches. Another design option is using available means of lowering the modulus of the track on the bridge. Altering the stiffness of the tie pad or the tie itself can reduce track modulus and increase track damping. Another factor in track design for bridges is the bridge deck configuration. Use of liner materials such as timber planks, ballast mats, or waterproofing “protection board” might be effective in reducing the stiffness of track laid on a bridge.

**NUCARS™ Study**

Track behaves as a load and energy distributing structure. The load distributing characteristic of track is a function of its stiffness. Energy dissipation is a function of damping. Track damping and stiffness are very important characteristics in seeking ways to reduce vertical impact loads. A study was done by TTCI using NUCARSTM to quantify the contribution of track stiffness and damping to impact load reduction.
For this parametric study, track modulus was varied from 5,200 lbs/in/in (representative of good open track with elastic fasteners) to 100,000 lbs/in/in. The results of a typical hopper car traversing a diamond crossing are shown in Figure 3. With no changes in the running surface under load, the effect of the stiffness on the maximum impact loads is negligible. Track stiffness can create running surface defects under load and contribute to differential settlement in track structures. A running surface deviation can generate impacts as high as three times the static wheel load. It is important to minimize the track stiffness differential to alleviate the running surface deviations that can be present under load in transition areas.

The NUCARS™ study also characterized the effect of track damping on impact attenuation. Damping was varied up to 2,500 lbs/in/sec/tie/rail. The results shown in Figure 4 indicate that there is an optimal damping value of approximately 300 lbs/in/sec/tie/rail. At the optimal value, impact loads were decreased by approximately 30 percent. Field testing indicates that track damping is typically around 50 lbs/in/sec/tie/rail. Adding damping to the track structure can be achieved through adding damping pads and modifying the subgrade.

**DIFFERENTIAL SETTLEMENT MODEL**

A differential settlement model was developed to predict average settlement as well as differential settlement for a given track structure change. The model will be used as a design tool in designing track transitions effective at minimizing differential settlement. The model consists of subgrade and ballast deformation models to predict settlement in each layer for a cycle of loading. Geotrack™ is used to predict the dynamic load for
different types of structures and vehicle loading. The load will change as the differential settlement occurs. Thus, for each cycle, Geotrack™ is used to predict the change in the load environment. Figure 5 shows output from the differential settlement compared to field data measured at the site modeled. There are several important factors to note in the output from the differential settlement model:

- A high settlement rate is evident at the beginning of a cycle. With tonnage, the settlement begins to achieve a steady state. It is important to note that with every tamping cycle where a track raise occurs the track settlement cycle starts all over and steady state must be re-established.

- The field data was taken on new construction. The settlement in the first 10 mgt is higher than after this initial period and atypical of an existing structure. As tonnage was accumulated on the bridge the differential settlement model and the field data followed the same trend.

A parametric study is currently being conducted to look at different structures and type of soils.

LABORATORY AND FIELD TESTING

TTCI conducted laboratory tests of commercially available noise and vibration attenuation pads for the track. Since impact attenuation is not the explicit goal of these products, it is difficult to obtain published data on the relevant properties. Tests were conducted to develop mechanical properties data that can be used to evaluate track pads for impact attenuation.
Rail seat pads, tie plate pads, and under tie pads were tested. The following properties were determined from the laboratory tests:

- Stiffness was determined by looking at the force and the deflection relationship of each pad.

- Equivalent viscous damping can be determined by calculating the total energy dissipated. The stress-strain curve for a vibratory system is referred to as the “hysteresis loop.” The area enclosed by the hysteresis loop is proportional to the stress amplitude and represents the energy dissipated per cycle of vibration. The frequency of interest is at 200 Hz. This is the frequency at which the rail and tie vibrate in phase during laboratory testing. This is when the damping pad is being engaged by the system.

- The permanent set was determined from a creep test. Deformation is an important factor in determining each pad’s durability.

- A durometer reading was measured to compare with product literature.

Table 2 lists the results of the laboratory tests. It is evident from the laboratory results that the available product literature is not helpful in determining impact attenuation characteristics for these pads. A durometer reading is not a good indicator of damping characteristics; however it may be an indicator of the pad’s durability. Pads with low durometer readings are often associated with a soft rubber. This type of material has been shown to provide short service life as a rail seat pad in concrete tie applications.
The type of environment where these pads will be used needs to be taken into account. Field experience indicates that pads with a low durometer reading do not withstand the load environment of a concrete tie rail seat. Pads with a low durometer reading initially provide good damping to the track structure, but fail early in comparison to the life of a concrete tie. However, they cannot be discounted from all uses.

