Advancing Implementation of Geosynthetic Reinforced Soil-Integrated Bridge Systems (GRS-IBS)

Final Report
October 2017

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16. Abstract

The Federal Highway Administration (FHWA) has developed and promoted geosynthetic reinforced soil-integrated bridge system (GRS-IBS) technology to deliver accelerated bridge construction economically, primarily for relatively small bridges. The technology harnesses the stiffness of GRS to eliminate the need for piling or other conventional foundation systems. Eliminating piling typically results in cost and schedule benefits.

Despite the cost and time savings and performance benefits associated with GRS-IBS technology, it has not experienced widespread implementation. Use of the technology is likely becoming more common and widespread, particularly with several agencies deploying GRS-IBS on numerous occasions. However, other agencies have likely not implemented GRS-IBS because of a lack of familiarity with the technology and its implementation benefits.

To help overcome this lack of familiarity, the research team documented recent implementations focusing on technical performance and practical lessons from agency experiences in contracting and constructing these types of bridges. These GRS-IBS experiences were culled from a literature review, interviews with agency and contractor personnel, and the research team's experience with construction and performance observations of the Rustic Road GRS-IBS project in Boone County, Missouri.

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Advancing Implementation of Geosynthetic Reinforced Soil Integrated Bridge Systems (GRS-IBS)

Final Report
October 2017

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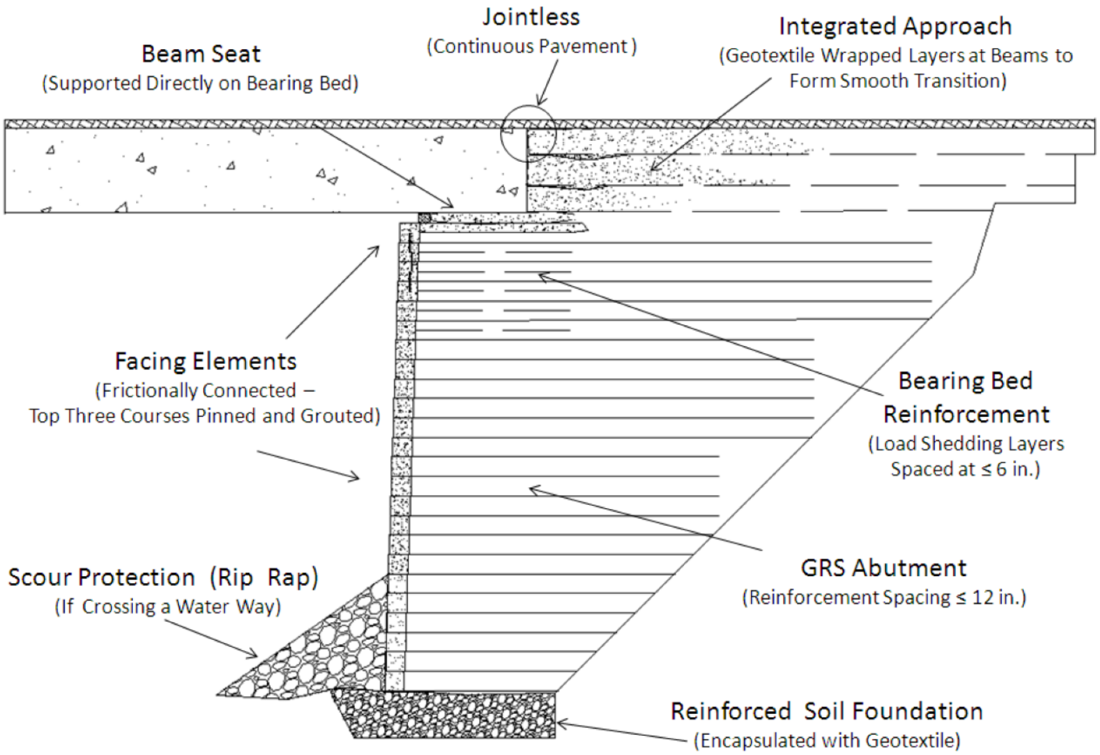
The authors gratefully acknowledge the engineers and contractors who graciously offered their time to share their geosynthetic reinforced soil-integrated bridge system (GRS-IBS) experiences: Gerald Albert (PennDOT), Daniel Alzamora (FHWA), Anousone Arounpradith (MoDOT), Jeremy Bexten (APAC Kansas, Inc.), Khamis Haramy (FHWA), and William Schlatter (Defiance County, Ohio).

INTRODUCTION

The geosynthetic reinforced soil-integrated bridge system (GRS-IBS) is a technology developed and promoted by the Federal Highway Administration (FHWA) to deliver accelerated bridge construction economically, primarily for relatively small bridges. A schematic of a typical GRS-IBS abutment is shown in Figure 1 (Adams et al. 2012).



Adams et al. 2012

Figure 1. Components of a GRS-IBS abutment

The technology harnesses the stiffness of GRS to eliminate the need for piling or other conventional foundation systems. Eliminating piling typically results in cost and schedule benefits. As shown in Figure 1, the reinforced soil provides a continuous foundation for both the superstructure and the integral approach. This integration reduces the likelihood of the “bump at the end of the bridge” that is often associated with pile foundations. Eliminating the bump is another benefit frequently cited by GRS-IBS proponents.

Despite the cost and time savings and performance benefits associated with GRS-IBS, the technology has not experienced widespread implementation. Use of the technology is likely accelerating, with several agencies deploying GRS-IBS on numerous occasions, but other agencies have not implemented GRS-IBS, likely because of a lack of familiarity with the technology, its benefits, and how it's designed and constructed.

To help overcome the lack of familiarity with the GRS-IBS, the research team has documented recent implementations focusing on (1) technical performance and (2) practical lessons resulting from agency experiences with contracting and construction of the GRS-IBS. These GRS-IBS experiences were culled from a literature review, interviews with agency and contractor personnel, and the research team's experience on the Rustic Road GRS-IBS project in Boone County, Missouri.

The FHWA has also invested in implementation of the GRS-IBS by introducing the technology during the first round of its Every Day Counts (EDC) initiatives, designating the technology as an accelerated bridge construction (ABC) technique in the second round in 2013, and then including the GRS-IBS as its own initiative in the third round. The FHWA has also published the following guidance documents:

- *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (Adams et al. 2012), which includes design and construction guidance.

- *Sample Guide Specifications for Construction*, which was published by the FHWA (2012) to accompany the guide.

- *Geosynthetic Reinforced Soil Integrated Bridge System Synthesis Report* (Adams et al. 2011), which was published earlier to supplement the guide when it was released.

- *Composite Behavior of Geosynthetic Reinforced Soil Mass* (Wu et al. 2013), which documents technical aspects of GRS behavior from laboratory and full-scale GRS experiments.

