Load-carrying GMSE Bridge Abutments: Lessons Learned from Field Monitoring Evaluations

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ABSTRACT

This paper presents summary of findings from a case study in a geosynthetic-reinforced soil (GRS) integrated bridge system (IBS). The GRS-IBS cited in this study was constructed in Virginia by Virginia Department of Transportation (VDOT). The GRS-IBS was 2.2 m high, 9 m wide, and had a 3.6 m bridge span. The facing of the structure was constructed with standard concrete masonry unit (CMU) blocks. AASHTO No. 8 aggregate was reinforced with woven geotextiles that were spaced 0.2 m within the primary reinforcement zone and 0.1 m within the bearing bed zone. The foundation of the GRS-IBS was constructed with VDOT 21B aggregate encapsulated by a woven geotextile which rested on bedrock. This article summarizes the observations related to (1) the vertical stresses within the body of GRS-IBS during and after construction and (2) evaluation of the connection load and stress-strain conditions right behind the facing of the GRS-IBS. Observations presented in this article were based on the data obtained from the instruments installed during construction and monitored over time. The noted vertical stress distributions in this study were used to evaluate the effects of reinforcement spacing, width of the beam seat, and seasonal variations. The results showed the effectiveness of the bearing bed (close spacing) in reducing applied stresses within the abutment and how the width of the beam seat controls the magnitude of the applied stresses on the GRS abutment. The observations from the field also showed that the distributions of both lateral stresses and reinforcement strains with depth were approximately uniform. The connection loads estimated using lateral stresses and reinforcement strains behind the facing were comparable.

INTRODUCTION

Geosynthetic Reinforced Soil - Integrated Bridge System (GRS-IBS) is a technology developed by the Federal Highway Administration (FHWA) to construct bridge abutments to support low volume of traffic (Adams and Nicks, 2018). Similar to other reinforced soil structures, such mechanically stabilized earth (MSE) bridge abutment, GRS-IBS is constructed with layers of compacted granular backfill material reinforced with geosynthetics (i.e., primarily geotextile but occasionally geogrid) where the geosynthetics is frictionally connected to the facing typically constructed using concrete masonry units (CMU) blocks. The vertical reinforcement spacing in GRS-IBS is limited to 0.3 m. Some of the features that distinguishes GRS-IBS from other reinforced soil bridge abutments are the jointless connection between the bridge superstructure and integrated approach to alleviate any potential bump that may occur on the surface of the road and the presence of bearing bed zone with secondary reinforcements underneath the superstructure and reinforced soil foundation (RSF).

The internal stability evaluation in the design of GRS-IBS is based on empirical observations of the large-scale laboratory tests (mini-pier tests) performed by FHWA (Nicks et al., 2013). The vertical stress distribution is estimated using Boussinesq's theory of stress distribution. The connection strength at the facing is not evaluated as part of the internal stability evaluation because GRS is assumed to be internally supported by closely spaced reinforcement and the facing element is not considered as a structural component except providing frictional connection (Adams and Nicks, 2018).

This paper presents the summary of findings from previously developed National Cooperative Highway Research Project (NCHRP) project reports and published articles on a case study in a field monitored GRS-IBS constructed in Virginia (Zornberg et al. 2018 and 2019, Gebremariam et al. 2020a and 2020b;). The field monitoring program was designed and implemented to evaluate: (1) the vertical stresses during and after construction and (2) the connection loads and stress-strain conditions right behind the facing of the GRS-IBS. The stress and strain measurements from the field were quantified based the theoretical methods outlined in the design of GRS-IBS by FHWA and MSE structures by American Association of State Highway and Transportation Officials (AASHTO).

FIELD MONITORED GRS-IBS CONSTRUCTED IN VIRGINIA

The field monitored GRS-IBS project site is located on route 720 in Harrisonburg, Virginia. The construction took place between August 1 and September 15, 2015 and was conducted by collaboration of Virginia Department of Transportation (VDOT) and George Mason University. VDOT's design of the GRS-IBS was conducted following the guidelines specified in the Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide (Adams et al. 2011).

The GRS-IBS was 2.2 m high, 9 m wide and had a 3.6 m bridge span. The facing of the structure was constructed with standard concrete masonry unit (CMU) blocks. AASHTO No. 8 aggregate and woven geotextile reinforcements were used to construct the abutment. The vertical reinforcement spacing was 0.2 m within the primary reinforcement zone and 0.1 m within the bearing bed zone. The foundation of the structure was constructed with VDOT 21B aggregate encapsulated by a woven geotextile which rested on bedrock. The bridge slab was constructed using precast reinforced concrete segments and the integrated approach (the roadway behind the bridge slab) was constructed using VDOT 21B aggregate and a woven geotextile. The foundation soil consisted of limestone bedrock with pockets of stiff clay. Figure 1 shows the field monitored GRS-IBS as being constructed in Virginia.