To obtain the optimal damping of 300 lbs/in/sec/tie/rail in the track structure, damping may be added at different levels within the structure. Figure 6 shows the various types of pads available. Installation of rail seat pads and tie plate pads are the easiest modifications that can be made to an existing structure. Placement of damping in this level of the track structure provides impact attenuation for the high frequency loads due to wheel impact as the wheel traverses a running surface defect. Attenuating the higher frequency impact can minimize broken components such as broken plates, broken bolts, and cracked ties. These pads, however, require a higher performance and durability as they are subjected to both a harsh load environment and varying atmospheric elements such as heat, cold, and moisture. Rail seat pads and tie plate pads have the potential to be squeezed out from under the rail or plate work requiring more maintenance.

Major modifications must be made to an existing track structure when ballast mats and under tie pads are installed. These pads provide damping lower in the structure helping to attenuate the lower frequency impacts due to wheel bounce. These types of impacts are responsible for ballast breakdown and running surface misalignments. Although these pads will not be exposed to the elements, they will not be easy to
maintain. These pads will also have to resist the abrasive action of the ballast. Thus a durable material with a long service life is required.

Laboratory data alone does not give the complete picture of how each of these pads will affect the damping of the structure. The second step in the testing process is in-track testing of the pads. A test panel, installed at FAST, was designed to simulate the foundation of a typical crossing diamond. The laboratory test pads are being evaluated for contribution to impact attenuation and durability. Laboratory data will then be correlated with the field data. This study is being done to determine an effective way to predict field performance from laboratory tests.

FAST AND REVENUE SERVICE TESTING
Bridge/Bridge Approach Transitions
A concrete span ballasted deck bridge at FAST and several test sites on a western coal route in revenue service have been monitored to determine the effects of different tie material on the track stiffness transition issue. Table 3 summarizes the test locations and conditions and Figure 7 provides the results from all test locations.

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.

The plastic ties on the concrete span ballasted deck bridge minimize the track stiffness differential with the approach. The average moduli on the bridge and the bridge
approach have no statistical difference. Plastic ties may be a good match for concrete tie territory.

Two different types of rubber pads were tested in revenue service. The 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 pads were successful at lowering the bridge modulus to below that of the approach track. This method of addressing 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 damping characteristics will be discussed with the FAST test results.

Track stiffness transitions are also being monitored at FAST. The characteristics of the bridge being monitored are as follows:

- Concrete span ballasted deck
- 5-degree curve, 4-inch superelevation
  - 12-inch ballast low rail
  - 16-inch ballast high rail
- Ties
  - Phase 1 – Typical concrete ties
  - Phase 2 – Concrete ties with rubber pad A
  - Phase 3 – Concrete ties with pad designed to meet stiffness requirements
- Approach Characteristics
  - Concrete Ties
  - Constructed fill of compacted silty sand
The bridge and bridge approach were tested to determine the stiffness and damping characteristics for each phase of testing. Figure 8 provides the results from phase 1 and phase 2. Phase 3 data is currently being collected. In phase 1, the bridge modulus was 1.3 times higher than that of the approach. The damping characteristic of the bridge was low at approximately 50 lbs/in/sec/tie/rail.

Phase 2 testing consisted of installing concrete ties, with rubber pads on their bottoms as used in revenue service tests, on the bridge. The bridge modulus was lowered to approximately 3,500 lb/in/in. The damping characteristics of the bridge were improved by the addition of the rubber pads.

Strain gauges were placed on the bottom of the bridge spans to measure the impacts into the structure. Impacts were measured for both typical concrete ties and concrete ties with rubber pads installed on the bridge. Figure 9 shows the results from the two tests. In the short span the rubber pads improved the impact attenuation by approximately 12 percent. This is consistent with the NUCARSTM model prediction for a damping value of 120 lbs/in/sec/tie/rail.

The intent of Phase 3 was to determine if the desired properties could be designed into a track transition. The desired properties were no stiffness differential between the bridge and the approach and damping of 120 lbs/in/sec/tie/rail. Laboratory tests were conducted on two new rubber pad designs. These tests were to evaluate the stiffness and damping characteristics compared with the first pad tested. Another goal of these tests was to design a method to determine how a pad will perform in track. The results from
the laboratory tests are shown in Figure 10. The stiffness was increased without
compromising the damping characteristics of the pads.

The concrete ties with pad 3, chosen for testing in track, are currently being
installed on the bridge at FAST. Vertical track modulus measurements and hammer tests
will be performed to determine the pad characteristics.

