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Reinforced Railway Transitions to Mitigate Differential Displacements

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Summary

The University of Illinois at Urbana-Champaign (UIUC), an Association of American Railroads (AAR) affiliated lab, and Transportation Technology Center, Inc. (TTCI) are investigating the effectiveness of Geosynthetic Reinforcement Systems (GRSs) in mitigating differential bertical movement at railway transitions. The performance, benefits, costs, installation complexity, as well as the transient and permanent differential displacements of existing reinforced transitions are being monitored. The project includes the use of GRSs as an alternative for mitigating and remediating differential movement at transitions.

The data presented are interim results generated to date on the performance of GRSs for railway bridge transitions. In particular, two (2) GRS transitions—one ballast-based and the other wall-based—have been reviewed and their performance are summarized herein. The ballast-based GRS transitions results show that one of the Geoweb approaches and the HMA approach on the new mainline exhibit larger tie displacements, about 0.39 inches (10 mm) near the edge of the concrete curbs in the ballast but reduce to about 1 mm in the open track suggesting that the track at the edge of the curb is not well supported, than the old mainline. The other two (2) approaches (Geoweb and Grouted Subgrade) exhibit consistent tie displacements of about 0.11 to 0.16 inches (3 to 4 mm) because this the old mainline so it have already experienced some movement. The HMA approach was observed over time and displays a gradual increase in tie displacement near the abutment, causing progressive increases in tie displacement further from the abutment.

The wall-based reinforcement uses back-to-back mechanically stabilized earth (MSE) reinforced walls to create a grade separation at the transition zone. MSE wall displacement data show that each of the walls exhibited movement between 0 and 0.7 inches (0 and 19 mm), with the maximum displacement usually occurring in the bottom row of block caused by the geogrids engaging and developing tension.

Anticipated recommendations resulting from this and previous work include:

- Geosynthetic reinforced transitions reduce differential vertical displacements at railway transitions by stiffening the approach and in some cases softening the structure abutment.
- Geosynthetic reinforced transitions are performing well under Class 1 freight loads.
- Geosynthetic reinforced transitions are less expensive than deep foundation supported abutments.

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INTRODUCTION

Track geometry problems are a large maintenance issue at railway transitions and cost railroad companies approximately $200 million a year according to the Association of American Railroads (AAR)[1]. One item of concern is the reoccurring differential displacements within the bridge transition zone and at the approach/structure interface. This interface involves softer approach track and a nearly rigid abutment or structure. This differential vertical displacement frequently occurs because the ballast in the approach is not sufficiently compacted so settlement occurs quickly due to loading. This ballast settlement causes a "bump" or "dip" shortly after traffic starts at the entrance and exit of the bridge unless a sufficient over-lift is used during ballast placement.

This "bump" or "dip" amplifies the applied loads as gaps develop between the bottom of the tie and ballast, which can further degrade and damage the surrounding ties, fasteners, ballast, and rail. These tie-ballast gaps result in re-distribution of the applied loads, which causes additional ties to develop tie-ballast gaps and an expansion of the area experiencing differential displacements. Successfully addressing track geometry problems at railway transition zones can lower maintenance costs and minimize slow orders for safety concerns and are important for the operation of track in the United States.

One reason the geometry problem at transition zones has not been alleviated is a suitable design or remedial measure has not been developed to mitigate the problem. Most commonly, these vertical displacements are attributed to the significant change in stiffness as the train passes over the abutment, which increases the dynamic loads within the transition region[1,2,3]. Because of the significant change in long-term stiffness from the approach to the structure, e.g., bridge deck, the majority of past research on transitions has focused on reducing or smoothing the stiffness difference between the open track, transition zone, and bridge abutment or deck[1,4].

Despite all of the possible stiffness related solutions, few field studies have tested the benefits of these remedial measures. One field study[5] near Marysville, Kansas, compares the permanent displacements of a "control" site with three different transitions treated with either Hot Mix Asphalt (HMA), geoweb, or reinforced soil. Despite the remedial action, the subsequent permanent vertical displacements at the remediated sites are greater than at the "control" site near Marysville. The explanation for the lack of success of the remedial measures is the track modulus of the bridge remained greater than the approach by a factor of two (2), meaning an abrupt and significant stiffness difference still existed at the bridge approach after repair.

To accomplish the main objective of this project, two (2) reinforced bridge transitions were investigated and monitored herein. The reinforced transitions are different because the first transition utilized geosynthetic reinforcement in the ballast only and the second transition utilized a geosynthetic reinforced wall system to create a grade separation[6]. As a result, these two (2) field applications provide a range of possibilities for geosynthetic reinforcement in railway transitions.

