Design and Performance of Three Remediated Bridge Approaches

Christopher Moale
Engineering Standards
CSX Transportation
Jacksonville, FL
Email: Christopher_Moale@csx.com

Damon Smith
Engineering Standards
CSX Transportation
Jacksonville, FL
Email: Damon_Smith@csx.com

Timothy D. Stark
Professor of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
205 N Mathews Ave
Urbana, IL 61801
Office: (217) 333-7394
Email: tstark@illinois.edu

Stephen T. Wilk
Graduate Research Assistant
University of Illinois at Urbana-Champaign
205 N Mathews Ave
Urbana, IL 61801
Office: (217) 333-7394
Email: swilk2@illinois.edu

Jerry G. Rose
Professor of Civil Engineering
University of Kentucky at Lexington
Office: (859) 257-4278
Email: jrose@engr.uky.edu

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ABSTRACT

This paper presents the design and performance of three remediated freight bridge approaches in Maryland. Prior to remediation, an open-deck timber bridge spanning the Anacostia River had an un-remediated northern approach and a southern approach constructed with an existing slurry/grout fill material. In 2014 and 2015, the existing bridge was converted to a concrete ballasted deck bridge while remediating the north approach with a 6 inch (150 mm) thick Geoweb layer backfilled with crushed aggregate (CR-6) and overlain by 12 inches (300 mm) of ballast. A second concrete ballast deck bridge was constructed just east of the existing bridge with the north approach having an 8 inch (200 mm) thick hot-mixed asphalt (HMA) layer overlain by 12 inches (300 mm) of ballast and the southern approach was constructed with 6 inch (150 mm) thick Geoweb backfilled with CR-6. The objective of the remedial measures was to balance transient and permanent displacements between the bridge and approach by increasing track support in the approach and allowing some track displacement on the bridge.

To assess the remediated bridge approaches, non-invasive instrumentation was used to measure transient track displacements and the loading environment of the approaches. The non-invasive instrumentation includes high-speed video cameras to measure transient rail and tie displacements and accelerometers to measure tie accelerations. The results show low transient tie displacements and accelerations along the track especially in the northern Geoweb remediated approach of the existing bridge.

INTRODUCTION

Maintaining track geometry at railroad bridge transitions can be a reoccurring issue for railroads [1-5]. This differential rail elevation is largely due to the disparity in stiffness and transient displacements between the approach and bridge deck. This differential rail elevation can amplify loads and accelerate ballast degradation in the approach requiring frequent track resurfacing to maintain track geometry in the approach [5,6].

To maintain track geometry and reduce maintenance, railroads have experimented with various design and remedial solutions to increase the approach track stiffness, reduce the approach track settlement, and/or reduce the bridge track stiffness to balance the stiffness and settlement between the bridge and approach. These solutions have evolved from emphasizing a single track component to viewing the track as a system and incorporating multiple solutions in a single design with a goal of balancing the rail elevation between the bridge and approach [7]. For example, previous techniques involve only a single solution such as: (1) stiffening the approach superstructure by adding additional rails, reducing tie spacing, or using larger ties [8], (2) stiffening the approach substructure with concrete panels, grout, hot-mixed asphalt (HMA), and other stabilizing methods [1,3], or (3) decreasing bridge track stiffness by installing ballasted bridge decks or rail pads. The effectiveness of these solutions range from no benefit to a reduction in track maintenance.

Examples of incorporating multiple solutions into a single design include installing ballasted bridge decks, concrete wing walls, and HMA underlayment [7,9-10] or installing ballasted bridge decks and rail pads on the bridge track while maintaining clean and drained ballast in the approach [11]. Both of these designs have led to a balance of rail elevations between the bridge and approach during train passage with minimal need for track maintenance after construction or remediation. The use of under-tie pads in only the approach to reduce tie and ballast degradation is also being investigated for freight and high speed passenger traffic [12].

This paper presents a design combination developed by CSX to mitigate differential movement at bridge transitions by incorporating multiple solutions, including: ballasted bridge decks, concrete curbs, and a Geoweb underlayment. The performance of the Geoweb design is compared with an HMA underlayment by monitoring multiple bridge approaches using non-invasive instrumentation.

SITE DESCRIPTION

History

The CSX bridge selected for remediation is located in Hyattsville, MD and spans the Anacostia River between CFP 120.4 and CFP 120.5 on the Baltimore Division, Capital Subdivision – Alexandria Extension. The existing Class 2 single mainline track had an annual tonnage of 30 million gross tons (MGT). The track structure includes an open deck bridge (see Figure 1) and an existing grout filled subgrade on the southern approach of the existing bridge, which was installed at an unknown date. The existing track experienced reoccurring track geometry defects associated with track profile, cross level, and warp defects at the approaches.

