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Under-tie Pad Performance at Bridge Transition Zones

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Transportation Technology Center, Inc. (TTCI) evaluated the performance of under-tie pads (UTPs) installed under concrete ties at a bridge approach at the Facility for Accelerated Service Testing (FAST) and the results suggest UTP concrete tie bridge approaches may lengthen maintenance intervals compared to conventional concrete ties without UTPs. In revenue service, UTPs have been used to reduce differential settlement at bridge approaches and to provide a smoother transition by reducing vibration. FAST is located at the Federal Railroad Administration's Transportation Technology Center near Pueblo, CO. This work was performed under the Association of American Railroads (AAR) Strategic Research Initiatives program.

The FAST test setup included one control case containing conventional concrete ties without UTPs, and one test case containing concrete ties with UTPs. For the test case, 50 ties with UTPs were installed at an open deck bridge approach in a 5-degree curve at FAST. For the control and test cases, top-of-rail (TOR) elevation (settlement) measurements were monitored at various tonnages to assess performance of these track systems. Additionally, for both cases, a "SmartRock" — a ballast-particle-shaped wireless device developed by Penn State University — was installed at the tie-ballast interface to monitor ballast particle movement in real time. The TOR measurements and SmartRock results allowed the performance of each bridge approach case to be characterized.

Previous studies have found that the application of UTPs at bridges can balance track stiffness and increase track damping for the track on the bridges.[1,2] Recent research showed that UTPs at bridge approaches could reduce the load impact on the ballast layer and provide better load distribution; thus reducing ballast degradation and local settlement at the bridge approach.[3] Although use of these pads in the bridge approach actually increases the stiffness change, the reduction in vibration, pressure, ballast degradation, and settlement appear to be more beneficial. To evaluate the bridge transition performance, 50 ties with UTPs were installed on a bridge at FAST. This study compares the track settlement and ballast particle movement with and without UTPs at the bridge approach.

TEST SECTION DESCRIPTION

The test section (Figure 1) was located at the west side of the East Steel Bridge in FAST Section 3. The train had 3 locomotives and 110 coal cars with 39-ton axle loads. Operations are restricted to a maximum speed of 40 mph.

Key Findings:

- After 36.8 million gross tons (MGT) of accumulated load, the control bridge approach section without under-tie pads (UTP) experienced about 0.7 inch of settlement within the first 10 ties of the approach, causing a dip on the rail running surface. SmartRock measurements showed larger vertical ballast accelerations at the bridge approach than at the adjacent open track on the same curve.
- The UTP test case showed smaller ballast vertical accelerations indicating that the UTPs provided damping in the track reducing tie and ballast contact forces.
- The control (without UTP) bridge approach required a maintenance surfacing interval approximately every 30-40 MGT.
- To date, the UTP bridge approach has shown larger total settlement, but reduced surface roughness (i.e., more uniform settlement) resulting in longer maintenance cycles (reduced tamping) compared to the control case. The UTP bridge approach was surfaced first at 61.3 MGT, then at 92.6 MGT, and has not been surfaced again to date (302 MGT).

**National Railroad Passenger Corp. (Amtrak)*

Two test setups were investigated: 1) control case with conventional concrete ties; and 2) test case with 50 concrete ties with UTPs installed at the beginning of the bridge approach.

Standard concrete ties and UTPs donated by Amtrak were used in the testing. The control section was tested initially and then 50 UTP ties were installed at the same approach to replace the ties that were in the control section.

Figure 1. Bridge approach

TEST INSTRUMENTATION

Figure 2 shows an example of the SmartRocks used to monitor ballast particle movement under dynamic train loading. This wireless sensor is composed of a tri-axial gyroscope, tri-axial accelerometer, and tri-axial magnetometer that record real-time dynamic rotation, translation, and orientation in 9 degrees of freedom; respectively.

