Design and Performance of Three Remediated Bridge Approaches

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ABSTRACT

This paper presents the design and performance of three remediated freight bridge approaches in Maryland. Prior to remediations, an open deck timber bridge spanning the Anacostia River had an unremediated 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 Geoweb similar the northern approach of the existing bridge. 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 measured 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.

INTRODUCTION

Maintaining track geometry at railroad bridge transitions is a reoccurring issue for railroads [1-5]. This is largely due to the disparity in stiffness and transient displacements between the approach and bridge deck that results in a differential rail elevation during train passage. 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 stiffness and displacements 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, many previous techniques involve only: (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.

This paper presents a design combination developed by CSX to mitigate differential movement at bridge transitions by incorporating 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, 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 combinations of remedial measures, 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 bridge prior to re-construction in 2013](image)

**Remediation Selection and Design**

To balance transient displacements between the bridge and approach and reduce the need for maintenance, stabilization measures were incorporated in bridge design standards. CSX typically uses ballasted bridge decks, concrete curbs for confinement, and HMA underlayment. The ballasted bridge deck allows additional movement of the bridge track, 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 transitional zone between the bridge and approach. Increased confinement strengthens the ballast and results in reduced ballast settlements [12]. 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.

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 overlying 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, performance comparisons can be made between the two techniques.

To compare the response of the Geoweb approach and the existing HMA underlayment, Geoweb was installed in two approaches while HMA underlayment was only installed in one approach. The remaining approach consists of the existing grout slurry. The approach name and locations 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.](image)

**Construction**

The bridge upgrade and Geoweb/HMA installation occurred in July 2014 and March 2015 with the Geoweb installation involving the following components from bottom to top:

- Install 6 inch (150 mm) thick layer of CSX approved crushed aggregate for the subgrade
- Install nonwoven geotextile 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. In particular, Figure (3a) shows the Geoweb material arriving on site, Figure 3(b) shows the crushed aggregate 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.
Figure 3: Various stages of approach reconstruction: (a) Geoweb, (b) crushed aggregate 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 completion.

Figure 4: Photograph of the remediated bridge

SITE PERFORMANCE
On 16 November 2015, non-invasive monitoring of three of the four transition zones for comparing the various remedial measures in the approaches was performed. 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. The high-speed video cameras measure 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 [6,13].

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 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) 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 [13].

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 typically produces 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 load transfer and track with poor load transfer. Poor track support that results in track movement, vibrations, and/or impacts that are easily recorded by the accelerometers [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.
The three measured 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 and track behavior under two freight trains was measured. 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. The two passing trains are a loaded coal train entering the bridge (southbound) at about 20 mph/32 km/hr (Train #1) and a second train consisting of seven locomotives exiting the bridge (northbound) at about 20 mph/32 km/hr (Train #2).

At Approach #2 (HMA), three high-speed video cameras were used and captured the response of a single train because there was insufficient time to move the accelerometers to the other approach as the particular track of train passage, i.e. east or west, was not known until directly prior to train passage. The accelerometers need to be setup about 5 minutes prior to train passage to allow the data acquisition system tested. The video cameras were placed about 14, 23, and 53 feet (4.3, 7.0, and 16 meters) from the bridge abutment. The single passing train Approach #2 was an intermodal train exiting the bridge (northbound) at about 10 mph/16 km/hr (Train #3).

Only a single camera was installed at Approach #4 (Grout) and located about 11 feet (3.4 meters) from the bridge abutment. This video camera recorded Train #1 but the loaded coal train was entering the bridge at 20 mph (16 km/hr) instead of exiting the bridge.
Figure 7: Instrumentation layouts at: (a) Approach #1 (Geoweb), (b) Approach #2 (HMA), and (c) Approach #4 (Pre-existing Grout).

**Results**

To compare the performance of these three transition zones, the peak tie displacements are compared to assess the effectiveness of the Geoweb, HMA, and pre-existing subgrade grout approaches. 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 three approaches are displayed in Figure 8(c).

The results show consistent peak transient displacements of about 0.1 to 0.15 inches (3 to 4 mm) at Approach #1 (Geoweb), suggesting 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 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 measurement but confirms the importance and confinement that the wing walls provide. 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 but decreased significantly, e.g., to about 0.04 inches (1 mm), in open track based on visual observations.

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 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. 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 transient accelerations were observed at Accel #1 (11 ft.), which is probably caused by the accelerometer being placed at a location that is moving independently from the rest of the tie, e.g., a tie splinter. This tie defect or split will produce local vibrations that increase the tie acceleration. The remaining time histories are similar to Accel #8 (81 ft.).
Future testing will investigate changes in transient displacement and acceleration over time and increased loading. Based on current measurements, the Geoweb installation appears to have accomplished the objective of producing a strong roadbed that allows smooth load transfer from the track to the subgrade. While the Geoweb is significantly less stiff than the HMA, this may not be a major factor as long as the trackbed maintains good support. The HMA produces a stiff track and it is unclear whether the increased transient displacements near the curb will stabilize or if the excessive 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].