In 2015, the bridge was scheduled to be upgraded to a ballasted bridge deck along with the construction of a second ballasted deck bridge directly adjacent to the original, thus creating a double mainline with only 15 MGT per line. Current CSX bridge standards typically include: ballasted bridge decks; concrete curbs for ballast confinement; and an HMA underlayment, because of its ability to hold track geometry and reduce maintenance. The scheduled upgrade of two approaches and the creation of two more provided CSX with an opportunity to assess the effectiveness of these various solution combinations, e.g., Geoweb and/or HMA. If the Geoweb application at this location is considered successful and feasible, Geoweb could be installed at a higher MGT and FRA Class Track and eventually be incorporated into CSX Engineering Standards.

Figure 1: Photograph of original open-deck timber bridge prior to re-construction in 2013

Remediation Selection and Design

To balance transient displacements between the bridge and approach and reduce the need for maintenance, stabilization measures have been incorporated in CSX bridge design standards. CSX typically uses ballasted bridge decks, concrete curbs for ballast confinement, and HMA underlayment. The ballasted bridge deck allows some track movement on the bridge, which helps balance the transient and permanent displacements between the bridge and approach. Ballasted bridge decks have reduced maintenance but generally need to be used with stabilization measures in the approach to fully mitigate differential movement at the approach. The concrete curbs provide confinement to the ballast and subgrade at and near the bridge abutment, which creates as a confined transitional zone between the bridge and approach. Increased confinement strengthens the ballast and results in reduced ballast settlement [13]. The last stabilization technique, an HMA underlayment, is typically installed under the ballast to increases ballast confinement, better distribute the applied load to the subgrade, and provide a barrier/separation layer between the ballast and subballast to reduce subgrade migration into the ballast and water reaching the subgrade.

Geoweb was selected as a potential alternative to HMA because of an anticipated reduction in cost, installation, increased roadbed strength, and good drainage. Geoweb is a stabilizing material comprised of polyethylene cells that resemble a "web" when stretched out. The cells are 6 inches (150 mm) in depth and are filled with a compacted crushed aggregate material with the Geoweb cells providing confinement to the crushed aggregate. This stabilized subbase then "locks in", confines, and supports the overlaying ballast layer and provides greater ballast modulus, load distribution, and also provides a barrier layer between the ballast and subgrade. The expected benefit of Geoweb over HMA is a reduced expense and installation time and it also anticipated that the Geoweb will provide increased roadbed strength and drainage. By installing Geoweb and HMA side-by-side, a performance comparison could be made between the two techniques during this study.

To compare the response of the Geoweb approach and the existing HMA underlayment, Geoweb was installed in two approaches while HMA underlayment was installed in one approach. The remaining approach consists of the existing grout slurry. The approach name and locations of the various solutions are listed below and an overview of the four sites is shown in Figure 2.

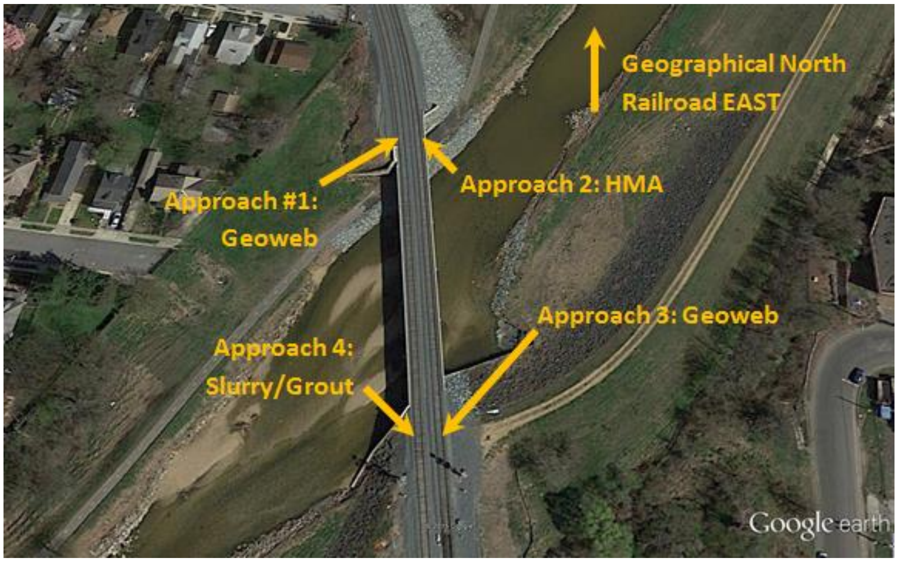


Figure 2: Overview of CSX bridge CFP 120.4 in Hyattsville, MD.