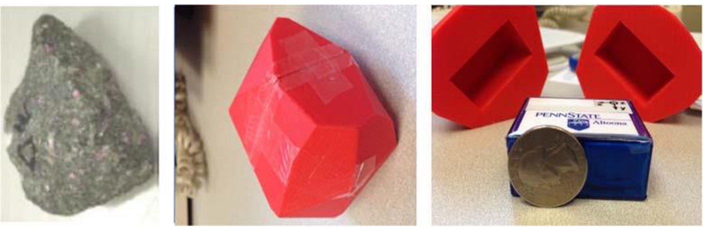

Figure 2. A photo of Penn State's SmartRocks

Three-dimensional printing technology was employed to form the shape of the SmartRock similar to a real ballast particle. An appropriate material was chosen so that the contact stiffness, equivalent specific gravity, and moment of inertia of each SmartRock were as close as possible to those of the real ballast particles. The strength of the SmartRock is greater than limestone and similar to that of granite.[4]

A total of 10 SmartRocks were installed for each test case. During each test, the SmartRocks were placed in the ballast underneath both high and low rail sides of different ties, as shown in Figure 3, to record particle movement under train passages. In addition, TOR measurements were monitored at various tonnages.

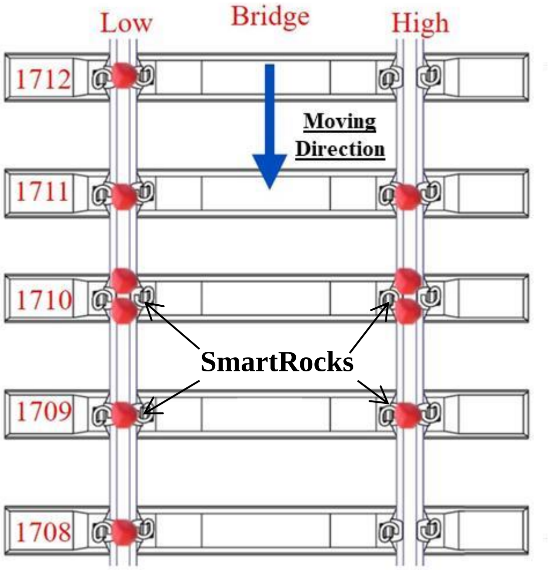

Figure 3. Schematic of instrumentation locations

TEST RESULTS AND ANALYSIS

SmartRock Measurements

Figure 4 shows an example of SmartRock vertical accelerations on the high rail side for the control case and UTP case at the bridge approach. Similar patterns are observed from data recorded by the other SmartRocks.

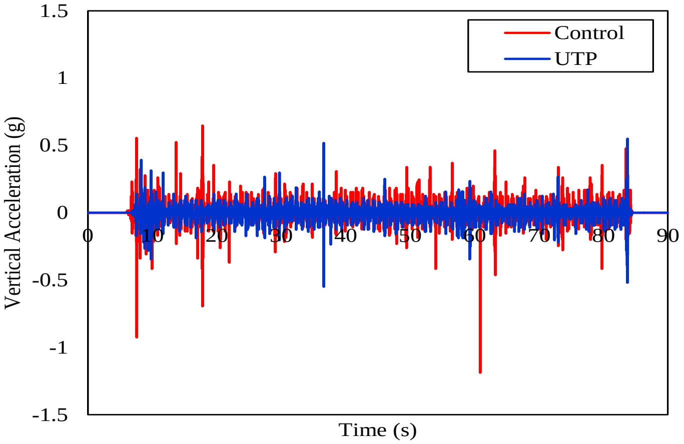

Figure 4. SmartRock vertical acceleration time histories

The SmartRocks were installed in the ballast layer and were in contact with surrounding ballast particles. The measurements recorded revealed vibration information of individual ballast particles inside the ballast layer. Ballast acceleration ranged from –1.25 g to +0.6 g in the control case and from –0.5 g to

+0.5 g in the UTP case, resulting a significant percent reduction in terms of acceleration range. Further, the peak acceleration decreased from 1.25g to 0.5g in the UTP case.