The Overview chapter of this report summarizes the most pertinent information from the FHWA guidance documents. Information from case histories and interviews are documented in the GRS-IBS Experiences chapter, and a detailed summary of the Rustic Road project from design through early service life performance is included in the Rustic Road GRS-IBS chapter. A summary of useful technical observations and practical lessons learned is included in the final Summary and Conclusions chapter of the report.

The researchers also developed a standalone Implementation Aid document, which repackages the conclusions from this project. The authors intend for this document to facilitate efficient dissemination of the most relevant implementation findings and to encourage implementation of these types of bridge systems.

OVERVIEW OF GRS-IBS TECHNOLOGY

The first documented implementation of GRS in the US occurred in the 1970s for construction of slopes and retaining walls for the U.S. Forest Service (Foreword by J. Pagan-Ortiz in Adams et al. 2011). In the past decade, the FHWA has published several comprehensive research and guidance reports related to GRS, as explained in the Introduction chapter. Summaries of the most relevant portions of the FHWA publications are presented in the following sections, which focus on technical behavior, design, and construction.

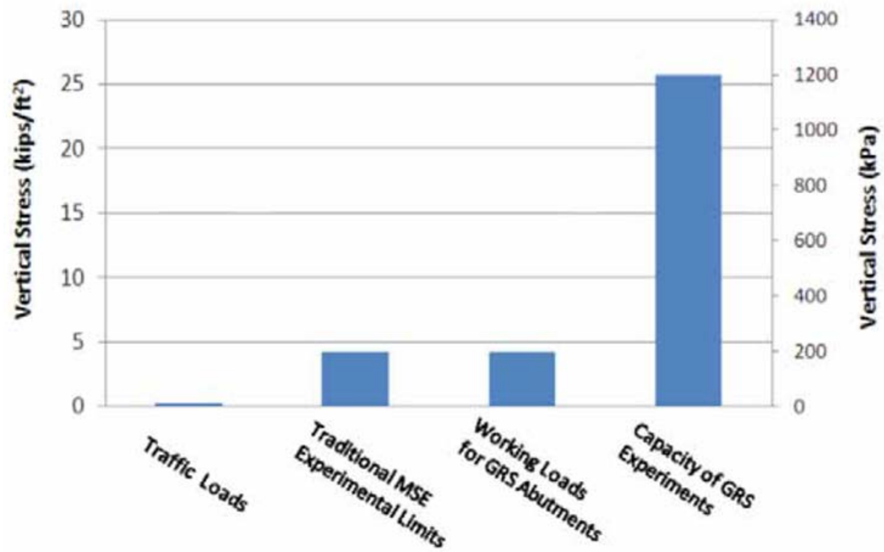
Composite Behavior of GRS

GRS refers to the composite material consisting of compacted soil and closely spaced (≤12 in. per FHWA regulation) layers of geosynthetic reinforcement. The FHWA *Composite Behavior of Geosynthetic Reinforced Soil Mass* report (Wu et al. 2013) explains that strength and stiffness of a soil mass are improved by reinforcement, which increases confinement of the soil while reducing lateral movement and dilation. As demonstrated by Figure 2, GRS is internally stable; the wall facing for GRS is not structural.

Adams et al. 2011

Figure 2. Free-standing GRS structure

The authors emphasized the distinction between GRS, which is a composite material, and mechanically stabilized earth (MSE), which also contains layers of compacted soil separated by reinforcement but does not behave like a composite material. Thus, while it is appropriate to consider individual tensile forces from the reinforcement for MSE walls, such an approach is not adequate for GRS because it neglects the effect of close reinforcement spacing on the behavior of the soil mass. As demonstrated in Figure 3, the composite behavior for closely spaced reinforcement has resulted in applied surcharges to GRS that are several times greater than those applied to MSE.



Adams 2010

Figure 3. Surcharges imposed on MSE and GRS

The difference in the role of reinforcement between MSE and GRS is reflected in the required tensile strength for each. For MSE, the required reinforcement strength, T_{req}, is directly proportional to the reinforcement spacing, S_v, per Equation (1):

$$T_{req} = \sigma_h \times S_v \quad \textbf{(1)}$$

where σ_h is the lateral earth pressure at the reinforcement depth. For GRS, as shown in equation (2), the relationship between the required reinforcement strength and reinforcement spacing is more complicated than for MSE because of the composite nature of GRS:

$$T_{req} = \left[\frac{\sigma_h}{0.7^{\left(\frac{S_v}{6d_{max}}\right)}}\right] \times S_v \quad \textbf{(2)}$$

where d_{max} is the maximum grain size of the backfill. Equation (2) was developed by Wu et al. (2013) based on the results of analytical modeling and laboratory tests of full-scale physical models. Typically, a factor of safety (or reduction factors) would be applied when selecting the design reinforcement.

Design of GRS-IBS

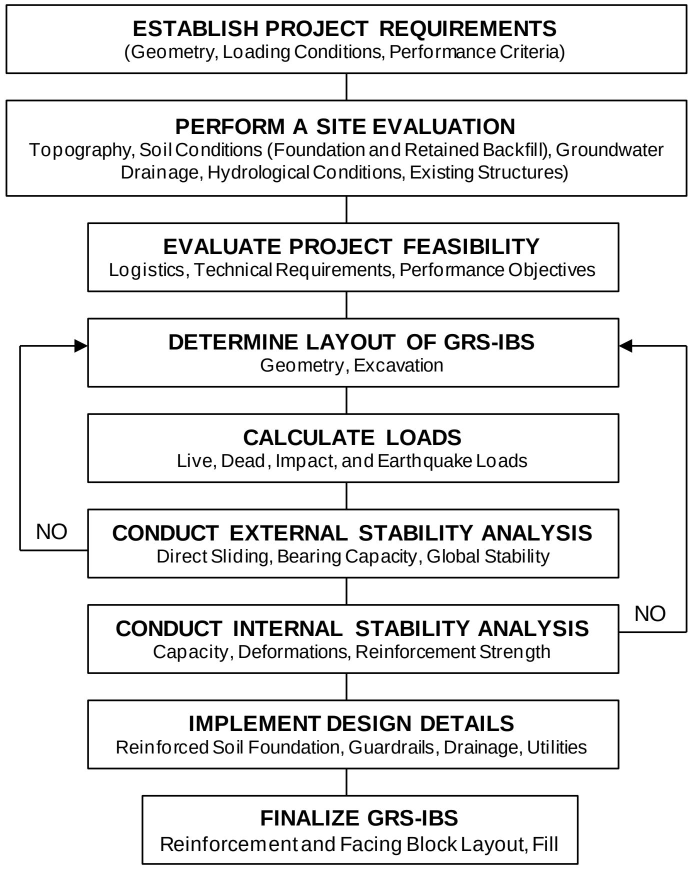
Early implementations of GRS primarily involved retaining walls and slopes, but its use for bridges via the GRS-IBS (e.g., Figure 1) has accelerated since the FHWA introduced the GRS-IBS as an Every Day Counts initiative in 2011 (Adams et al. 2011). As part of the initiative, the FHWA published the *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (Adams et al. 2012) and the *Geosynthetic Reinforced Soil Integrated*

Bridge System Synthesis Report (Adams et al. 2011). The guide includes recommended material specifications and procedures for design and construction of GRS-IBS, as well as recommended inspection methods, quality assurance/quality control (QA/QC) procedures, and maintenance procedures. The synthesis report documents technical background for the GRS-IBS, including research studies and case histories used to develop the implementation guide.