**Special Trackwork Transitions**

Crossing diamonds transitions are likely to be higher impact locations when compared to
switches and turnout frogs. The impacts result from the wheel traversing the flangeway
gap. The vertical impacts generated can in rare cases be as high as five times static wheel
load. Another issue at crossing diamonds is differential settlement. Because of two
directional traffic, these areas see higher tonnage rates than surrounding track and tend to
settle faster. The crossing diamond then becomes a low spot in the track structure.

Adding damping to a crossing diamond transition can help mitigate the effects of
the impacts generated from wheel impact and wheel bounce. It can also be beneficial to
strengthen this area of the track structure to minimize the differential settlement. TTCI is
working with suppliers to develop a prototype transition design and begin testing at
FAST.

A schematic of the prototype design can be seen in Figure 11. Damping is added
at two layers in the track structure. The subgrade treatment is a hot mix asphalt to add
strength with a ballast mat to add damping. The damping in this layer is to attenuate the
low frequency vibration due to the wheel bounce. The damping pads below the plate
work are to attenuate the high frequency vibrations from the wheel impact. The goal of
the two layers of damping is to reach the optimal value of 300 lbs/in/sec/tie/rail. The optimal value should attenuate the impacts by 30 percent. Installation of the diamond foundation is scheduled for the fall of 2005.

**CONCLUSIONS**

Theoretical work suggests there are opportunities to improve performance of track transition areas. NUCARSTM modeling suggests that adding damping to a track structure can improve impact attenuation by up to 30 percent. Different ways to add damping to the track are being investigated. Rail seat pads, tie plate pads, ballast mats, and subgrade treatments are all potential solutions.

The parametric study using Geotrack™ suggests the best method for raising approach track stiffness is subgrade treatment. The study also suggests the best method of reducing bridge track stiffness is to alter tie to pad properties.

Field testing indicated that different tie materials can provide effective ways to improve the track stiffness transition. Plastic ties installed on bridges in concrete tie territory have been successful in eliminating the stiffness differential for the first 240 MGT. The first iteration of concrete ties with rubber pads was successful in lowering the modulus below that of the approach and increasing the damping properties of the bridge structure. Thus, this method appears capable of addressing both track stiffness and damping issues and is a promising solution because the desired properties can be designed into the pads.
A library of predictive tools is being developed to provide a way to design effective track transitions to address stiffness, damping, and differential settlement. Field testing has proved that there are effective ways to address each of these issues.

ACKNOWLEDGEMENTS

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<table>
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<tr>
<th></th>
<th>Wood Tie Approach</th>
<th>Wood Tie on Concrete Bridge</th>
<th>Concrete Tie Approach</th>
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<td><strong>Rail Section</strong></td>
<td>136 RE</td>
<td>136 RE</td>
<td>136 RE</td>
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<td><strong>Ties:</strong> Material/ spacing</td>
<td>7x9 hardwood / 19”</td>
<td>7x9 hardwood / 19”</td>
<td>Tangent Track concrete tie/24”</td>
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<td><strong>Ballast:</strong> Material/ Thickness</td>
<td>Traprock/12”+6”subballast</td>
<td>Traprock/12”+6”subballast</td>
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<td><strong>Subgrade:</strong> Material/ Thickness</td>
<td>Typical medium strength slit-loam</td>
<td>Pre-stress concrete box; equivalent stiffness derived from field measurements</td>
<td>Typical medium strength slit-loam</td>
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<td><strong>Track Modulus (lbs/in/in)</strong></td>
<td>3400</td>
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### Table 2: Laboratory Test Results

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<tr>
<th>Pad ID</th>
<th>Pad Type</th>
<th>Pad Description</th>
<th>Stiffness (^1) (kip/in)</th>
<th>Damping (^2) (lb/in/sec)</th>
<th>Permanent Set (^3) (in)</th>
<th>Durometer Reading (^4)</th>
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<td>Rail Seat</td>
<td>Black rubber with micro-cells</td>
<td>556.76</td>
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<td>Rail Seat</td>
<td>Aqua polyurethane with abrasion plate</td>
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1) The pad was loaded with a 6-inch base rail. The deflection of the pad was measured from 0 to 50 kips. The stiffness was then calculated from the force deflection relationship.

2) Damping was measured at 200 hz – the characteristic rail on tie frequency.

3) Permanent set is the measured permanent deformation that occurred during a creep test. The pad was loaded from 0 to 50 kips in 5-kip increments. Each interval was held for duration of 30 minutes.

4) The hardness of pad was measured with a Shore hardness test ASTM D2240 (also known as a durometer reading).
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