Effect of Hand Tamping on Transition Zone Behavior

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ABSTRACT

A common maintenance technique to correct track geometry at bridge transitions is hand tamping. This paper presents a non-invasive track monitoring system involving high-speed video cameras that evaluates the change in track behavior before and after hand or pneumatic tamping at a bridge transition zone experiencing reoccurring track geometry deviations. The track monitoring shows significant permanent vertical displacement (settlement) in the transition zone during the first few wheel passes after tamping (~0.6 inches) and a return to the pre-tamping transient behavior after about four train passes. This implies that significant differential settlement occurs between the transition zone and bridge abutment immediately after the first passing train which can result in increased dynamic loads in the transition zone and further deteriorate the transition zone geometry. Methods to reduce this initial settlement are discussed in the paper.

INTRODUCTION

Railroad ballast plays an important role in the track structure and provides four key functions: (1) distributing the axle loads to the subgrade, (2) restraining the track laterally, longitudinally, and vertically, (3) providing adequate drainage, and (4) maintaining proper track crosslevel, surface, and alinement (*1*). As a granular material, the ballast layer eventually settles from repeated loading resulting in track geometry deviations which can increase the dynamic loads and further deteriorate the track geometry (*2*). This inevitable process forces railroad companies to resurface the track frequently to maintain desirable track geometric features and allow the ballast to perform the above mentioned functions as intended.

The most common resurfacing technique used in the United States is tamping which essentially involves raising the track to the desired elevation and squeezing the crib ballast from both sides of the tie to fill the space underneath the tie. Tamping has proven to be an efficient and cost-effective resurfacing technique but is effective for only a temporary period of time before resurfacing is required again due to the natural settlement of the ballast from particle rearrangement and breakage (*2*). This is especially true in track with abrupt changes in stiffness such as bridge transition zones where differential stiffness, settlement, and damping can result in significantly higher dynamic loads (*3-5*) which accelerates track degradation and represents a significant maintenance cost for railroad companies in the United States (*6*).

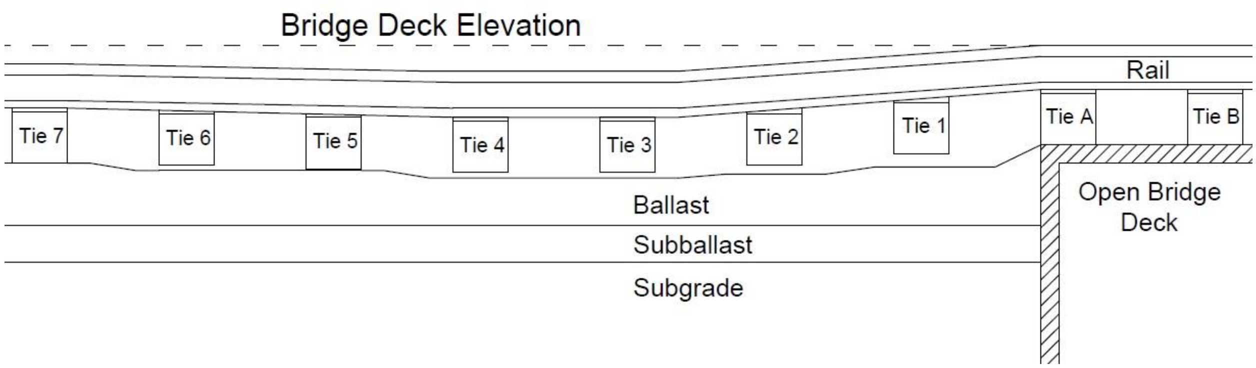
This paper (1) investigates the conceptual ballast behavior during a tamping cycle in a high-maintenance track location such as a bridge transition zone and illustrates certain portions of this cycle with field data and (2) discusses some limitations of the current tamping process along with a few potential ideas to improve tamping in high-maintenance regions where implementing different techniques may prove cost-effective.

TAMPING CYCLE AND BALLAST COMPACTION

The primary reason for tamping and resurfacing is the inevitable ballast settlement from particle rearrangement and breakage during repeated axle loadings. While ballast settlement is a continuous process, it has been often split into two distinct phases: (1) the "compaction" phase and (2) "post-compaction" phase (*7,8*).

The first "compaction" phase occurs immediately after tamping and can involve significant settlement from particle rearrangement as the ballast re-densifies into a more compact state where the magnitude of settlement is typically inversely related to the initial density. The loose ballast condition immediately after tamping is historically well-known from observations of lower track modulus (*9*) and this initial settlement has been included in many settlement models (8,*10*). The second "post-compaction" phase involves a linear or decreasing relationship between settlement and loading and is caused by several mechanisms, including: continued densification of the ballast, infiltration of the ballast in the subballast or subgrade, volume reduction from particle breakdown and abrasion, and lateral or longitudinal movement of the ballast particles (*8*). This settlement eventually reduces the ability of the ballast to properly distribute train axle loads and restrain track movement, requiring the track to be resurfaced. If this resurfacing is not performed and the track geometry further deteriorates, the track geometry problem can evolve into a safety issue.