Chapter 3 of the FHWA guide presents information regarding materials for GRS-IBS walls, the most significant of which are shown in Figure 1. The facing elements for the GRS-IBS are most frequently concrete masonry unit (CMU) blocks. CMU blocks have several advantages: they are relatively inexpensive, serve as formwork for compaction of backfill material, and extending the geosynthetic material between the rows of CMU blocks serves as a frictional connection. As an alternative to CMU blocks, other flexible facing elements can be used, including gabions or timbers. Vennapusa et al. (2012) reported success for a GRS-IBS project in Buchanan County, Iowa that used grouted rip-rap facing.

Selection of GRS backfill material is critical since the GRS is a structural component directly supporting the bridge load. The guide recommends either well-graded or open-graded aggregate backfill, but notes that all GRS-IBS abutments at the time of publication (2012) used open-graded backfill because of its constructability and high hydraulic conductivity. The guide specifically recommends open-graded backfill for projects sites located in a flood zone. The Rustic Road GRS-IBS project is such a site. The guide states GRS backfill must be properly compacted to a minimum of 95 percent of maximum dry density from a standard Proctor test (AASHTO T-99). The guide notes that many types of geosynthetic materials can satisfy strength requirements for most implementations of GRS, but all GRS-IBS abutments constructed at the time of publication had used a biaxial, woven polypropylene geotextile. Such geotextiles are typically selected because they are relatively inexpensive and easy to place.

A detailed GRS-IBS design procedure is presented in Chapter 4 of the FHWA guide, which begins with the outline of the procedure shown in Figure 4.



From Adams et al. 2012 as recreated to correct typo in Vennapusa et al. 2012

Figure 4. Design steps from *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide*

The guide states that GRS has been shown to perform well "under certain extreme conditions," but the guide limits its recommendations to GRS-IBS structures with heights not exceeding 30 ft and spans not exceeding 140 ft. The guide also emphasizes requirements for backfill compaction to 95% of maximum dry density and reinforcement spacing less than 12 in. in the introduction to the design guidance. The design procedure detailed in the guide and outlined in Figure 4 is similar to the procedure the FHWA recommends for design of MSE walls, with a few important differences. One difference is the third step, which involves evaluating the feasibility of using GRS-IBS. The guide primarily discusses the importance of evaluating scour for GRS-IBS over water since the GRS-IBS has no deep foundation elements. Another main difference is the load calculation. The GRS-IBS is subjected to significant loading from the bridge deck and live loading; in a typical MSE abutment, the bridge loads are transferred to deep foundation elements rather than the MSE backfill. Finally, the internal stability analysis procedure is notably different for GRS-IBS since GRS backfill is a composite material (e.g., the differences between Equations 1 and 2 for required reinforcement strength).

Construction of GRS-IBS

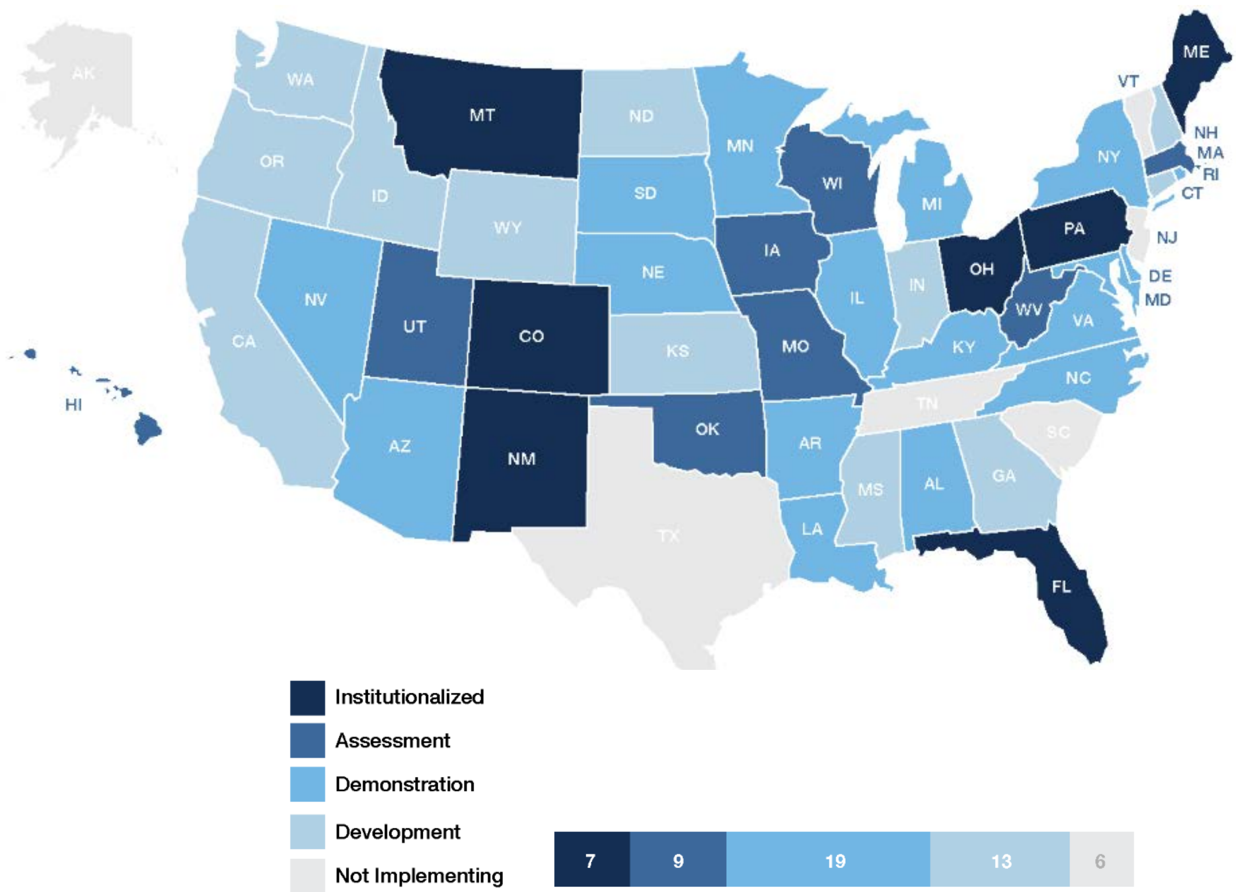
Chapter 7 of the FHWA *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (Adams et al. 2012) provides detailed procedures for construction of the GRS-IBS. The introduction to the chapter emphasizes the feasibility of quickly constructing the GRS-IBS since the construction is completed with "basic earthwork methods" and readily available materials. Most of the construction progress is completed with three relatively simple jobs: placement of wall face blocks, compaction of GRS backfill aggregate behind the blocks, and placement of reinforcement. The introduction also calls out four important details for successful GRS-IBS construction:

- A "level and even" bottom row of blocks, since each subsequent row of blocks and GRS course is built off the bottom row
- Optimized crew size and equipment
- Allowing the crew to become familiar with the construction procedure, specifically by having each member "do their part" in each of the three simple steps described above
- Locating the excavator such that it can place backfill material without tracking

The rest of the guide's Chapter 7 provides specific details for the construction procedures, including site preparation/excavation, construction of the reinforced soil foundation below the GRS, placement and compaction of backfill, placement of reinforcement, alignment of the wall face, preparation of the beam seat, placement of the superstructure, and approach integration. Photographs of these tasks for the Rustic Road project are included in the Rustic Road GRS-IBS chapter of this report.

GRS-IBS EXPERIENCES: SELECTED CASE HISTORIES AND SPECIAL TOPICS

Applications of GRS-IBS have grown considerably since introduction of the GRS-IBS during the first round of EDC. Figure 5 shows the implementation status as of January 2015 (FHWA 2015).



FHWA 2015

Figure 5. January 2015 status of GRS-IBS implementation from *EDC-3 Summit Summary and Baseline Report*

The GRS-IBS have been constructed in at least 35 states, which means most agencies are familiar with the technology, and there is a relatively wide pool of successful GRS-IBS applications. However, only seven agencies have institutionalized the GRS-IBS, which is an indication that additional information could be helpful. Examples from the pool of successful applications are documented in this chapter, focusing on applications that include useful performance information and applications with important practical lessons regarding administration and construction. The information presented in this chapter is primarily from interviews with agency and contractor personnel involved in the GRS-IBS projects. In the next chapter, similar information is presented with a detailed case history of the Rustic Road GRS-IBS project in Boone County, Missouri. Additional details for many of the case histories documented in this chapter were presented by Lindsey (2015).

Defiance County, Ohio: Experiences of an Early Adopter

Defiance County, Ohio constructed its first GRS-IBS in 2005, making it making it an early adopter of GRS-IBS. By 2014, the agency had constructed 30 GRS-IBS. The county adopted the GRS-IBS for many bridge replacement projects because the technology was the most cost-effective solution, except for cases when the entire existing abutment and foundation could be reused. The cost-effectiveness was especially appealing since county funding was limited. In addition, the speed of GRS-IBS construction made the technology appealing for bridge replacement projects.

Bedrock in Defiance County is typically around 80 ft below the ground surface. The depth of bedrock increases the relative cost savings of the GRS-IBS (since it eliminates the need for deep foundations). The aggregate specified for GRS-IBS backfill is readily available within the county, and the county specifies backfill material consistent with Ohio DOT specifications, so contractors are familiar with the material. The availability and familiarity of the backfill material likely increases the cost effectiveness of the GRS-IBS. For the first few GRS-IBS applications in Defiance County, bids came in above the engineer's estimate, mainly because contractors included more work days than estimated. As contractors have become more familiar with the technology, the bid prices have become more consistent with engineer estimates. In addition, the cost of the GRS-IBS has decreased with the number of applications. One explanation is that county engineers have become more comfortable with the technology as they have observed good performance by early GRS-IBS applications. As a result, their designs have become less conservative. For example, the size of the bearing pads has decreased since the early GRS-IBS applications.

Experience with construction of the GRS-IBS in Defiance County has been consistent with FHWA guidance. A five-person crew is typically used, with one person operating an excavator and the other four sharing backfill and facing responsibilities atop the abutment. The county reported construction times of two to three days for typical abutments, with as many as five days for large abutments. The county also reported that all GRS-IBS have been completed on time, and that contractors finding a "rhythm" to the GRS abutment construction procedure was important to this success.

Performance of the GRS-IBS in Defiance County has been good. No significant settlement or other major problems have been observed for any of the 30 GRS-IBS. Minor cracking of wall facing blocks was observed for some GRS-IBS, but the county reported the cracks were easy to fix. The county also reported conducting an informal experiment to test performance of the GRS-IBS constructed using uncompacted backfill and reported that the test application settled only 0.25 in. Additional details about the experiment were unavailable.

Pennsylvania DOT: Experiences in a State where the GRS-IBS is "Institutionalized"

Between 2011 and 2014, the Pennsylvania Department of Transportation (PennDOT) constructed six GRS-IBS bridges and local agencies in Pennsylvania constructed an additional seven. The Pennsylvania GRS-IBS have primarily been installed on low-volume, rural roadways.

PennDOT reported that the GRS-IBS has been a useful solution for bridge replacement projects on low-volume roads for the same reasons reported by Defiance County, Ohio: cost and schedule effectiveness. The agency's Bureau of Project Delivery developed a set of standard plans and notes (BD-697M) for the GRS-IBS. The standard includes notes regarding materials, design, and construction as well as drawings with standard plan details.

PennDOT has promoted the GRS-IBS to local agencies since the abutments can be constructed by local workforces without requiring specialized training. The PennDOT standard calls for clean stone (AASHTO No. 8, 67, or 57). Sourcing such stone can be difficult in Northern Pennsylvania, which reduces the cost effectiveness of the GRS-IBS for parts of the state. Otherwise, PennDOT and local agencies have not encountered any major issues during construction, and all projects have been completed on schedule and without any major cost overruns. The agency noted that GRS-IBS construction practices require project sites with significant storage space for wall facing and backfill materials, but the low-volume roads where PennDOT and local agencies have implemented the GRS-IBS have all had adequate space.

The completed GRS-IBS in Pennsylvania are performing well. Several have been surveyed for monitoring purposes, and no major movements have been observed. Included among the GRS-IBS that have been monitored are two bridges subjected to inundation: one bridge that was flooded by 6 ft of water during construction and another for which water rose to the bottom of the bridge girders. In addition, none of the Pennsylvania GRS-IBS have had maintenance issues, although all the GRS-IBS are relatively early in their service life. PennDOT reported that it was satisfied with the technology and plans to continue implementing it for low-volume bridges and promoting its use by local agencies.

Contractor Perspective and Implementation Challenges in Missouri

Missouri Department of Transportation (MoDOT) personnel considered use of GRS-IBS for several years, but had difficulty identifying an appropriate bridge project for trial use of the GRS-IBS, primarily because the agency does not have many single-span bridges. In 2013 and 2014, MoDOT built two GRS-IBS bridges, one in the Columbia and one in Russell County. In 2015, the agency also funded instrumentation and monitoring of the Rustic Road GRS-IBS project, construction of which was funded by the City of Columbia and Boone County. This project is presented in detail in the next chapter.