Note: Abutment on the left side is the one being instrumented.

Figure 1. Photo of the GRS-IBS during construction.

The AASHO No.8 aggregate backfill was classified as poorly-graded gravel (GP) with zero fines content in Unified Soil Classification System (USCS). The aggregate had a maximum particle size of 12.5 mm, a dry density of 1.6 g/cm^3, and a friction angle of 47.6 degrees. The VDOT 21B aggregate used to construct the RSF and the integrated approach had a maximum dry density of 2.2 g/cm^3 with optimum moisture content of 8% and a friction angle of 40 degrees. The woven geotextile used for reinforcement in the abutment and the RSF had an ultimate tensile strength of 70 kN/m.

The main purpose of the field monitoring program was to evaluate the vertical stress distribution close and away from the facing and lateral stresses and reinforcement strains immediately behind the facing of the structure. Earth pressure cells that were in circular shape (EPCs) and rectangular (RPCs) were installed at the site to measure vertical and lateral stresses in the abutment respectively. The size of the RPCs were constructed to fit right behind the CMU blocks. Foil type strain gages (SGs) were installed on the geotextile to measure reinforcement strains. The instrumentation program was monitored to record short-term responses of the structure due to self-weight of backfill and placement of bridge slab, in addition to the stage loading that was implemented during construction. Additionally, data from the embedded instruments were collected to evaluate the long-term responses due to traffic loads and seasonal variations. The characteristics of the field monitored GRS-IBS and detailed layout of the instruments embedded into the structure are presented in detail in Gebremariam et al. (2020a and 2020b).

EVALUATION OF VERTICAL STRESSES

EPCs were installed at five different layers on both abutments ranging from the layer just above the RSF to the aggregate layer just underneath the slab and in between the layers from the bottom to the top. The instrumentation layout was designed to include instruments within both primary reinforcement and bearing bed zones. The following sections describe the evaluation of the vertical stress measurements from the field site.

Effect of Vertical Reinforcement Spacing on Stress Distribution – Stage Loading

During construction, Abutment A was loaded with Jersey barriers to simulate staged loading. Staged loading was conducted to evaluate the effects of differences in vertical spacing between reinforcements on the stresses recorded within the GRS. Four staged loadings were applied on the primary reinforcement zone and three staged loadings were applied on the bearing bed zone. Therefore, a comparison of the vertical stress distribution in each of these zones could be used to evaluate the effects of reinforcement spacing.

The location of each applied staged load was approximately 0.3 m from the facing CMU blocks coinciding within the zones where EPCs were installed at different heights. In total, there were seven staged loadings, four of which involved the use of eight Jersey barriers and three of which involved the use of a single Jersey barrier. Details of Jersey barrier configurations at each layer can be found in Gebremariam et al. (2020a).

The Jersey barrier used in the staged loadings was 0.6 m wide and 3.6 m long and the magnitude of the pressure from one barrier was approximately 11 kPa. In the case of eight Jersey barrier applications, due to the configuration of how the barriers were stacked up on top of each other and the contact to the ground, the total applied load was 89 kPa where the first and third barrier was each approximately applying 39 kPa and the middle barrier was applying 11 kPa.

Figure 2a displays the response of EPCs 1 and 7 when both instruments were loaded with a single Jersey barrier that was located 0.8 m above the EPCs. EPC 1 was loaded as part of stage load 3 and located within the zone where the spacing was 0.2 m. EPC 7 was loaded as part of stage load 7 and located within the zone where the spacing was 0.1 m. Although stage load 7 included eight Jersey barriers, the comparison was made when only the first Jersey barrier was placed on the GRS. The results show that the stress measured by EPC 1 was higher than EPC 7, indicating that the stress values within the primary reinforcement zone (where the spacing between the reinforcements are larger) were higher than the ones in bearing bed zone.

Figure 2b presents the responses of EPCs 1, 2 and 3 to stage load 4 where the spacing was 0.2 m and EPCs 7, 8 and 9 to stage load 7 where the spacing was 0.1 m. In this comparison, both staged loads were conducted with multiple Jersey barriers (39 kPa), but the vertical distance between the location of the applied load and the instruments was 1.2 m and 0.8 m in stage loads 4 and 7, respectively. The results show that reduced stresses were measured by EPCs 7, 8 and 9, even though these instruments were located a shorter vertical distance from the applied load as compared to EPCs 1, 2 and 3. The stress measured by EPC 3 was less than the stresses recorded by EPCs 1 and 2, and the stress measured by EPC 9 was less than the stresses measured by EPCs 7 and 8 because EPCs 3 and 9 were horizontally farther away from the location of the applied load (Figure 2b). Nonetheless, the stress measured by EPC 3 was higher than that measured by EPC 9. These observations indicate a reduction in the stress distribution in the zone where reinforcements were vertically closer to each other (i.e., within the bearing bed zone).