While ballast settlement is undesirable anywhere in railroad track, it is especially problematic at locations where the potential for settlement varies considerably across a short distance such as bridge transition zones or culverts. This is because the rail and ties naturally rest upon the underlying layer, e.g. ballast or bridge deck, but local differential settlement and the high bending stiffness of the rail causes the rail and tie to be supported at the regions that experience the least amount of settlement and hang over regions that experience the greatest amount of settlement, i.e. hanging ties. At bridge transition zones, this leads to the “dip” where the rail is supported from the bridge deck and also out farther in the open track, i.e. 15 or 20 feet out, and results in either rail-tie or tie-ballast gaps in the transition zone. Two examples of tie-ballast gaps in transition zones are displayed in Figure 1 where the rail is supported at the bridge deck (Tie A) and Tie 7 in both situations.



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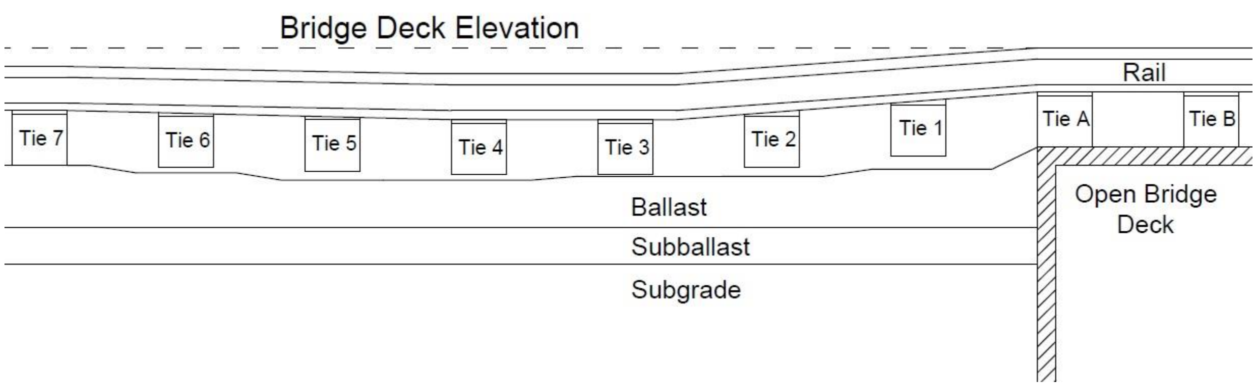

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Figure 1: Two Example Diagrams of Bridge Transition Zones with Tie-Ballast Gaps.

The existence of hanging ties leads to a situation where the train load will not be evenly carried by all ties, e.g. 30 to 50% of the axle load taken by the underlying tie (*11*), but redistributed which increases the load on surrounding better supported ties (*12*). Bridge transition zones with track system gaps are complicated situations because of the variation in track support and rail elevation between the bridge, transition zone, and open track. Therefore, while the load distribution is difficult to quantify, the train load is not expected to be evenly distributed throughout the transition zone but instead concentrated on the few well- or better supported ties in the transition zone. For example, in Figure 1, the ties expected to receive the concentrated dynamic load would be Tie 5 in Figure 1(a) and Tie 3 in Figure 1(b). This concentrated dynamic loading, from uneven ballast settlement in transition zones, will overload the ties and underlying ballast and can lead to the accelerated degradation of the transition zone track. Additionally, this uneven loading will also result in concentrated loading of several end ties on the bridge deck, resulting in crushing and short tie life.

INSTRUMENTATION

To investigate how actual transition zone track behavior after tamping compares with the conceptual cycle mentioned in the previous section, a non-invasive monitoring system using high-speed video cameras was developed to detect transient rail and tie movement and evaluate overall track performance. This monitoring system is used to compare the transient track behavior at a particular tie before and after tamping and evaluates the amount of settlement that occurs immediately after tamping, i.e. “compaction” phase.

This paper emphasizes the results of the high-speed video cameras and how they can be used to identify track system gaps and evaluate track performance by measuring the rail and tie transient time histories. High-speed video cameras (Figure 2) were selected because of their mobility, the only contact with the track system is placing removable targets on the rail and tie, and the recorded video provides a visual account of track movement. The cameras typically record at a sampling frequency of 240 frames per second and are capable up to 1000 frames per second which is sufficient to capture and quantify the track movement even for high-speed passenger trains.

Figure 2: Photograph of the High-Speed Video Camera.

INSTRUMENTATION SITE

The instrumented site is a double transition surrounded by an open deck bridge to the north and an asphalt crossing to the south that has developed noticeable rail-tie and tie-ballast gaps from ballast settlement. The site was instrumented on 21 October 2014 and 22 October 2014 with a high-speed video camera that measured the rail and tie displacements of two different tie locations. On the morning of the second day (22 October 2014), the bridge transition zone was hand tamped using a hand tamper. This allowed for the pre- and post-tamping behavior to be measured with a high-speed video camera.