All three GRS-IBS in Missouri have performed well. Design, construction, and implementation challenges were experienced for each of the three GRS-IBS; the challenges are presented in this section and in the next chapter. MoDOT plans to continue using the GRS-IBS in the future and promoting GRS-IBS to local agencies, including assistance with design as necessary.

The GRS-IBS in Columbia supports Paris Road over a business spur of Interstate 70 (Business Loop 70). As shown in Figure 6, a pedestrian bridge is immediately east of the Paris Road GRS-IBS, with a railroad bridge just to the west.

Figure 6. Paris Road GRS-IBS in Columbia, Missouri

The contractor was required to maintain traffic on the Business Loop throughout construction. In addition, overhead power lines run along the south side of the Business Loop. These access constraints, coupled with the 20 ft height of the abutments, complicated construction operations. The contractor leased land nearby in order to have a construction staging area; even with the leased land, it was difficult accommodate both the aggregate stockpile and the facing blocks required for GRS construction operations. In addition, the contractor had to bench the excavation in order to facilitate excavation of the abutment foundations to the required depth. After construction was complete, the contractor described the access constraints as the most challenging aspect of the project.

The backfill material used for the Paris Road GRS-IBS was MoDOT Type 7, a well-graded base material. As shown in Table 1, the backfill material has a maximum particle size of 1.5 in. and a maximum fines content of 12%.

Table 1. Gradation for MoDOT Type 7 aggregate gradation

Sieve	Percent Passing by Weight
1.5 in.	100
1 in.	70–100
No. 8	15–50
No. 200	0–12

These gradation characteristics satisfy the requirements for well-graded material stated in the FHWA *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (Adams et al. 2012), but the material had to be specially made at the quarry. The contractor initially had difficulty satisfying project compaction requirements, 95% of maximum dry density, with the Type 7 material. To meet the specifications, the contractor began using a heavier compactor and wetting the backfill, which was initially placed dry. After implementing the adjustments, the contractor satisfied compaction requirements without difficulty. Despite slowdowns resulting from tight work areas and trouble meeting the compaction requirements, the contractor met the scheduled deadline on the Paris Road project, although several 50-hour weeks were required to avoid delays.

The backfill difficulties on the Paris Road project—sourcing the well-graded material and meeting compaction requirements—are in contrast to the experience on the other two GRS-IBS projects in Missouri, which used open-graded material. With the open-graded material, a method specification is allowed; the specification requires a certain number of passes with the vibratory compactor. Satisfying the method specification is simpler than satisfying the performance specification (95% of maximum dry density) required for the well-graded material.

As noted in the FHWA implementation guide, small CMU blocks are the most common wall facing for a GRS-IBS. However, MoDOT has observed durability issues when using the small CMU blocks in other applications, particularly applications where the blocks are subjected to road salts. Accordingly, large wet-cast concrete blocks were specified for both the GRS-IBS projects designed by MoDOT. (Large wet-cast concrete blocks are more durable than the small dry-cast CMU blocks.) Remarks by MoDOT, the Paris Road contractor, and consulting engineers familiar with the two types of facing revealed the relative advantages and disadvantages listed in Table 2.

Table 2. Comparison of large wet-cast and small dry-cast CMU blocks for GRS-IBS wall facing applications

Fabrication:	**Dry-Cast**	**Wet-Cast**
Typical Size:	**8 in. by 12 in.**	**18 in. by 36 in.**
Advantages:	Significant experience	More durable
	Lightweight; can be placed by hand	Not subject to movement during vibratory compaction
Disadvantages:	Subject to movement during vibratory compaction	Heavy; must be placed with excavator
	Less durable; problems with freeze-thaw testing	Difficult to level
		Requires shop drawings

After construction was complete, the Paris Road contractor stated use of small CMU blocks rather than the wet-cast blocks would be the most significant change he would make to the design of the Paris Road GRS-IBS.

A problem with the GRS-IBS is education of the contractors on how to properly roll out the geosynthetic reinforcement. In order to alleviate this confusion, MoDOT typically specifies bi-axial geosynthetic, but the issue is how to best roll out the sheets when the wall gets higher. Also, when the wing walls are flared out, contractors will sometimes not place the geosynthetic material down in the correct orientation or will use small bits and pieces to cover the backfill and not have a single, continuous piece of geosynthetic reinforcement. As with any new technology, there is a learning curve and once the local contractors are more comfortable with the GRS-IBS, MoDOT can expect the cost estimates to drop, thus making bridges more affordable in Missouri.

MoDOT noted that the relative inexperience with GRS-IBS technology makes cost predictions difficult. The agency also noted how contractor unfamiliarity leads to higher bid prices. The agency noted the unit price of GRS and excavation for the Paris Road project—about $100 per sq ft of wall face—as significantly greater than the typical agency price for MSE, which is $55 per sq ft. However, the agency stated that difference is only partly due to inexperience with the GRS-IBS, noting that site access difficulties increased cost for the Paris Road project. In addition, the MSE unit cost does not include excavation costs, since the agency typically includes excavation as a roadway expense. Finally, and significantly, the MSE unit cost would be accompanied by a bridge requiring a foundation system, most often driven piles. A GRS-IBS does not include separate foundation costs since the GRS serves as the foundation.

The contractor on the Paris Road GRS-IBS is primarily a pavement and bridge construction contractor, with less experience constructing MSE walls. The contractor reviewed the GRS-IBS implementation material promoted by the FHWA, including the YouTube video regarding construction procedures, prior to construction of Paris Road GRS-IBS. The contractor found the material useful, but noted that the differences in backfill material, compaction equipment, and facing material represented significant departures from the video, which complicated operations. The contractor also noted that the height of the Paris Road abutments resulted in a longer construction schedule than implied by the video.

Additional Experiences

The review of GRS-IBS literature and discussions with FHWA personnel revealed other noteworthy experiences with GRS-IBS:

- Between 2011 and 2015, the FHWA implemented about 10 GRS-IBS bridges. The design and construction experiences were all consistent with the information in the FHWA implementation guide (Adams et al. 2012). All projects used specifications similar to the FHWA sample guide specifications for construction (2012) that accompany the guide; the agency found the specifications to work well. Four of the GRS-IBS were instrumented and monitored. The performance of all has been satisfactory, with only minor deformations observed for the instrumented GRS-IBS. None of them experienced a "bump at the end of the bridge."