BALLAST BASED REINFORCEMENT CASE

This Class 2 freight bridge is located in Hyattsville, Maryland and spans the Anacostia River. The original Class 2 single mainline track had an annual tonnage of 30 million gross tons (MGT). The track structure included an open deck bridge 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 upgraded to a ballasted bridge deck along with the construction of a second ballasted deck bridge directly adjacent to the original bridge. This resulted in a double mainline with only 15 MGT per line afterwards for a total of 30 MGT. This upgrade provided an opportunity to assess the effectiveness of the following geosynthetic ballast reinforcement solutions in the bridge approach: Geoweb, HMA, and subgrade grouting. To compare the effectiveness of these ballast reinforcement solutions, the Geoweb was installed in two (2) approaches, HMA underlayment was installed in one (1) approach, and existing grouted subgrade remained in-place. The approach name and location of the various ballast reinforcement solutions are shown in an aerial view of the bridge in **Figure 1**.

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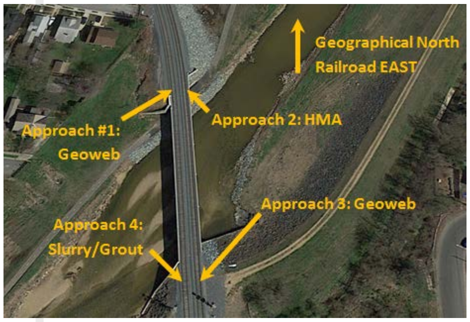

Figure 1: Overview of ballast reinforced bridge transition in Hyattsville, Maryland.

A comparison of peak transient locomotive tie displacements for the four (4) approaches is displayed in **Figure 2**. To illustrate the potential variation in transient tie displacement along the track and the impact of the ballast reinforcement near the transition, the peak locomotive tie displacements at 13 ft. and 54 ft. from the bridge for all four approaches at different times are displayed in **Figure 2(a)**.

The results in **Figure 2(a)** show consistent peak locomotive transient tie vertical 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 slightly larger transient tie displacements (0.4 inches or 10 mm) near the edge of the concrete curbs in the ballast 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[7]. Approach #3 (Geoweb) displayed similar behavior as Approach #2 (HMA) with vertical displacements (0.43 inches) at the edge of the concrete 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 (Grouted Subgrade) showed about 0.15 inches (4 mm) of transient tie displacement near the end of the concrete curb and remained near constant in the open track.

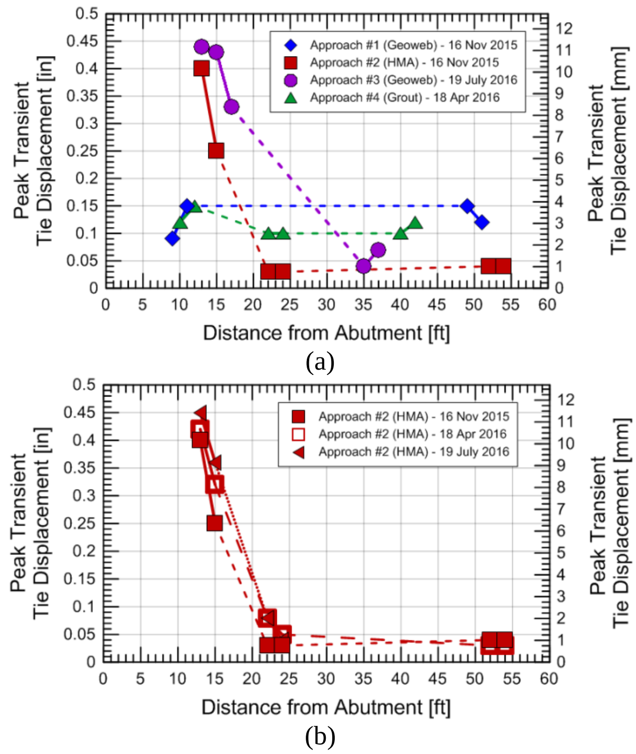

Figure 2: Peak locomotive transient tie displacements from: (a) all four approaches, and (b) peak locomotive transient tie displacements at Approach #2 (HMA) over time.

Figure 2(b) shows the change in peak locomotive transient tie vertical displacements 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 re-distributed to ties further from the abutment, which progressively creates poor tie support conditions away from the abutment. This can gradually increase the loads on these ties and increase tie-ballast gaps 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 the existing line.

In summary, rail and tie vertical displacements and tie accelerations of the Geoweb and HMA approaches were

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measured using video cameras and accelerometers, respectively, at various times. The main findings to date are:

- Both Geoweb and HMA remedial measures are providing good support to the approach track and helping to balance the transient vertical displacements in the approach and bridge. This has resulted in no maintenance being required since remediation over five years ago and an accumulation of about 75 MGT on each track.
- Geoweb underlayment is a possible alternative to HMA because it provides good ballast confinement, load distribution to the subgrade, separation between the ballast and subgrade, and reduced cost and installation time.