Construction

The bridge upgrade and new Geoweb/HMA installation occurred in July 2014 and March 2015, respectively. The Geoweb installation involves the following components from bottom to top:

- Install 6 inch (150 mm) thick layer of CSX approved crushed aggregate for the subgrade
- Install nonwoven geotexile to provide separation between the subgrade and Geoweb
- Install 6 inch (150 mm) thick Geoweb
- Fill Geoweb with properly compacted and CSX approved crushed aggregate limited to three feet (0.9 meters) infills to prevent distortion
- Install 12 inches (300 mm) of standard AREMA #4a granite ballast

Figure 3 shows various stages of Geoweb installation at this bridge. In particular, Figure (3a) shows the Geoweb material arriving on site, Figure 3(b) shows the crushed aggregate (CR-6) subgrade, Figures 3(c) shows the Geoweb installation and aggregate compaction, and Figure 3(d) shows installation of the 12 inch (300 mm) ballast section. The Geoweb extends for 50 ft. (15.3 m) from the bridge abutment. The HMA extended for 250 ft (76.3 m).

(a) (b)

(c) (d)

Figure 3: Various stages of approach reconstruction: (a) Geoweb, (b) crushed aggregate (CR-6) subgrade, (c) Geoweb installation, and (d) ballast installation.

Figure 4 shows the remediated double mainline track. The track was returned to service in May 2015 and no track surface defects have been reported since remediation.

Figure 4: Photographs of remediated bridge: (a) looking south and (b) looking north

SITE PERFORMANCE

Three days of non-invasive monitoring was performed to assess all four bridge approaches on: 16 November 2015, 18 April 2016, and 19 July 2016. This monitoring was performed to compare the various approach remedial measures and monitor changes over time. Of particular interest is the transient track displacements and tie accelerations from passing trains because these metrics provide insight into track stiffness, support, and service life.

Instrumentation

Three high-speed video cameras and eight piezo-electric accelerometers were used to non-invasively monitor the remediated approaches. Each high-speed video camera measures the rail and tie displacements of two adjacent ties while piezo-electric accelerometers attached to the tie measure tie acceleration time histories. This instrumentation is mobile and can be set up and removed in about 30 minutes allowing for multiple locations to be instrumented within a single day and has been used repeatedly in the past at other sites [6,14]. The accelerometers were installed on two of the four approaches while the high-speed video cameras were used on all four.

Three high-speed video cameras were placed about 20 feet (6 meters) from the track shoulder as shown in Figure 5(a) and measured transient vertical displacements by tracking the centroid of orange plastic targets attached to the rail and tie (see Figure 5(b)). To reduce the influence of ground and wind vibration, a target is also placed on an 18 inch (150 mm) long stake driven into the ballast two feet (0.6 meters) from the tie edge. The camera records at 240 frames per second (fps), which is fast enough to capture the full track displacement time history because the majority of track displacement occurs within a frequency of 1 to 5 Hz [14].

Eight piezo-electric accelerometers were attached to the timber ties with superglue and are shown in Figure 6. Tie accelerations are a more qualitative measurement than rail and tie displacements, but are sensitive to movements, vibrations, and impact loads within the track so they provide insight into how the track is transmitting the applied loads to the ballast. For example, track with good support and a smooth load transfer from the wheel to the ballast, i.e. minimal relative movement between track components, typically exhibits tie accelerations less than 5g [6]. However, increased tie accelerations have been observed from wheel flats (>200g), rail joints (~150g), rail-tie impacts (~100g), tie-ballast impacts (~40g), and fouled ballast (~40g), which provides good contrast between track with good and poor load transfer. Poor track support results in track movement, vibrations, and/or impacts that are easily recorded by the accelerometers and exceed 5g [6]. The sampling rate of the accelerometers is 4,000 Hz, which is fast enough to capture the wide range of frequencies (<500 Hz) experienced in timber tie railroad track.

(a) (b)

Figure 5: Photograph showing: (a) high-speed video camera (see arrow) and (b) orange plastic targets attached to rail, ties, and driven stake in foreground.