- A GRS-IBS was constructed to carry Rock County Road 55 over Minnesota Southern Railway in 2013. The project and results of instrumentation and monitoring were presented during a 2016 Transportation Research Board (TRB) webinar regarding the performance of GRS-IBS (Nicks et al. 2016). The bridge has a clear span of 78 ft, and a 5.3 percent grade. The GRS-IBS was instrumented with Shape Accel Arrays (SAAs) to measure vertical and horizontal displacement profiles beneath and within the abutment, respectively, to survey targets on the wall facing, which were read with on-site total station devices and earth pressure cells behind the bridge girders and within the GRS foundation. After construction, settlement of up to 2.0 in. and lateral movement up to 0.9 in. were observed, with some minor creep occurring both laterally and vertically in the three years after construction. Cracking was observed in the facing blocks and in the pavement at the ends of the beam.

- In 2013, a GRS-IBS was constructed for a stream crossing under Chesapeake City Road in Delaware. The GRS-IBS was constructed with AASHTO No. 8 stone backfill, a woven polypropylene geotextile, and split-face CMU blocks. The University of Delaware instrumented the GRS-IBS with inclinometers, piezometers, earth pressure cells, and strain gages to measure stress in the reinforcement. Results of the instrumentation were presented during the 2016 TRB webinar (Nicks et al. 2016). The performance was satisfactory, with a maximum wall facing lateral deflection of 0.4 in., maximum wall facing settlement of 0.5 in., and no apparent scour. The maximum measured strain along the reinforcement was less than 0.5%. Temperature had a significant effect on the reinforcement strain.

- A GRS-IBS was constructed for Route 7A over Housatonic Railroad in Massachusetts in 2014. The project was also presented during the 2016 TRB webinar (Nicks et al. 2016). The GRS-IBS achieved 49% cost savings compared to the original design. The GRS-IBS included a 105 ft single-span bridge with a 30 deg. skew atop 24 and 28 ft tall abutments. The abutments were monitored with survey targets on the wall face, inclinometers to measure lateral displacement within the abutment, and earth pressure cells beneath and behind the bridge girders. Observed settlement of the GRS-IBS was less than 2 in., and lateral displacement fluctuated within a 0.2-in. range, apparently an effect of temperature.

- Warren et al. (2014) instrumented and monitored a 140 ft long GRS-IBS in Ohio to evaluate lateral pressures associated with thermal stresses on the bridge. Warren et al. measured stresses within the bridge girders and in the GRS behind the girders, observing GRS behaved "significantly more like a system with unrestrained boundaries" than like a fixed system. During three years of monitoring, the end restraint decreased only slightly, and the GRS approach "remained engaged with the superstructure as it expanded during temperature increases and contracts during temperature decreases." The observed performance was noted as superior to conventional integrated abutments, for which thermal effects produce a "ratcheting effect" that increases girder stresses over time.

RUSTIC ROAD GRS-IBS: DESIGN, BIDDING, CONSTRUCTION, AND PERFORMANCE

Rustic Road is a low-volume road just east of Columbia, in Boone County, Missouri. The road crosses the North Fork of Grindstone Creek to provide passage to approximately 10 residences before reaching a dead end. In 2013, deterioration of the original Rustic Road bridge (Figure 5) led to a bridge load rating that precluded fire trucks from crossing it.

Figure 5. Original Rustic Road bridge showing deterioration of the outer girder, including corrosion through an entire portion of the web near the abutment

In response, the City of Columbia and Boone County initiated a bridge replacement project. The replacement project was identified as a candidate for the GRS-IBS because the bridge is relatively short in span (50 ft) and height (14 ft) and because of the need for rapid replacement, given there are no detours for the roadway south of the bridge and that relatively frequent flooding of the project site made the project an interesting GRS-IBS test case. Recognizing the interesting test case, MoDOT enlisted the research team to monitor performance of the bridge for approximately 18 months after its construction. Details of the Rustic Road project, including design, bidding, construction, monitoring, and performance, are summarized in the following sections. Additional details are included in a MoDOT report by Boeckmann et al. (2016) and an MS thesis by Lindsey (2015).

Design

Design of the bridge replacement was completed by Bartlett and West, Inc. of Jefferson City, Missouri. The design was completed largely in accordance with the FHWA *GRS-IBS Interim Implementation Guide* (Adams et al. 2012), which was summarized in the GRS-IBS Overview chapter of this report. Since Rustic Road is a hydraulic application of the GRS-IBS, a separation geotextile wrapping around each course of backfill (immediately behind the facing blocks) was included to prevent loss of material in the event of loss of facing blocks. The GRS abutments are directly atop limestone bedrock, so foundation scour was not a concern.

GRS-IBS was not the only innovative initiative included in the Rustic Road bridge replacement project. The superstructure consists of four tub girders with attached precast bridge deck sections (as shown in Figure 6).

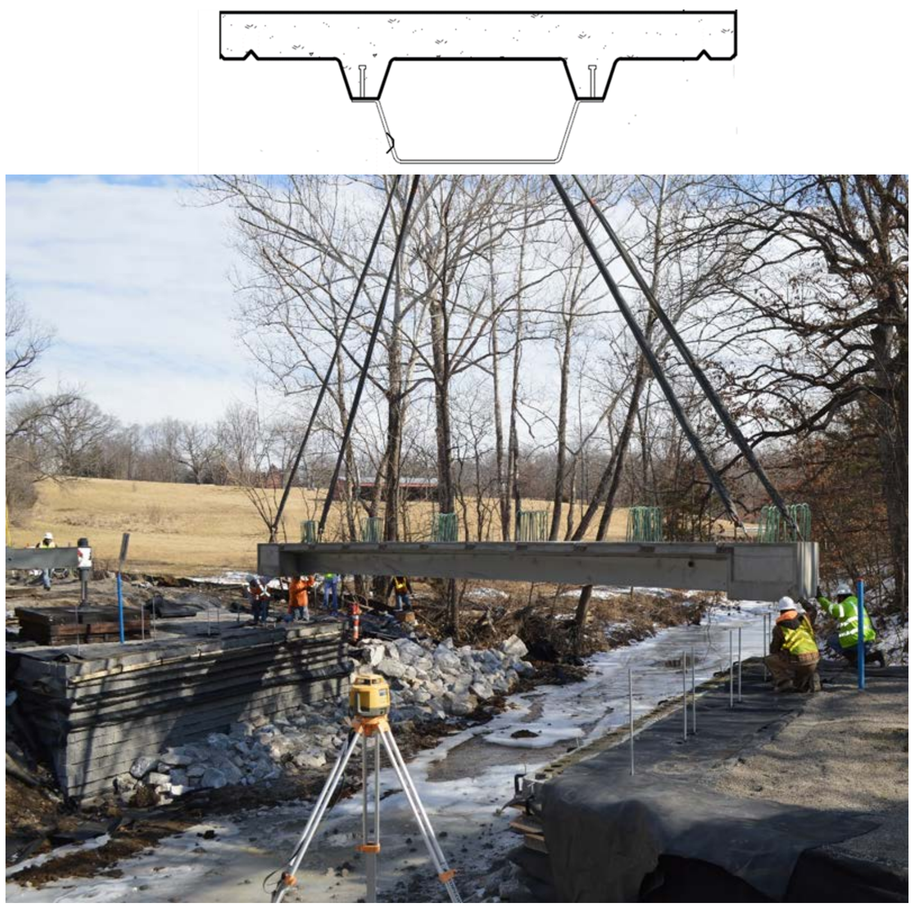


Figure 6. Tub girders with precast bridge deck: cross-section (top) and tub girder being lowered into place (bottom)

The four pieces were fabricated off-site, and placement of the girders was completed during the course of one day. To counter buoyancy forces on the tub girders, each girder was anchored to plates embedded approximately 3 ft in the GRS via the bolts shown in Figure 6. Embedment of the plates is discussed in the Construction section later. Vent holes were also included in the girders to prevent trapped air from forming between the tubs during a flood.