TOR Measurements

Figure 4 shows the TOR measurements at the bridge approach for both cases.

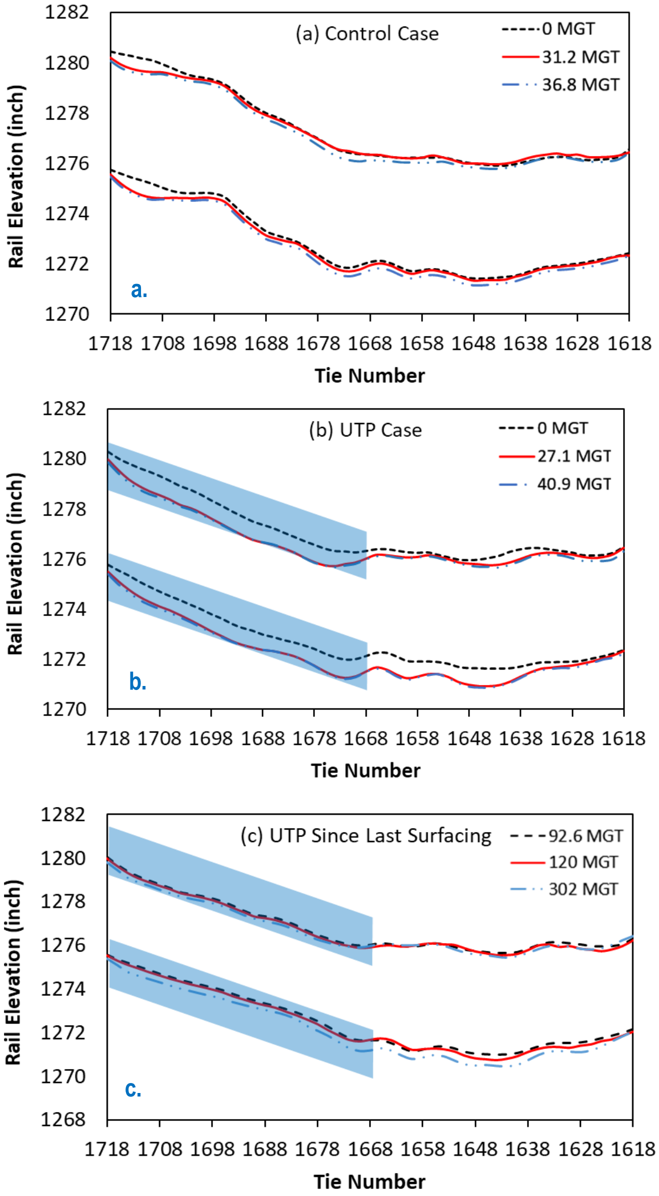

Figure 4. TOR measurements of the first 100 ties at the bridge approach (a) control case (b) UTP case (c) UTP since last surfacing

The measurement started at the first tie (No. 1718) of the bridge approach and ended at the 100th tie in open track (No. 1618). The initial measurement taken on this section was 0 MGT in the control case. This bridge approach has been installed at FAST for many years and experiences relatively frequent maintenance. After testing the control case, 50 UTP ties were installed at the beginning of the same bridge approach (tie No. 1668 to No. 1718) to evaluate the track performance with UTP ties. In the UTP case, the MGT count restarted at zero.

As shown in Figure 4a, the greatest settlement at the bridge approach in the control case was about 0.7 inch at both rails and occurred at a location close to the bridge (ties 1706-1712). The settlement generated a dip at the bridge approach amplifying the dynamic loading going into the ballast layer and causing further ballast degradation and settlement. However, as shown in Figure 4b, the UTP case reduced the severity of the rail dip because the settlement was more uniform over a longer track section; thereby providing a smoother transition from the bridge to the open track. The maximum settlement in the UTP case was higher than that in the control case (0.9 inch versus 0.7 inch). This may be due to a new ballast layer placed before the UTP installation, or a faster ballast consolidation. The UTP section was surfaced twice in the first 92.6 MGT and has since accumulated over 200 MGT without surfacing maintenance. In addition, the settlement at the bridge approach and open track was much smaller than that in the control case or the first 92.6 MGT of the UTP case (see Figure 4c).