(a) (b)

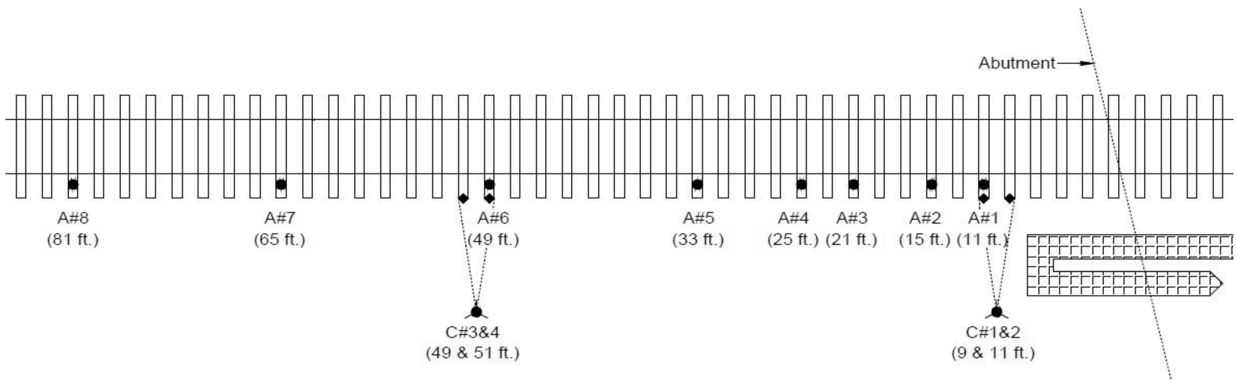
Figure 6: Photograph showing Approach #1: (a) video camera targets and piezo-electric accelerometer attached to Tie #1 near the bridge abutment and (b) accelerometer attached to Tie #8 in the open track.

The four approaches were instrumented to varying levels as shown in Figure 7. At Approach #1 (Geoweb), all eight accelerometers and two high-speed video cameras were installed. The accelerometers were placed at varying locations 10 to 80 feet (3 to 24 meters) from the bridge abutment with the goal of determining if track behavior changed from the approach to open track. The two video cameras were located about 10 and 50 feet (3 and 15 meters) from the bridge abutment to compare differences in track behavior between the approach (10 ft) and open track (50 ft) and the effectiveness of the concrete wing walls or curbs.

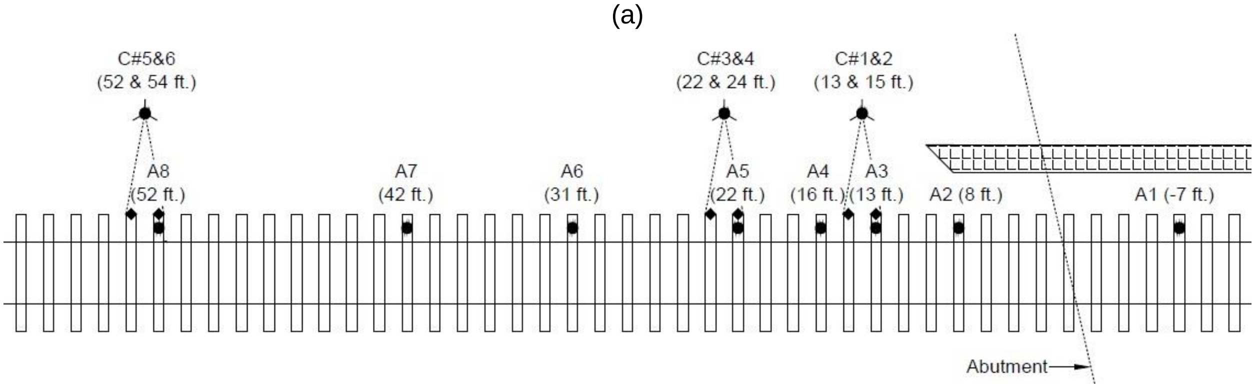
At Approach #2 (HMA), three high-speed video cameras and eight accelerometers were used to capture the approach response. The video cameras were placed about 14, 23, and 53 feet (4.3, 7.0, and 16 meters) from the bridge abutment and the accelerometers were placed at various distances on the bridge, approach, and open track (Figure 7b). The accelerometers were only used on the 18 April 2016 trip but video cameras were used on all three trips to evaluate changes in displacement over time.

At Approach #3 (Geoweb) and Approach #4 (Grout), only high-speed video cameras were used. Five ties were recorded in Approach #3 (Geoweb) on 19 July 2016 while six ties were recorded in Approach #4 (Grout) on 18 April 2016.

The recorded trains varied in type, weight, and length but all had speeds ranging from 15 to 25 mph. To reduce the influence of train type and weight, the locomotives are emphasized in the results as they will have the most consistent weight. Train direction is not observed to influence the displacements or acceleration results.