The GRS backfill material for the Rustic Road GRS-IBS consists of open-graded aggregate meeting specifications for AASHTO No. 89 stone. The GRS reinforcement is a high-performance, woven polypropylene geotextile. In addition, needle-punched, nonwoven polypropylene geotextile was wrapped around each GRS layer just inside of the wall facing blocks. The separation geotextile was included to prevent loss of material in case of damage to the facing blocks. The facing blocks were 8 in. tall by 12 in. long by 8 in. wide split-face gray CMU blocks. Below grade solid red CMU blocks (i.e., the first five courses of GRS) of the same dimensions were used for scour resistance and detection (via any exposure during the life of the abutment).

Bidding and GRS-IBS Technology Transfer

The design of Rustic Road GRS-IBS was initially completed in spring 2014, with bid letting in May 2014. The engineer's estimate for construction costs was $301,000, with $92,500 for construction of the GRS abutments. The bid advertisement resulted in a single bid for $447,000, with $227,500 for construction of the GRS abutments—nearly 150 percent greater than the engineer's estimate for GRS. The bid was rejected, with Boone County opting to re-let the bridge in September 2014. The county and its consultant, Bartlett and West, implemented several changes in schedule, design, and strategy to attract lower bids for the second letting:

- The construction timeline was revised to allow more flexibility. The initial bid documents included a notice to proceed date of June 16, 2014, and required the bridge to be open to traffic by July 16, 2014. In hindsight, the tight timeline, especially in the height of construction season, was viewed as overly restrictive and a prime reason many potential contractors declined to bid on the project. The revised schedule for the second bidding limited contractors to 25 working days, but the 25 day period could fall anywhere between September 4 and January 15, 2015.

- To solicit more bids, the second letting was actively advertised to potential local contractors.

- The county enlisted the FHWA to help educate potential bidders about GRS-IBS, since most bidders were unfamiliar with the technology. The county held a pre-bid meeting with potential bidders. A FHWA expert attended the meeting, showed potential bidders videos regarding GRS-IBS construction, and answered questions from the contractor. The FHWA expert was also on hand at a Second Strategic Highway Program (SHRP2) showcase on GRS-IBS that occurred two days after the pre-bid meeting. Additional details on the showcase are discussed next.

- Several revisions to the design were implemented to improve constructability:

- A suggested skew detail was added to the plans. Rustic Road’s skew complicates construction of the corners; the detail was intended to improve abutment constructability. During construction, the contractor did not strictly adhere to the suggested detail.

- The original plans called for two different types of separation geotextile to be used, with a more restrictive permittivity requirement for the separation geotextile in the bearing bed reinforcement zone. The revised plans were simplified by calling for a single type of separation geotextile with the less restrictive permittivity requirement.

- Minimum strength requirements for the geosynthetic reinforcement were reduced slightly to allow more classes of geosynthetic to be used.

- The original plans called for “capstone” blocks to be used as the top row. The revised plans removed this requirement, instead requiring the contractor to grout the openings in the top row of blocks.

After implementing these revisions, the second letting resulted in four bids. The low bid was $375,500, with $102,700 for the GRS abutments. The GRS portion of the bid was 10 percent greater than the engineer’s estimate.

The SHRP2 GRS-IBS showcase was held August 28, 2014, in Columbia, Missouri. The showcase featured FHWA GRS-IBS experts as well as presentations by other professionals familiar with GRS-IBS, including local engineers, municipal and county engineers, MoDOT personnel, and contractors. Morning presentation topics included the Rustic Road GRS-IBS design and bidding lessons learned (i.e., the bullet points above), and the Paris Road GRS-IBS, which was under construction at the time of the showcase. In the afternoon, attendees visited the Paris Road GRS-IBS construction site.

During an open discussion about costs for GRS-IBS, the FHWA expert remarked that unit costs for GRS should be similar to those for MSE, since the two retaining structures are composed of the same materials and are constructed using similar techniques. A local contractor’s response was informative. He noted that small bridges like those for which GRS-IBS is typically applied are mostly built by contractors without MSE experience, and that MSE walls are often built by contractors without experience building bridges. Large contractors experienced with both bridge and MSE construction are unlikely to bid on a contract for a single, small bridge (i.e., GRS-IBS). As a result, the pool of potential bidders for GRS-IBS projects is composed of contractors who are unfamiliar with at least part of the GRS-IBS construction process. This unfamiliarity likely increases bid prices.

Construction

The construction progress is documented through the images in Figures 7–34 and generally followed the sequence and procedures outlined in the FHWA *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide*, although several unique aspects of the project required deviations. For example, limestone bedrock was encountered at depths shallower than anticipated, requiring excavation via a rock chipping hammer (Figures 7 and 8) to achieve adequate abutment embedment.

Figure 7. Rock chipping hammer being used to excavate limestone bedrock below south abutment

Figure 8. Rock chipping hammer and backhoe being used to excavate limestone bedrock below south abutment

Figure 9. Compaction of reinforced soil foundation for south abutment

Adams et al. 2012

Figure 10. Placement of bottom row of CMU blocks for south abutment with red blocks used for first five rows for scour indication and leveling of the bottom row being critical per the FHWA implementation guide

Figure 11. Compaction of second course for south abutment with worker standing on corner blocks to prevent movement

Figure 12. Wrapping separation geotextile around second GRS course of south abutment

Figure 13. Placement of reinforcement between second and third courses of south abutment

Figure 14. Completed third course of south abutment

Persistent seepage entered the excavation for the north abutment from a permeable layer exposed by the excavation. A submersible pump was used to remove water from the excavation prior to compaction (Figure 15).

Figure 15. Pump being used to remove seepage water from north abutment prior to compacting

Figure 16. Concrete saw being used to cut CMU block for corner of north abutment

Figure 17. Compacting tenth course of GRS of north abutment after placing second telltale device for measuring settlement

Figure 18. Placing reinforcement around instrumentation (inclinometer and telltales) atop tenth course of GRS of north abutment

Figure 19. Completed tenth course of GRS of north abutment

The crew experienced difficulty with the facing blocks creeping outward during vibratory compaction, which was conducted according to a method specification requiring three to five passes. To reduce the displacement, the crew clamped lumber to the reinforcement extending out in front of the wall from just beneath the course being compacted (Figures 20 and 21).