The instrumented site involves the south end of the railway bridge transition zone displayed in Figure 3. The traffic is considered Class 4 for track operations and consists of mixed freight, loaded coal, and intermodal trains passing from 30 to 60 mph. The bridge is roughly a 50 ft. steel open deck bridge constructed in 1923 with few bridge or transition zone design features to minimize differential displacements. The first six ties are longer at 10 feet in length instead of the standard 8.5 foot ties and a timber support connected to the bridge abutment was placed under the first two ties in attempt to limit track settlement but the timber support has become tilted and likely does not receive any load. Nearly every tie in the southern transition zone contains either a rail-tie and/or tie-ballast gap and ballast fouling is prevalent in and around all of the ties. The rail-tie gaps are found within 16 ft. (5 m) of the bridge abutment and tie-ballast gaps are mainly observed 16 ft. (5 m) or more from the abutment. The rail-tie gaps develop from the upward reaction force of the rail after unloading which pulls the spikes from the tie. Because the rail-tie gaps are found within 16 ft. (5 m) of the bridge abutment, this suggests that the upward reaction force is greater within the 16 foot zone than outside it.

Additionally, an asphalt road crossing exists about 70 ft. (20 m) south of the bridge abutment, which results in two transitions in the instrumented region, i.e., a transition from an asphalt crossing to open-track to a steel open deck bridge, and likely blocks drainage. This means that both north and southbound trains experience "galloping" or "bouncing" when passing over the nearby transition zones because of the multiple abrupt changes in track displacements, modulus, and geometry (*13*).

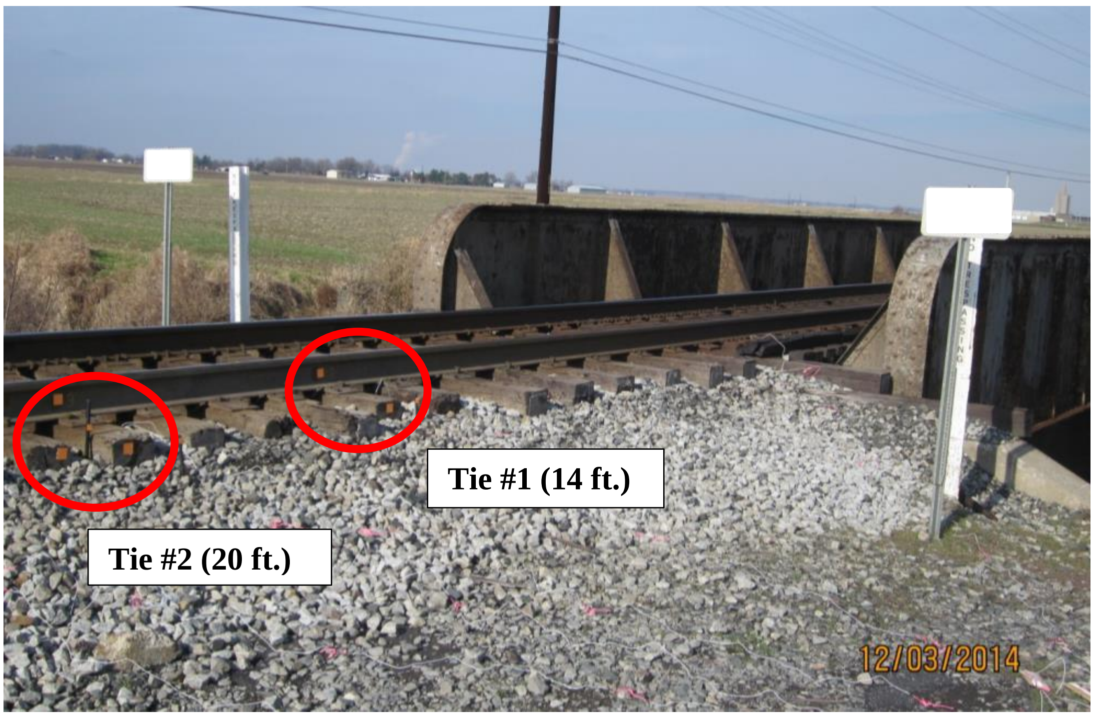


Figure 3: Photograph of the South End Bridge Transition

The two ties of focus in this paper are located 14 ft (4.3 m) and 20 ft (6 m) from the bridge abutment because they display different behavior. The first tie (14 ft.) from the bridge abutment displays a rail-tie gap and the second tie (20 ft.) from the bridge abutment displays a tie-ballast gap. A high-speed video camera measures the rail and tie displacements of the east end of both ties.

MEASURED TRACK BEHAVIOR

Pre-Tamping

Figure 4 compares the pre-tamping rail and tie displacements measured with a high-speed video camera for: (a) Tie #1 (14 ft.) and (b) Tie #2 (20 ft.). The train measured at Tie #1 (14 ft.) consists of a northbound (approach) intermodal train moving at a velocity of 58 mph while the train measured at Tie #2 (20 ft.) consists of a southbound (exit) loaded autorack train moving at a velocity of 49 mph. Train direction did not seem to affect the tie behavior at Tie #1 (14 ft.) and Tie #2 (20 ft.) but did have noticeable effects to accelerometers further from the bridge abutment (36 to 51 ft). The likely explanation is the train “gallops” or “bounces” after exiting the bridge or asphalt crossing.