(a)



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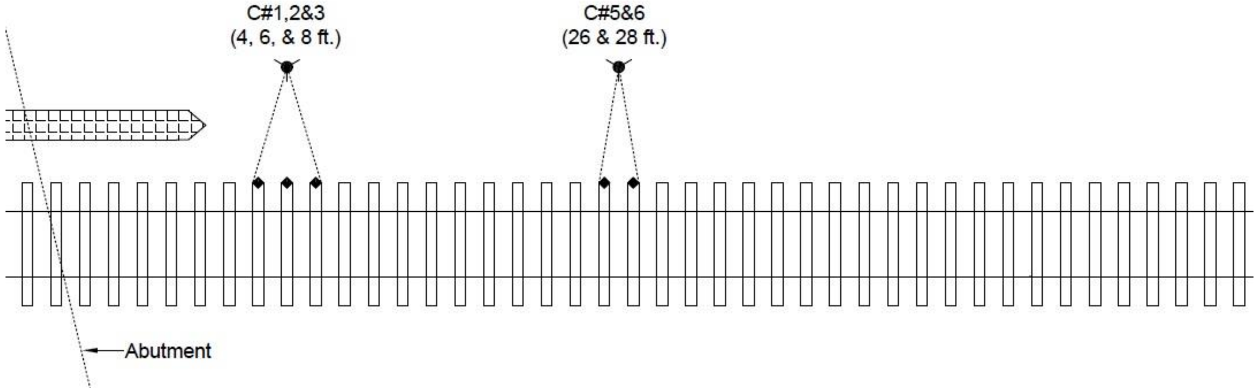

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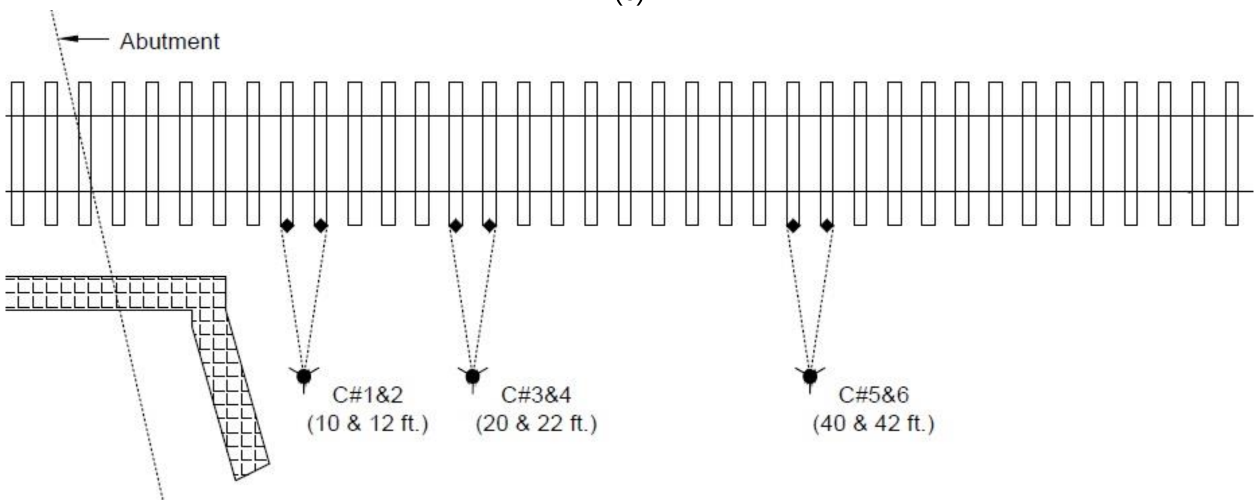


(d)

Figure 7: Instrumentation layouts at: (a) Approach #1 (Geoweb) on 16 November 2015, (b) Approach #2 (HMA) on 18 April 2016, Approach #3 (Geoweb) on 19 July 2016, and (d) Approach #4 (Pre-existing Grout) on 18 April 2016.

Results

To compare the performance of these four bridge approaches, the peak tie displacements are compared to assess the effectiveness of the Geoweb, HMA, and pre-existing subgrade grout remedial measures. The subgrade grout is used as the "control" approach. To avoid differences in peak displacement from varying train weights, the peak displacement magnitudes from the leading locomotives are used because the locomotives applied similar loads.