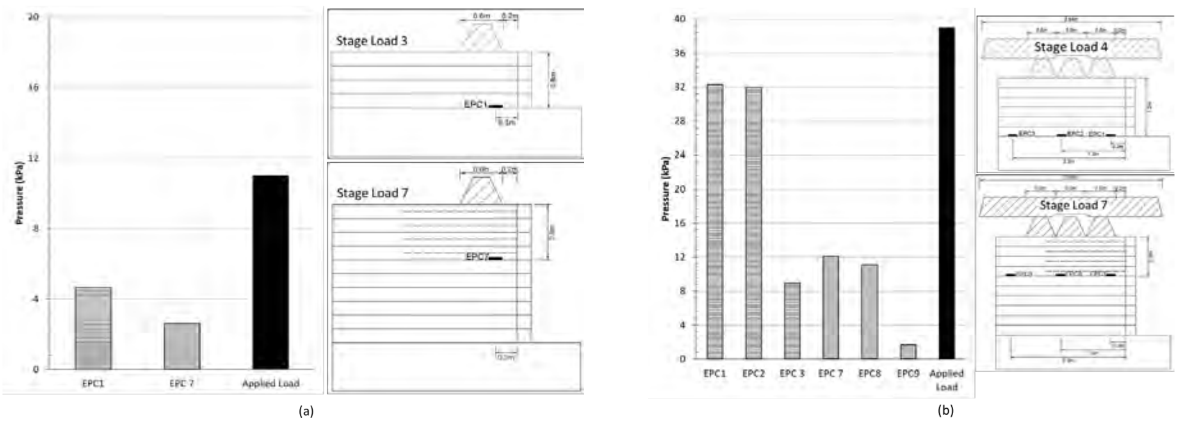


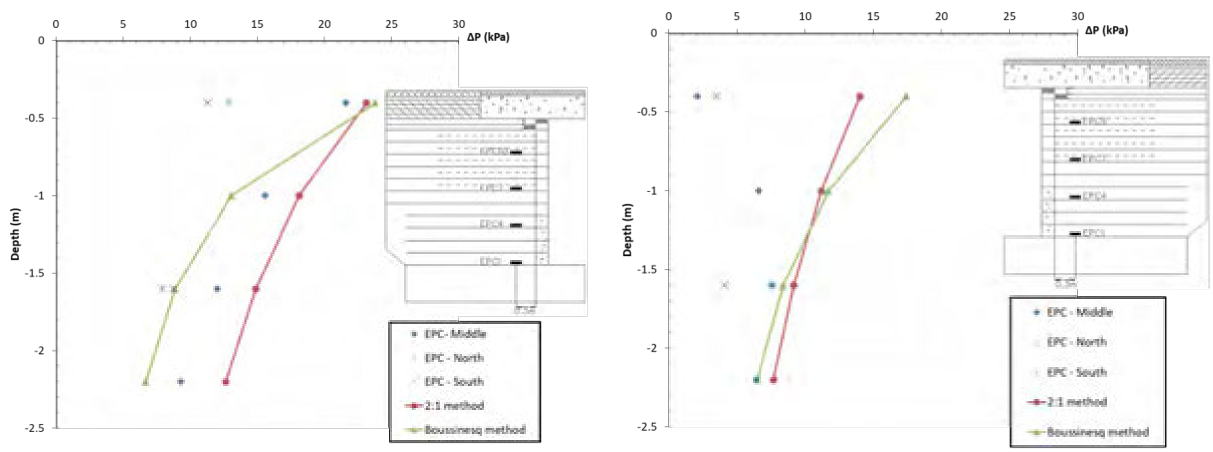
Figure 2. Comparison of vertical stresses measured in the field monitored GRS-IBS during stage loading by means of (a) single Jersey barrier; and (b) from multiple Jersey barriers (figure after Gebremariam et al. 2020a).

The consistent trends observed in Figure 2 (with both single and multiple Jersey barriers) demonstrate that closely spaced reinforcements contribute to reduced vertical stresses in the GRS bearing bed zone. In single Jersey barrier loading, the magnitude of stress was reduced 1.8 times and in multiple Jersey barrier loading, the magnitude of stress was reduced 2.7 to 5.4 times. Moreover, this indicates that the effect of closely spaced reinforcements becomes more prominent with an increase in applied loads. Overall, the results obtained from the staged loadings reveal that a decrease in reinforcement spacing (increased number of reinforcements) leads to reduced vertical stresses in the GRS mass.