Only two seconds of the time histories are shown to better illustrate the differences in track behavior. The rail-tie gap location (Tie #1, 14 ft.) only shows significant peak displacement of the rail (0.4 in/~10 mm) while the peak displacement of the tie is insignificant (0.05 in/~1.25 mm). This is expected because the rail-tie gap limits the amount of loading the rail applies to the tie and is expected to redistribute to surrounding ties. The tie-ballast gap location (Tie #2, 20 ft.) shows peak rail displacement of 0.2 inches (5.0 mm) and tie displacements of 0.25 inches (6.4 mm). It is typically expected that the rail displaces more than the tie but due to a potential centerbound tie condition, the end of the tie bends when loaded resulting in greater displacement at the end of the tie. Additionally, the rail-tie gap location (Tie #1, 14 ft.) experiences more rail displacement than the tie-ballast gap location (Tie #2, 20 ft.), which is expected because the rail-tie gap location (Tie #1) is closer to the bridge abutment and likely experienced greater substructure settlements.

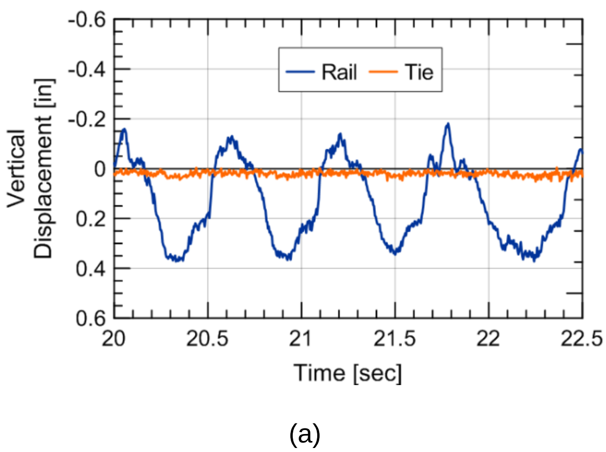


Figure 4: **Video Camera Measured Rail and Tie Displacements at: (a) Tie #1 (14 ft.) and (b) Tie #2 (20 ft.) for a Passing Freight Train on 21 October 2014.**

Post-Tamping: 1st Train

On the morning of the second day, the transition zone was resurfaced using a hand tamper. The rail was lifted about 7/8 of an inch at Tie #1 (14 ft.) and was resurfaced with an overlift, e.g. rail elevation in the transition zone was slightly higher than on the bridge, with the hope that the ballast would eventually equalize so the rail elevation in the transition zone would end up being about the same as the elevation of the bridge deck. After tamping, the rail and tie displacements at Tie #1 (14 ft.) from the first passing train, a northbound (approach) loaded autorack train moving at a velocity of 25 mph, was measured and the first 18 seconds (13 train trucks) are displayed in Figure 5. Tie #2 (20 ft.) was not able to be measured because of a maintenance vehicle blocking the view.

Figure 5 illustrates that the loading from the first train truck results in significant settlement of the rail and tie. The tie settles about 0.5 inches (13 mm) after the first truck and eventually reaches 0.7 inches (18 mm) by the end of the train. The rail shows about 0.45 inches (11 mm) of settlement by the end of the train. The reason the tie settles more than the rail is that a gap develops between the rail and tie because the upward reaction force of the rail after unloading pulls the spikes from the ties. As more trains pass and the ballast settles further, this repeated upward reaction force will continue to pull the spike from the tie and increase the rail-tie gap.

The initial truck loading produced about 0.7 to 0.8 inches (18 to 20 mm) of ballast settlement and video of the train shows ballast particles pushed out from underneath the tie. One explanation is not enough ballast particles were supporting the tie and rail to the specified elevation and therefore were not able to withstand the entire train loading. This caused the few ballast particles to either be pushed into the underlying ballast, pushed outside of the tie, or suffered from particle breakage. The presence of ballast fouling may have facilitated this process. The magnitude of ballast settlement may also be related to the pre-tamping ballast condition because ballast after tamping is observed to have a "memory" of its pre-tamping state (*2*). Either way, the first train immediately compacted and re-densified the ballast and resulted in about 0.8 or 0.9 inches (20 to 23 mm) of substructure settlement which can then cause the concentration of train loads and reinstitute the track deterioration process.