A comparison of peak transient locomotive tie displacements is displayed in Figure 8 along with sample tie displacement time histories. To show the potential variation in transient tie displacement along the track, the tie displacement time histories for Tie #1 (13 ft.) and Tie #6 (54 ft.) at Approach #2 (HMA) are compared in Figures 8(a) and (b), respectively. The peak locomotive tie displacements for all four approaches are displayed in Figure 8(c).

The results in Figure 8(c) show consistent peak locomotive transient tie displacements of about 0.1 to 0.15 inches (3 to 4 mm) at Approach #1 (Geoweb), which suggests consistent track behavior along the track. Approach #2 (HMA) shows larger transient tie displacements (0.4 inches or 10 mm) near the edge of the concrete curbs but these displacements quickly reduce to only 0.04 inches (1 mm) in the open track. This suggests the track at the edge of the curb is not well supported, which was also observed during the measurements and confirms the importance of approach confinement on transition performance as reported in [7]. Approach #3 (Geoweb) displayed similar behavior as Approach #2 (HMA) with large displacements (0.43 inches) at the edge of the curbs and then a stiff open track. The cause of the increased transient displacements for the HMA approach, e.g. ballast, subballast, and/or subgrade, is not known but could be from inadequate compaction of the ballast/subballast or increased loading. Approach #4 (Grout) showed about 0.15 inches (4 mm) of transient tie displacement near the curb and remained near constant in the open track.

Figure 8(d) shows the change in peak locomotive transient tie displacement over time in Approach #2 (HMA). The results show a gradual increase in tie displacement with time. It is likely that the poorly supported ties at 13 ft (4.0 m) and 15 ft (4.6 m) from the abutment are causing the train load to be passed to ties further from the abutment, which progressively spreads poor tie support conditions away from the abutment. This can gradually increase the loads on these ties and increase ballast settlement further from the abutment. Subgrade settlement could be a second explanation as both Approach #2 (HMA) and Approach #3 (Geoweb) were installed on new track while Approach #1 (Geoweb) and Approach #4 (Grout) were installed on an existing line.