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 all three approaches.
SUMMARY

To investigate the feasibility of Geoweb underlayment at 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 compared using video cameras and accelerometers. Some of the main findings 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 between the approach and bridge. This has resulted in no maintenance being required since installation over two years ago and an accumulation of about 20 MGT on each track.
- Based on field measured transient displacements, the HMA resulted in a stiffer track than the Geoweb but unsupported ties have developed near the end of the concrete curb. The long-term implications of these unsupported ties are not clear at this time but future monitoring is planned to assess the impact.

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REFERENCES


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AREMA 2016 Annual Conference & Exposition
**Introduction**

- Transition zone design and remediation techniques
  - Balance transition zone and bridge displacements
  - Geoweb and hot-mixed asphalt (HMA)
- Mobile, non-invasive instrumentation
  - Measure tie displacements and accelerations
  - Variations along track

**Original Bridge (Hyattsville, MD)**

- Class 2 single mainline
- 30 MGT
- Open-deck bridge
- Reoccurring track geometry defects
  - Profile, crosslevel, and warp

**Remediation Selection**

- Scheduled upgrade:
  - Concrete ballasted-deck bridge
    - Conversion of existing open deck
    - Constructed new concrete ballast deck
  - Double mainline
- Approach remediation
  - Approach #1: Geoweb
  - Approach #2: Hot-mixed asphalt (HMA)
  - Approach #3: Geoweb
  - Approach #4: Existing slurry grout
- Compare effects of remediation

**Roadbed Construction**

- Geoweb (50 ft.):
  - 6” (150 mm) of crush aggregate for subgrade
  - Nonwoven geotextile
  - 6” (150 mm) thick geoweb
  - Fill geoweb with crushed aggregate
  - 12” (300 mm) of AREMA #4A granite ballast
- HMA (250 ft.):
  - 6” (150 mm) of crush aggregate for subgrade
  - 8” (200 mm) of HMA
  - 12” (300 mm) of AREMA #4A granite ballast
Roadbed Construction

- Geoweb installation (50 ft.)
  Approach #1

- Ballast installation
  Approach #3

Remediated Bridge

- Geoweb
  Approach #1

- Geoweb
  Approach #3

Instrumented Approaches

- 4 Approaches instrumented
  - Approach #1 (Geoweb) & Approach #2 (HMA),
  - Approach #3 (Geoweb) & Approach #4 (Existing Grout)
- 3 Days of testing
  - 16 November 2015
  - 18 April 2016
  - 19 July 2016
  - Semi-annually

Non-Invasive Instrumentation

- High-speed video cameras → Rail and tie displacements
- Accelerometers → Tie accelerations
  - Track system, loading, vibration, impact, double-integration
- Measure track performance
  - Well-Performing: ~1 to 2 mm, <5g, minimal track maintenance
  - Poorly-Performing: > 4 mm, >10g, periodic track maintenance

Approach #2 (HMA)

- Ballasted-deck bridge
- Hot-mixed asphalt (HMA)
- Accelerometers & video cameras

Typical Video Camera Results

- Approach #2 (HMA)
  - Varying displacements along track
  - Hanging tie at end of structure

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Video Camera Results (Comparison)

- A#1 (Geoweb) v. A#2 (HMA) v. A#3 (Geoweb) v. A#4 (Grout)
  - A#2 (HMA) & A#3 (Geoweb): Hanging ties at edge of structure; less displacement away from abutment (approaches)
  - A#1 (Geoweb) & A#4 (Grout) show consistent displacements

Video Camera Results v. Time

- 16 November 2015 v. 18 April 2016 (~5 months) v. 19 July 2016 (~8 months)
- Approach #2 (HMA)
  - Gradual increase in approach displacements

Accelerometer Results

- Approach #1 (Geoweb) v. Approach #2 (HMA)
- Similar results (under 5g)

Design Solutions

- Balance Sheet
- Decrease bridge stiffness
  - Ballasted bridge deck
- Increase approach support and stiffness
  - Geoweb
  - HMA underlayment
  - Parallel concrete wall

Approach Walls

Summary

- Site Performance
  - All four approaches performing well
  - Existing approaches showing lowest displacement
  - Minor post construction settlement of new track
- Remediated bridge approaches
  - Balance approach and bridge displacements
  - Bridges: ballasted-deck & mats
  - Approaches: geoweb, hot-mixed asphalt (HMA), UTPs, & parallel concrete wall
- Constructability
  - Track time/outage
  - Project budgets

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