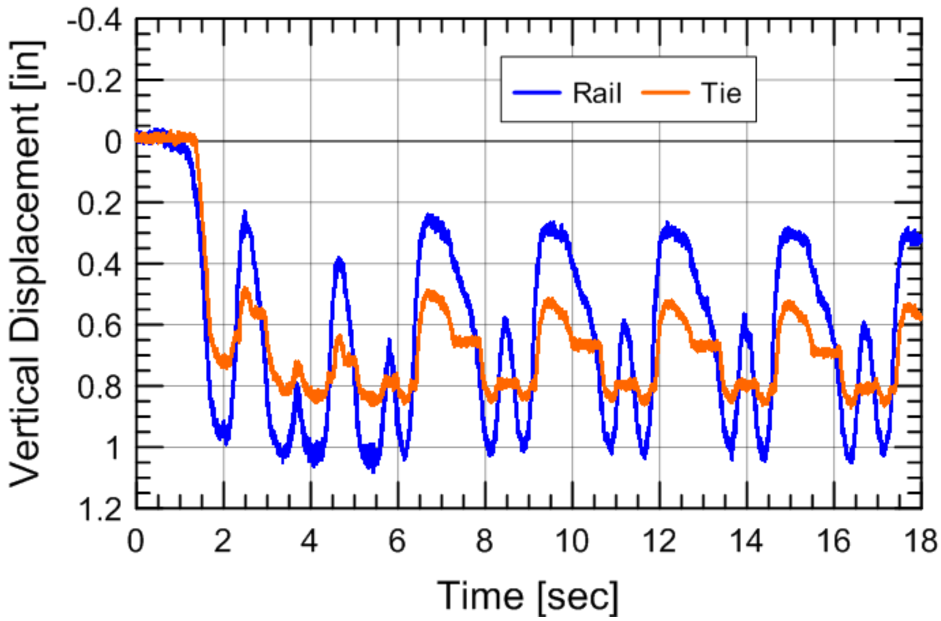
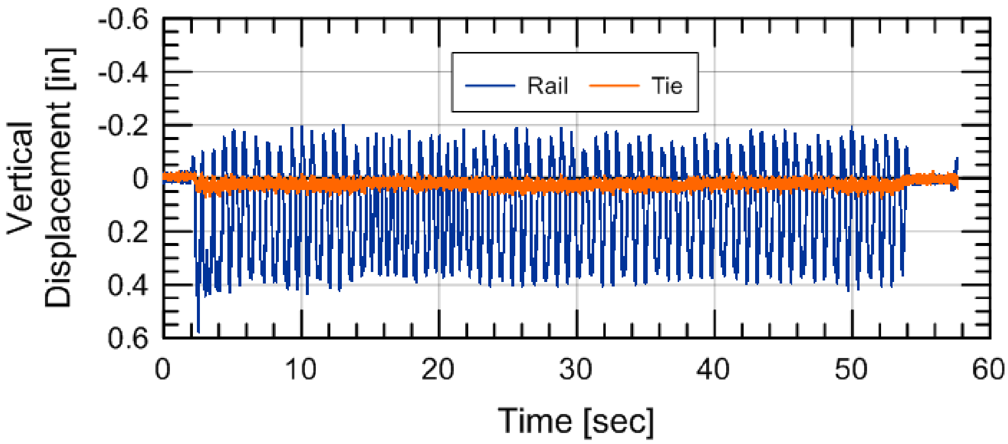


Figure 5: Video Camera Measured Rail and Tie Displacements at Tie #1 (14 ft.) for a Passing Freight Train immediately after Handing Tamping on 22 October 2014.

Post-Tamping: 6th Train

The first train produced the greatest amount of track settlement and the track seemed to reach equilibrium after about three to four trains. To evaluate how the track behaved after reaching equilibrium, the rail and tie displacement time histories from the sixth train after tamping is measured at Tie #1 (14 ft.) and displayed in Figure 6(b). This train is a southbound (exit off the bridge) loaded train moving at a velocity of 33 mph. By comparing the (a) pre-tamping and (b) post-tamping states, it is clear that post-tamping transient behavior quickly returns to its pre-tamping behavior after a few passing trains. Due to the continual upward force of the rail pulling the spike from the ties, the rail-tie gap reaches about 0.3 inches (8 mm) and will likely eventually increase to the 0.4 inch (10 mm) gap that existed pre-tamping.



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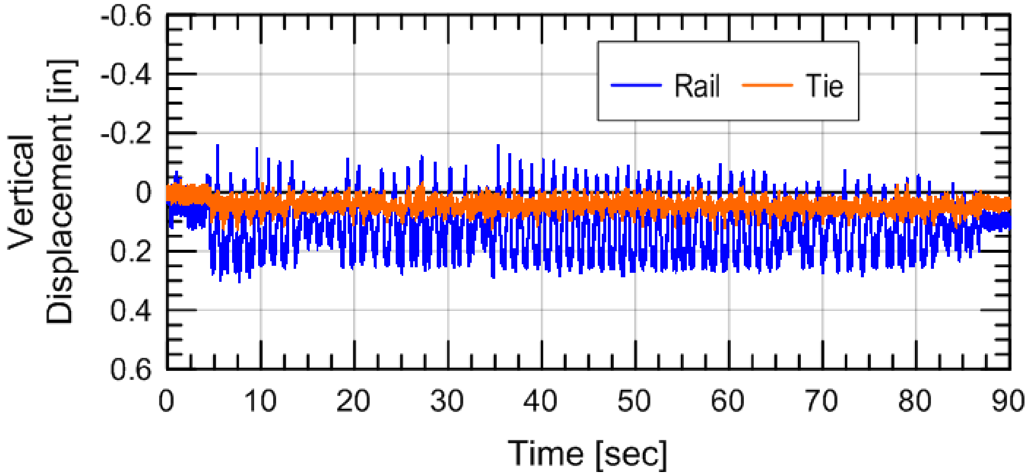

(b)

Figure 6: **Video Camera Measured Rail and Tie Displacements at Tie #1 (14 ft) (a) before tamping on 21 October 2014 and (b) the 6th train after tamping on 22 October 2014.**

The cumulative rail and tie settlement is estimated to be around 0.55 inches and 0.8 inches, respectively, and no noticeable changes in behavior were observed at Tie #2 (14 ft.) for the remainder of the day.

DISCUSSION

The field-measured rail and tie displacement time histories at a bridge transition zone illustrates the significant ballast settlement that can occur immediately after tamping, i.e. "compaction" settlement phase, which caused the track to nearly return to its original transient behavior after a few train passes. As mentioned earlier, this rapid settlement is detrimental to the transition zone because the differential substructure settlement results in the development of rail-tie and tie-ballast gaps as the rail remains supported and cantilevering from the bridge deck. The existence of rail-tie and tie-ballast gaps causes the redistribution of load and impacts which can result in higher local dynamic loads and accelerates the geometric deterioration in the transition zone section.