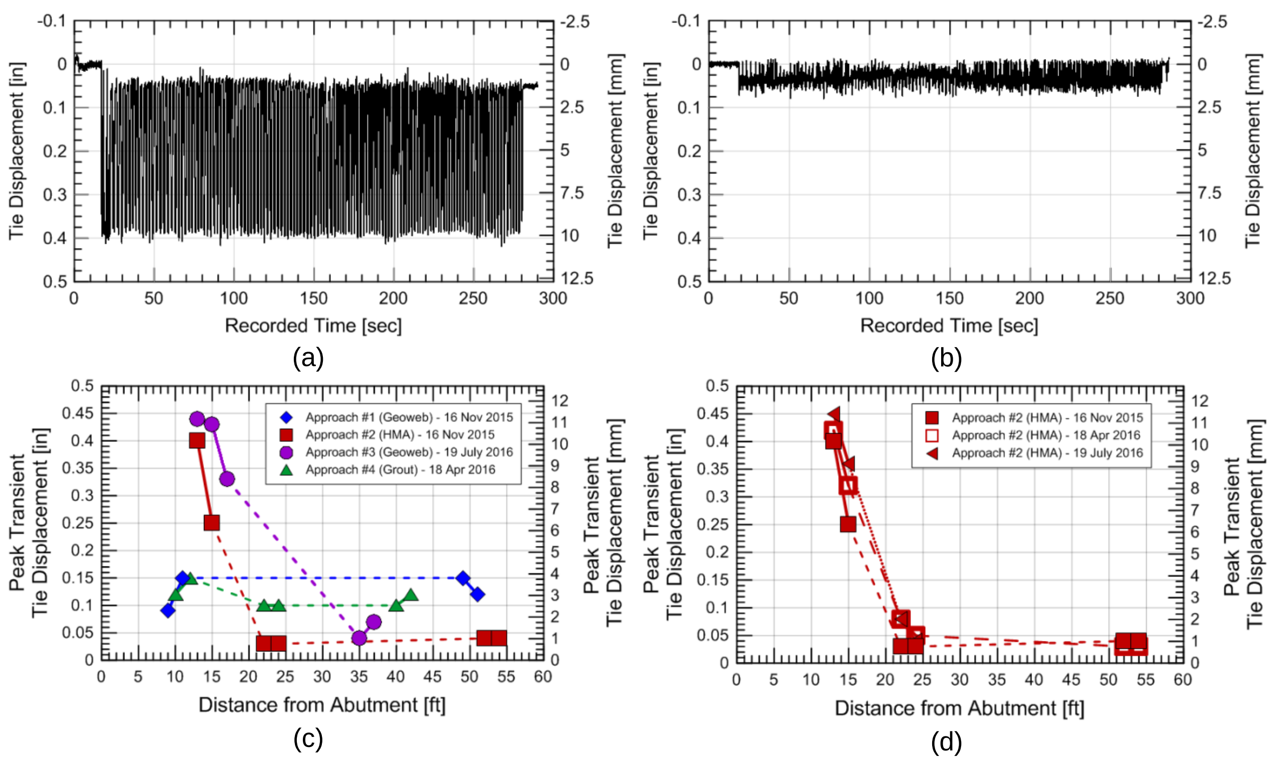
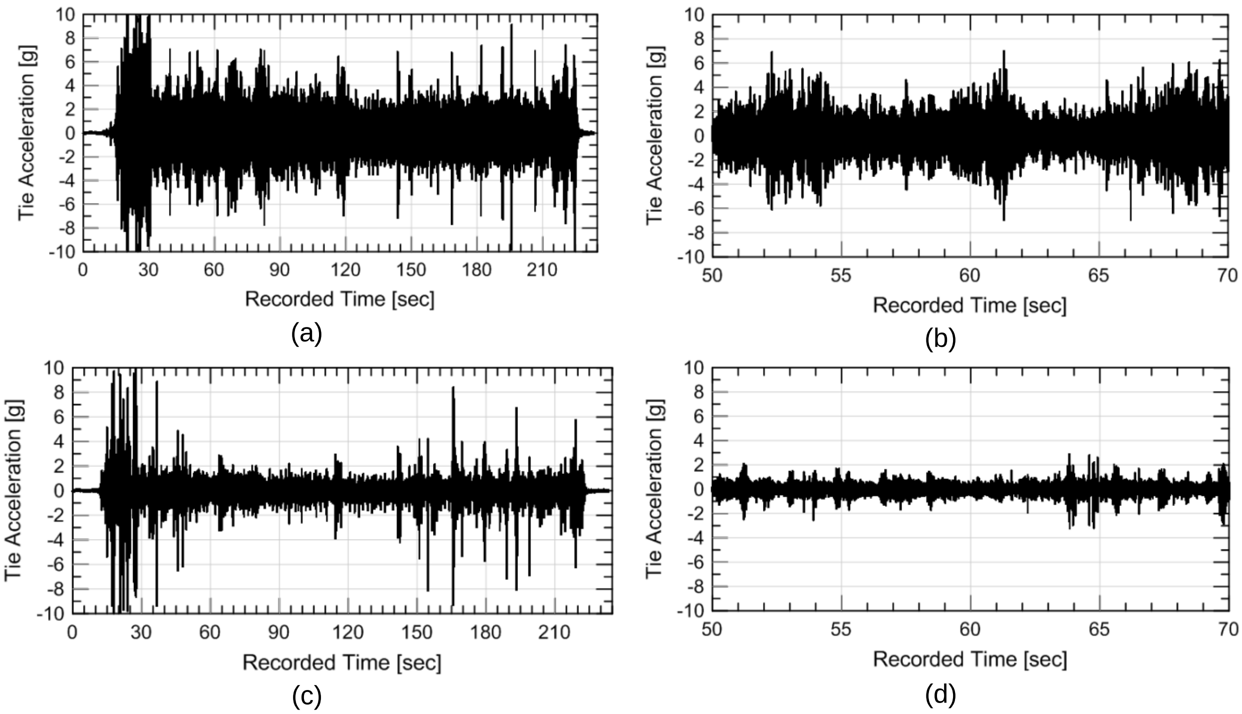
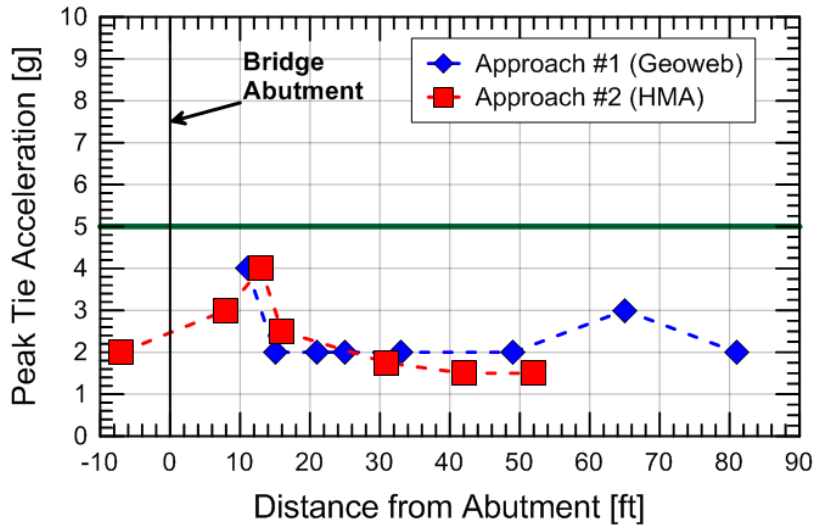