WALL BASED REINFORCEMENT CASE

To increase the volume of railway traffic and eliminate railway conflicts, a Class 1 railroad eliminated its diamond crossing by creating a grade separation using back-to-back mechanically stabilized earth (MSE) reinforced walls[6]. The MSE walls have a maximum height of about 25 ft. (7.5 meters) and an approximate total length of 1,610 ft (490 meters).

Figure 3 presents a cross-section through the MSE wall that shows the layers of horizontal geogrid that overlap in the middle of the wall system. **Figure 3** also shows the vertical drain between the two (2) tracks that drains precipitation so ponding does not occur around the tracks. One of the major design constraints was generating enough normal stress on the geogrids to prevent pullout. As a result, the final or top layer of geogrids had to be inclined at 45 degrees to generate sufficient normal stress to prevent geogrid pullout. The other layers were placed horizontal because Boussinesq stress distribution theory showed the maximum loading of the geogrids occurred between the first and second rows of the geogrid-reinforced wall blocks. In addition, no geogrids were placed 2 ft (0.6 m) below the track ties to prevent damage due to maintenance activities.

The MSE walls are being surveyed and monitored with inclinometers. The survey data as of 2013 shows the northwest wall face had moved between 0 and 0.31 inches (0 to 8 mm)[6]. The measured displacement of the southwest wall is between only 0 and 0.08 inches (0 to 2 mm) except for two points which have moved 0.38 inches (10 mm) and 0.71 inches (18 mm). For the northeast wall, measured displacements are between 0 and 0.43 inches (8 mm). Finally, the southeast wall displacement is between 0 and 0.59 inches (0 to 15 mm). For all four MSE walls, the maximum displacement is usually observed in the bottom row of block due to the geogrids engaging or developing tension. One of the tasks of this project is to monitor and survey the MSE walls in the summer of 2018 and update the survey and inclinometer data.

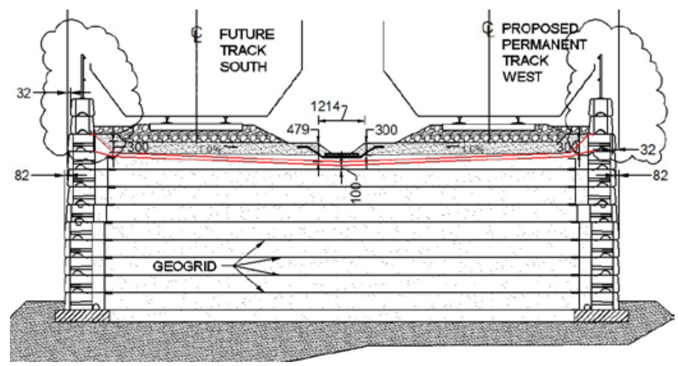

Figure 3: Cross-section through MSE wall with layers of overlapping and horizontal geogrids shown and the drain between the tracks to prevent ponding[6].

In summary, the MSE wall, rail, and tie measured displacements are small indicating the GRS is performing well. The main findings to date for this GRS application are[6]:

- Geosynthetic reinforcement can resist railway construction and loadings.
- The final or top layer of reinforcement/geogrids should be limited to approximately 3.9 ft (1.2 m) below track level to avoid possible damage during maintenance activities.
- The final or top layer of geogrids had to be inclined at 45 degrees to generate sufficient normal stress on them to resist pullout and the abrasive nature of the ballast and sub-ballast layers under cyclic train loading.
- To avoid water running over the wall, the sub-ballast layer was sloped to the center of the two tracks and the

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water evacuated every 45 m by a drain installed between the geogrid layers (see **Figure 3**).

CONCLUSIONS

Transition zones represent a challenge to the operation and maintenance of track because the reoccurring track geometry problems represent a safety issue and amplify loads that accelerate track deterioration in the transition[8,9,10]. The data and analysis presented herein, the following observations can be made about the use of geosynthetic reinforcement in railway transitions to reduce differential displacements:

- Geoweb underlayment is a viable material for reinforcing ballast in transition approaches because it provides good ballast confinement, load distribution to the subgrade, separation between the ballast and subgrade, and reduced cost and installation time.

- Geosynthetic reinforced structures appear to be a viable system for constructing railways bridges and grade separations as they have been for highways. The geosynthetic reinforcement stiffens the approach while the geosynthetic supported bridge abutment softens the abutment/structure. This increase and decrease in stiffness at the railway transition helps balance the vertical displacements between the approach and structure, which results in reduced differential displacements.

Future research is focusing on: monitoring of other reinforced railway transitions to understand the long-term performance and benefit of these systems in railways.

ACKNOWLEDGEMENT

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