While the problem of differential settlement at transition zones can never be completely eliminated because of the inevitable and sometimes random nature of ballast settlement, there have been many suggestions to reduce track degradation (*3,14,15*). Many of these options, however, involve new track design or installing new track components and require significant effort by railroad companies.

Another option would be attempting to limit the amount of initial ballast settlement, i.e. “compaction” phase, by ensuring the ballast is better compacted underneath the tie during tamping. If not, the first passing train will compact the ballast at the expense of track performance. If the settlement in this “compaction” phase is reduced, this will likely result in the track geometry being maintained for longer periods of time and require less frequent tamping. The additional time and money needed to compact the ballast underneath the tie can hopefully extend the tamping cycle by a few weeks or months and may eventually prove cost-effective.

Other possible limitations with the current method of tamping at high-maintenance locations is how new ballast is placed in the crib and squeezes the existing ballast underneath the tie. This implies that the degraded and fouled ballast, which tends to settle at a quicker rate than clean ballast (*16*), will be continually reused directly under the tie and result in further ballast degradation. If tamping methods instead pushed the ballast from one side instead of squeezing from both sides, this “ballast rotation” could extend the life and effectiveness of the ballast.

SUMMARY AND REMARKS

This paper reviews the ballast compaction cycle and presents field-measured rail and tie displacement values immediately after the hand tamping of a bridge transition zone. The main findings include:

- Before hand tamping, the bridge transition zone experienced multiple rail-tie and tie-ballast gaps because of the differential ballast settlement between the bridge, transition zone, and open track.

- After hand tamping, the first train pass immediately compacted the ballast resulting in 0.45 inches (11mm) of rail settlement and 0.7 inches (18 mm) of tie settlement. This occurred because not enough ballast particles were holding up the rail and ties to the specified elevation and therefore immediately “pushed out” during the first train loading.

- The ballast seemed to reach an equilibrium condition after about 4 trains and resulted in 0.5 inches of rail settlement and 0.8 inches of tie settlement with a 0.3 inch gap between the rail and tie. The transient behavior of the tie was very similar to the pre-tamping conditions.

- An “overlift” was used during hand tamping to account for the initial settlement. While it reduced the severity of track geometry deviations after the first few train passes, the significant transient movement, i.e. rail-tie gaps, will still generate increased dynamic loads and accelerate ballast degradation in the transition zone.

- Because of the large initial ballast settlements, emphasizing better ballast compaction and density during tamping of high-maintenance regions such as bridge transition zones may reduce this initial settlement resulting in the track geometry holding for longer time periods and hopefully increases tamping cycles for railroad companies.

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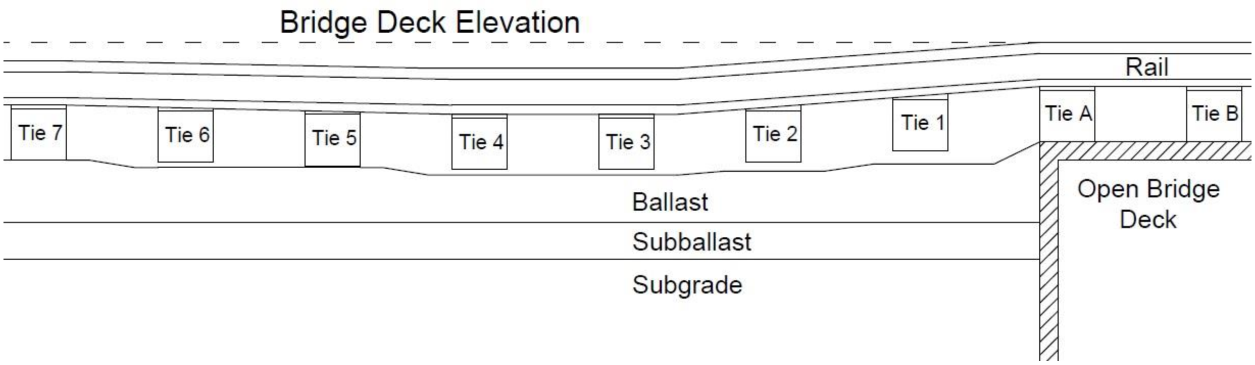