Figure 8: Transient tie displacement from: (a) Tie #1 (13 ft.) and (b) Tie #6 (54 ft.) in Approach #2 (HMA) from a loaded freight train on 16 November 2015, (c) peak locomotive transient tie displacements for all four approaches, and (d) peak locomotive transient tie displacements at Approach #2 over time.

The accelerations measured at Approach #1 (Geoweb) are displayed in Figure 9 with Figures 9(a and b) showing the full and 20-second acceleration time histories from Accelerometer (Accel) #1 (11 ft.) and Figures 9(c and d) showing the full and 20-second acceleration time histories from Accel #8 (81 ft.). Figure 9(e) shows the average peak tie accelerations for all eight locations along with peak tie accelerations from Approach #2 (HMA). The results show all of the monitored ties exhibit tie accelerations below 5g, which indicates a smooth load transfer to the ballast and little slack or transient movement in the track, i.e., good tie support. Isolated peak accelerations represent wheel irregularities or wheel/rail movement and are not considered representative of track structure performance. The greatest tie accelerations were observed at Accel #1 (11 ft.) at Approach #1 (Geoweb) and Accel #3 (13 ft.) at Approach #2 (HMA). While observed at similar distances from the abutment, the causes of the higher accelerations appear to be different. The higher acceleration at Approach #1 (Geoweb) is probably caused by the accelerometer being placed at a tie location that is moving independently from the rest of the tie, i.e., a tie splinter or split. This tie defect or split will produce local vibrations that increase the tie acceleration at that particular location on the tie. An unsupported tie is the attributed cause to the higher acceleration in Accel #3 (13 ft.) in Approach #2 (HMA).





(e)

Figure 9: (a) Full and (b) 20 second tie acceleration time histories for Accel #1 (11 ft.) and (c) full and (d) 20 second tie acceleration time histories for Accel #8 (81 ft.) in Approach #1 (Geoweb) and (e) average peak transient tie accelerations for Approach #1 (Geoweb) and Approach #2 (HMA).

Based on current measurements, all measured approaches have accomplished the design objective of a strong roadbed that allows smooth load transfer from the track to the subgrade. The primary difference between the approaches is the poorly supported ties near the end of the concrete curb on Approach #2 (HMA) and Approach #3 (Geoweb), which is not displayed on Approach #1 (Geoweb) and Approach #4 (Grout). This may be attributed to inadequate compaction of the ballast, reduction in confinement at the end of the curb, or subgrade settlement because Approach #2 and #3 are located on a new line while Approaches #1 and #4 are located on an existing line with a subgrade that had already experienced train and environmental loadings. At this point, it is unclear whether the increased transient displacements near the curb at Approaches #2 and #3 will stabilize or if the transient displacements will cause increased loading and spread ballast degradation to a longer length of track. Previous instrumentation of an HMA-installed bridge approach showed similar behavior with larger transient track displacements near the bridge abutment but this track has maintained good geometry over 17 years with an annual load of 70 MGT track [7].

SUMMARY

To investigate the feasibility of a Geoweb underlayment in bridge approaches, CSX remediated two approaches with Geoweb and a single approach with HMA at a bridge in Hyattsville, MD. The rail and tie displacements and tie accelerations of the Geoweb and HMA approaches were measured using video cameras and accelerometers and are compared herein. Some of the main findings to date are:

- Geoweb underlayment is a possible alternative to HMA because of good ballast confinement, load distribution to the subgrade, and separation between the ballast and subgrade and reduced cost and installation time.
- Both Geoweb and HMA remedial measures are providing good support to the approach track and helping to balance the transient displacements in the approach and bridge. This has resulted in

no maintenance being required since remediation over two years ago and an accumulation of about 20 MGT on each track.

- Based on field measured transient displacements, the approaches constructed on a new line have experience greater transient displacements at the end of the concrete curb while the approaches constructed on an existing line did not. This suggests the contribution of subgrade settlement to the measured transient displacements however inadequate ballast compaction and reduced ballast confinement may also play a role. The long-term implications of these unsupported ties are not clear at this time but future monitoring is planned to assess the performance with time.

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