Effect of Beam Seat Width on Stress Distribution – Slab Loading

The purpose of this evaluation was to compare the differences in stress distribution within the body of GRS-IBS where both abutments were constructed with the same materials and reinforcement spacing but with two different beam seat widths. One of the abutments had a beam seat width of 0.6 m (Abutment A), which is the minimum width required considering the length of the bridge span, and the other abutment had a beam seat width of 1.2 m (Abutment B, twice the width of Abutment A). Although both abutments were loaded with the same slab, the magnitude of surcharge loads in Abutments A and B were estimated to be 42 and 21 kPa, respectively.

Vertical stress distribution profiles developed in each abutment as determined from the EPCs are shown in Figure 3. The slab at this project site was constructed by multiple segments and it is believed that at the top, between the reinforced aggregate and the slab, in some locations, there were gaps. Even though the applied slab load for each abutment was the same on all sides (i.e., middle, north, or south sides), in areas where the EPCs coincidentally lined up with these gaps, the data recorded from the instruments showed different values. However, regardless of this condition, at the bottom of the GRS-IBS, in both abutments, the applied load has approximately reduced to one forth. Such observation indicates that the mechanism of vertical stress distribution does not change based on changes in the beam seat width, but that the beam seat dimensions have a significant effect on the applied load. This information could be used to adjust the width of the beam seat to reduce the applied loads on GRS-IBS and consequently, if needed, to adjust the height of the bearing bed (double reinforced zone).



(a) (b)

Figure 3. Vertical stress distributions due to bridge slab load at: (a) Abutment A and (b) Abutment B (figure from Gebremariam et al. 2020a).

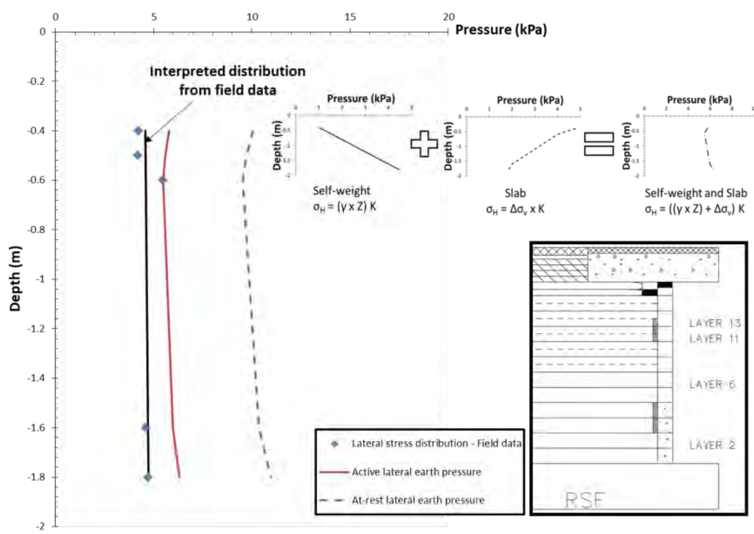
Figure 3 also shows comparison of the stress distributions calculated based on theoretical Boussinesq and 2:1 methods. Details of how the stresses from these theoretical methods were computed can be found in Gebremariam et al. (2020a). When the difference in stress magnitudes from each of the method were compared with each other, based on the differences in beam seat widths, the difference is in the order of 1.5 to 2 close to the top of the abutment. These differences decrease with depth as the magnitude of applied load also decreases. Although both theoretical stress distribution methods evaluated in this study showed similar trends, Boussinesq method appears to provide slightly better agreement for stress magnitudes when compared with the data obtained from the EPCs and the applied slab loads.

Effect of Seasonal Variations on Vertical Stresses – Truck Loading

The effect of seasonal variations on the vertical stress distribution within the GRS-IBS was monitored by loading the slab with a truck. The goal was to record changes in the measured vertical stress values. To capture the seasonal differences, the truck was parked over the slab at different times of the year: (1) at the beginning of September (response immediately after construction), (2) in December (response during winter season), (3) by March (response during spring season), and (4) by November (response during fall season). The results showed that the vertical stress distribution in the GRS abutment with AASHTO No. 8 aggregate used as backfill material was not significantly influenced by seasonal variations. The details of the truck loading program and associated results are presented in Gebremariam et al. (2020a).