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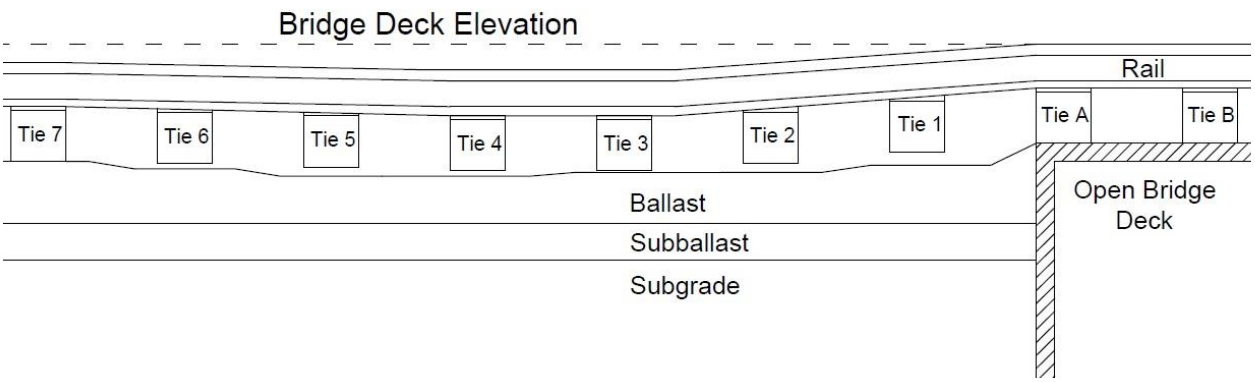

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Figure 1: Two Example Diagrams of Bridge Transition Zones with Tie-Ballast Gaps.

Figure 2: Photograph of the High-Speed Video Camera.

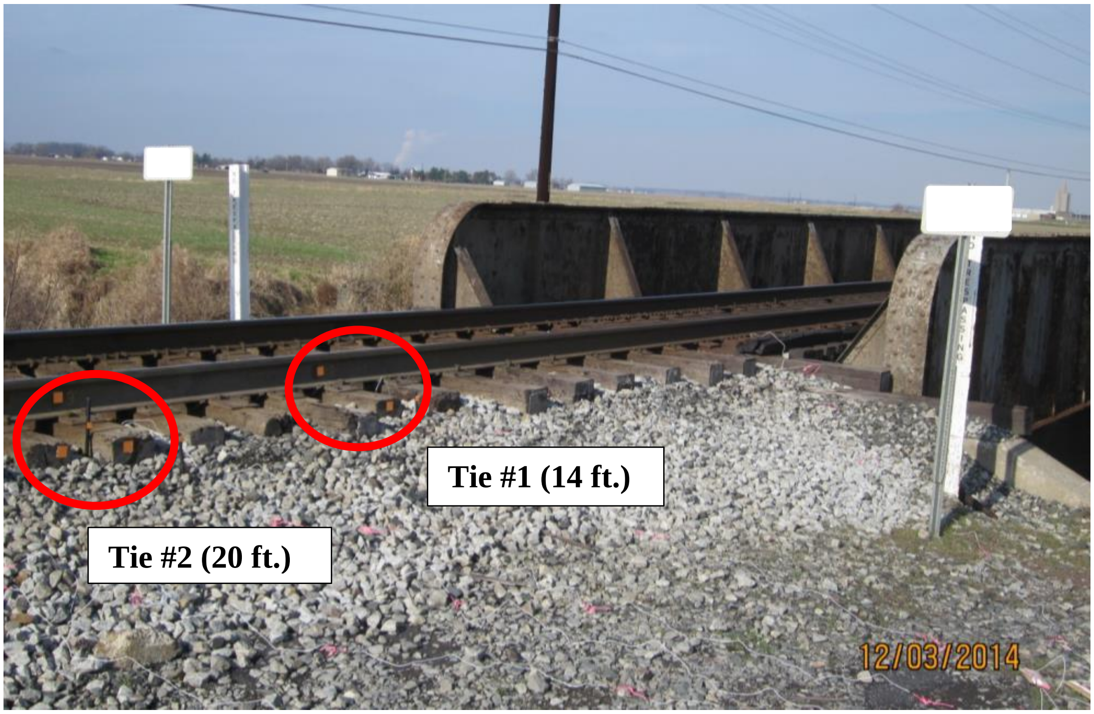
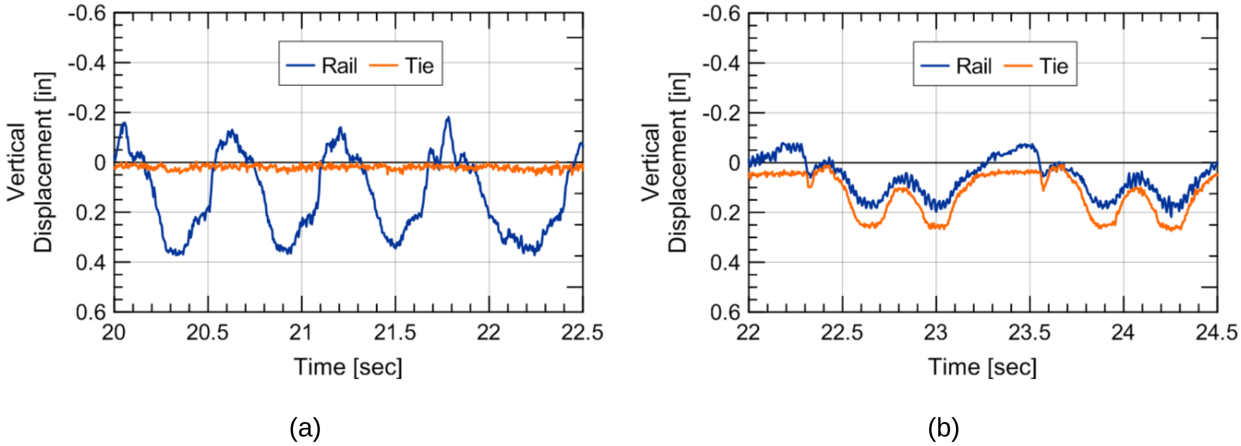