Figure 5 presents the surfacing intervals for the control case and the UTP case at the FAST bridge approach. The surfacing cycle was approximately 30-40 MGT in the control case. The UTP case has resulted in a longer average surfacing interval. In total, 302 MGT has been accumulated on the UTP ties since the installation of the UTP case.

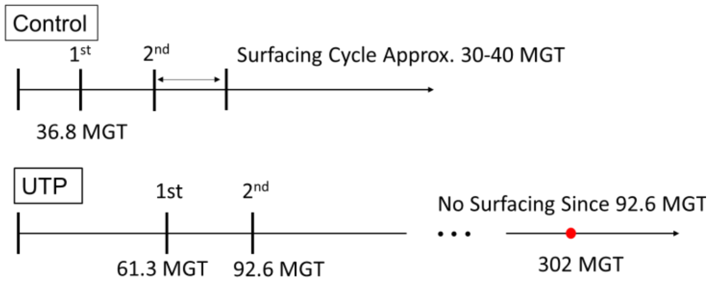

Figure 5. The surfacing intervals for the control case and the UTP case

To date, only two surfacing maintenance cycles have been conducted in the UTP test zone and they were performed within the first 100 MGT. The test section has not been tamped since 92.6 MGT. The average surfacing interval of the UTP case has been longer than the control case — a likely result of the reduced ballast acceleration and track surface roughness development. The more frequent surfacing cycle (still less frequent than the control case) in the first 100 MGT might be due to a faster ballast consolidation after the initial installation.

Even though the maximum track settlement was higher, the track with UTPs showed reduced surface roughness compared to the control case. Surface roughness was evaluated using a 31-foot mid-chord filter of the TOR measurements from each case (similar to a geometry car's 31-foot surface/profile channel)[5]. Figure 7 presents an analysis of the data.

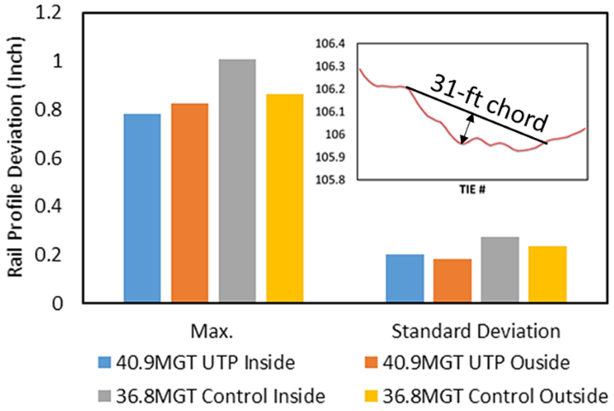

Figure 6. Analysis on the deviation of mid-ordinate from a 31-foot chord

As shown, a maximum deviation of 1 inch occurred on the low side rail in the control case. Also, the control case had larger standard deviation (greater variability) for both high and low rails. These indicate that the UTP case generated more uniform vertical profile and produced less surface roughness. Less surface roughness is associated with reduced wheel-rail impact loads; a primary driver for localized track degradation.

CONCLUSION AND FUTURE WORK

SmartRock measurements showed that the installation of the UTPs on the FAST bridge approach reduced ballast particle acceleration compared to the control case. These reduced ballast accelerations appear to provide reduction in track surface roughness at the approach.

Vertical profile data and TOR measurements indicated that the UTP installation at the bridge approach reduced the approach surface roughness and provided a smoother transition from the bridge to the open track compared to the control case. Although the UTP case provided more uniform track settlement, the track accumulated larger settlement in the UTP case than in the control case.

Future monitoring will help to understand the benefits and disadvantages of UTPs.

Acknowledgements

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