EVALUATION OF LATERAL STRESSES AND REINFORCEMENT STRAINS

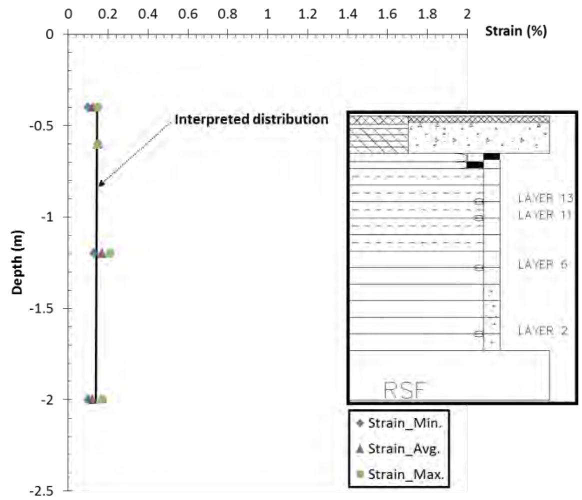
RPCs were installed at Abutment A at locations right behind the facing blocks. Figure 4 present the distribution of lateral stresses within the body of the GRS-IBS as determined from the installed instruments (due to self-weight and after the slab is placed) and based on theoretical calculations. Details of how these theoretical calculations were conducted can be found in Gebremariam et al. (2020b). The field data shows that with the placement of the slab, the lateral stress distribution becomes similar to that defined by the active condition and in general shows a uniform trend with depth. The magnitudes of the lateral stresses measured in the field were slightly lower that the theoretically calculated stresses under the active condition. However, the difference in magnitude of stress is in the order of 0.5 to 1 kPa, which is within the accuracy of the instrument. The results from the field measurements indicate that the theoretical active lateral earth pressure can be used to define the lateral stress distribution in GRS-IBS structures under service loads.



Note: Shaded areas within the insert indicate the location of RPC instruments

Figure 4. Lateral stress distribution within the body of GRS-IBS (figure from Gebremariam et al. 2020b)

Figure 5 presents the minimum, average, and maximum reinforcement strain values obtained from the SGs that were installed on the woven geotextile right behind the facing. Similarly to the lateral stress distribution, the strain distribution with depth also appear to be uniform. The maximum strain recorded in the field was significantly less than the maximum allowable geosynthetic strains (2%) in GRS-IBS design (Adams et al. 2011; Adams and Nicks 2018).



Note: Circles depicted within the insert indicate the location of SG instruments

Figure 5. Reinforcement strain distribution with depth in GRS-IBS after placement of slab load (figure from Gebremariam et al. 2020b).

The lateral stresses and strains measured from the field were then used to estimate the loads at the connection between the geotextiles and the concrete facing blocks. Details of the equations and approaches used for these computations can be found in Gebremariam et al. (2020b). When the connection loads (T_o) calculated from both of these approaches were compared, the magnitudes of the values were very close to one other and ranged between approximately 0.8 and 1.2 kN/m. Distribution of the calculated T_o with depth can be seen in Gebremariam et al. (2020b). Considering the difference in magnitude of the T_o values, the overall distribution is considered uniform.

CONCLUSIONS

This paper presents the summary of findings from a case study in a field monitored GRS-IBS constructed in Virginia. The main objectives of the study were to investigate: (1) the vertical stresses and stress distribution during and after construction (Gebremariam et al. 2020a) and (2) the connection loads and stress-strain conditions right behind the facing of the GRS-IBS (Gebremariam et al. 2020b). The stress and strain measurements from the field were compared with the theoretical calculations outlined in the design of GRS-IBS and MSE structures. The conclusions from this study are summarized as follows:

(1) The results from staged loading revealed that closely spaced reinforcements contribute to a reduction in vertical stresses in the bearing bed zone.
(2) The width of the beam seat affects the stress distribution within the GRS abutment. A wider beam seat effectively reduces the stress distribution in the structure that is caused by the superstructure.
(3) Boussinesq method appears to provide a slightly better estimation of the vertical stress distribution in GRS-IBS than the approximate 2:1 method.

(4) The magnitudes of the lateral stresses from the field after applying the slab load were close to the stresses predicted by the theoretical active condition and the stress distribution was found to be reasonably uniform.
(5) Reinforcement strains obtained from field measurements were significantly below the maximum allowable geosynthetic strains for the GRS-IBS design. The strain distribution with depth in GRS-IBS is interpreted as uniform.
(6) Connection load (T_o) values estimated using reinforcement strains and lateral stresses right behind the facing were in agreement, both in terms of distribution with depth and magnitude. Considering the difference in magnitude of the T_o values, the overall distribution is considered uniform.

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