Figure 3: Photograph of the South End Bridge Transition



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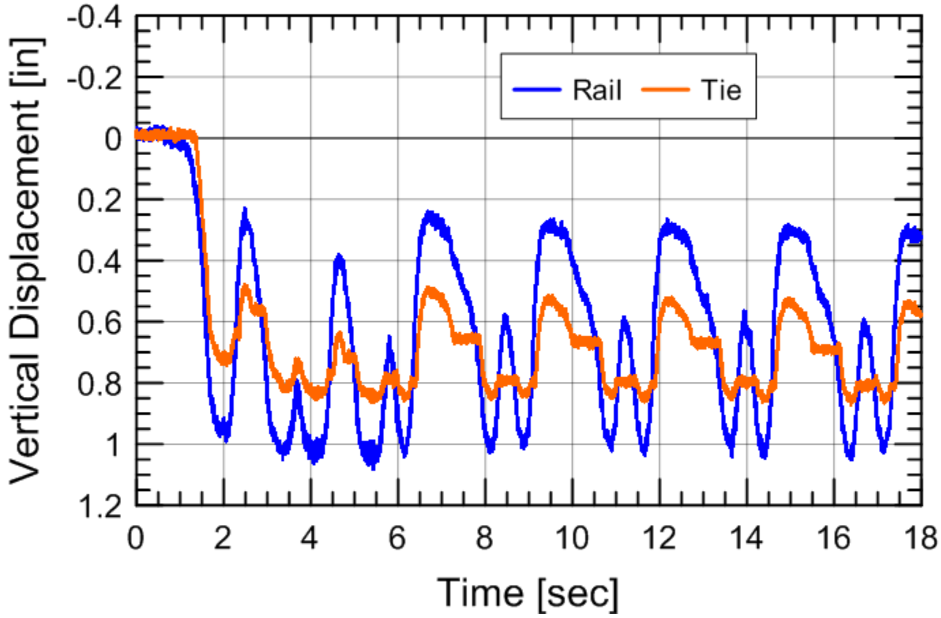

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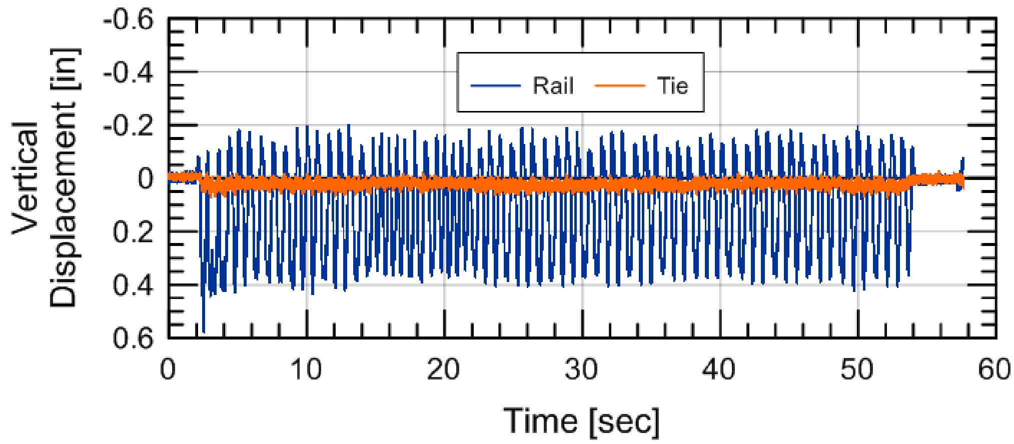

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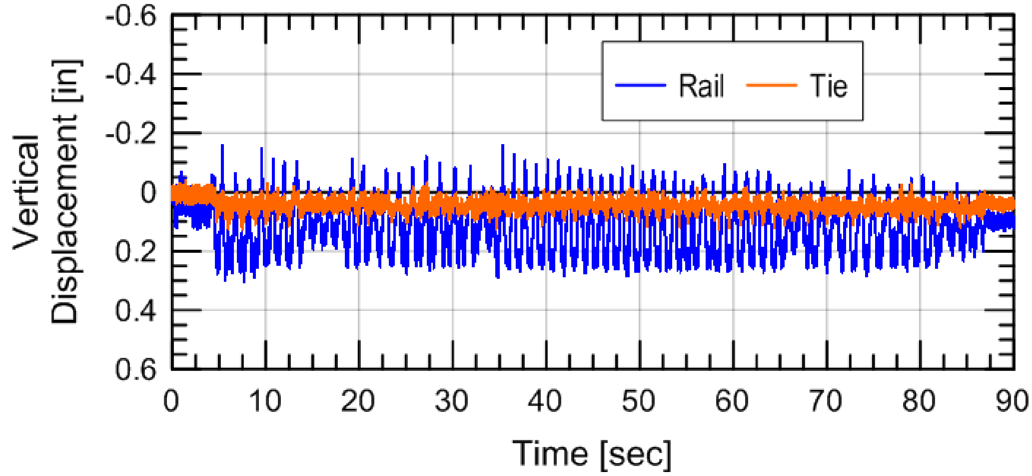

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