Figure 20. Leveling CMU blocks ahead of placing backfill with boards clamped to reinforcement used to prevent movement of blocks for previous course during compaction

Figure 21. Securing boards to reinforcement to prevent movement of the CMU blocks during compaction

Anchors were necessary to provide resistance against buoyancy forces against the tub girders (Figures 22 and 23).

Figure 22. Surveying and leveling to place anchor plates for girders

Figure 23. Four anchor plates (one per girder) placed approximately 3 ft below the top of each abutment within the backfill

The beam seat consisted of two 4 in. thick layers of aggregate wrapped with reinforcement. Styrofoam was placed in the front of each layer, and a row of narrow CMU blocks was placed in the back of each layer for each abutment (Figures 24–29).

Figure 24. Preparation of the beam seat for north abutment

Figure 25. Placement of reinforcement for bottom layer of beam seat for north abutment

Figure 26. Compaction of first layer of beam seat for north abutment

Figure 27. Preparation of second layer of beam seat for north abutment

Figure 28. Compaction of second layer of beam seat

Figure 29. Grouting CMU block openings of top layer of abutment

The crew ensured that the holes through the girders were aligned with anchor bolts (Figures 30–32). (Figure 6 also shows the lowering of the first girder.)

Figure 30. First girder being lowered into place

Figure 31. Placement of third girder

Figure 32. Crew places additional aggregate below first girder to achieve level surface

Images of the bridge after construction are shown in Figures 33 and 34.

Figure 33. Rustic Road GRS-IBS from the southwest

Figure 34. Rustic Road GRS-IBS from the northeast

Additional images from construction and details of the instrumentation installation are presented in the following Monitoring System and Performance sections.

The Rustic Road GRS-IBS was constructed by Mera Excavating, LLC, a small contractor based in mid-Missouri. Rustic Road was Mera's first experience with GRS-IBS and first project involving significant use of geosynthetic reinforcement. In an interview after completion of the Rustic Road GRS-IBS, Mera's project manager offered the following observations about the company's experience:

- The most significant challenge for Mera was preventing the small modular blocks from moving during vibratory compaction. Mera ultimately achieved this by clamping boards to excess geosynthetic reinforcement, but developing and implementing the strategy cost Mera time, and the supplies were an unanticipated expense.

- The skew of Rustic Road presented another challenge, partly by exacerbating the problem of facing blocks sliding during compaction and partly by complicating alignment of the facing blocks at the corners.

- Leveling the blocks was difficult at the base of the wall, which was founded on the limestone creek bed.

- Construction of the project during winter months resulted in approximately 15 percent waste of the GRS aggregate, stockpiles of which were covered with snow and ice on several occasions.

- Construction materials were easy to procure.

- Except for the aggregate overages due to freezing, Mera's cost estimate was largely accurate. Nevertheless, the project manager stated the company would likely increase its unit prices for construction of another GRS-IBS, primarily to account for time with the small modular block wall facing.

Monitoring System

To monitor the performance of Rustic Road GRS-IBS, a system of instrumentation, land surveying, and visual observations was implemented. The monitoring system included surveys to monitor external movement of the GRS-IBS, settlement plates and inclinometers to record displacement within the GRS-IBS abutments, earth pressure cells to measure total stresses within the abutment backfill, and piezometers to measure pore pressures within the abutment backfill. An overview of the monitoring system is included in Table 3.

Table 3. Summary of monitoring system performance metrics and corresponding monitoring system component details

<table>
<tr><th>Performance Metric</th><th>Monitoring System Component</th><th>Component Location(s)</th><th>Monitoring Frequency</th></tr>
<tr><td rowspan="3">External movement</td><td>Land Surveying (by City of Columbia)</td><td>• 12 reflective markers on face of each abutment
• 4 corners of bridge</td><td>Quarterly throughout monitoring period</td></tr>
<tr><td>Crack gages</td><td>Top of each wing wall</td><td rowspan="3">Monthly for first 12 months and every other month thereafter</td></tr>
<tr><td>Visual observation</td><td>Entire project site</td></tr>
<tr><td>Scour</td><td>Visual observation</td><td>• Rip rap in creek bed and on side slopes
• Red CMU blocks below grade on each wall face</td></tr>
<tr><td rowspan="2">Internal movement</td><td>Settlement plates (vertical displacement)</td><td>3 plates in a vertical line: bottom, middle, and top of the north abutment backfill</td><td>Quarterly throughout monitoring period</td></tr>
<tr><td>Inclinometer (horizontal displacement)</td><td>One casing per abutment</td><td>Monthly for first 12 months; every other month thereafter</td></tr>
<tr><td>Earth pressure</td><td>Vibrating wire earth pressure cells</td><td>• Two cells near bottom of north abutment
• 4 cells near top of north abutment (1 per girder)</td><td rowspan="2">Data logger recorded measurements every two hours; data collected during every site visit</td></tr>
<tr><td>Pore pressure</td><td>Vibrating wire piezometers</td><td>10 piezometers distributed throughout the north abutment</td></tr>
</table>

External movement is a critical indicator of the performance of any bridge system. External movement refers to displacement of the outside surfaces of the GRS-IBS, including settlement of the bridge or abutments and lateral displacement of the abutments (e.g., bulging). External movement of the GRS-IBS was primarily monitored via land surveying of the four corners of the bridge as well as 24 survey targets installed on the face of the abutments. The reflective targets are shown in Figure 35.

Figure 35. A grid of 12 reflective survey markers bolted to CMU blocks were installed on the face of each abutment: grid for north abutment with marker labels as established by the crew (left) and close-up view of a reflective marker (right)

The benchmark for all site surveys was a survey marker established in the limestone bedrock exposed in the bed of the creek below Rustic Road GRS-IBS.

Visual observations during regular monitoring site visits provided another indication of any significant external movement. Visual observations also allowed for monitoring of other performance metrics such as the presence of scour, which is observed via significant displacement of rip rap or exposure of the red CMU blocks, which were shown in Figure 10.

Internal movement refers to displacement within the GRS abutment backfill. Internal movement is an important measure that can explain observed performance. For example, information regarding vertical displacement within the abutment backfill would help explain the origin of observed settlement at the surface of the abutment. For Rustic Road, vertical internal movement was monitored using three settlement plates installed in the north abutment, and lateral internal movement was monitored using an inclinometer, with one inclinometer casing in each abutment.

As shown in Figure 36, the settlement plate devices consist of 12 in. square, 0.25 in. thick steel plates that were embedded in the backfill, with threaded steel rods extending up from the plates to the top of the abutment.

Figure 36. Installation of bottom settlement plate: placement and leveling on thin layer of coarse sand (left) and placement of loose PVC sleeve over steel rod to prevents friction between rod and aggregate (right)

Coarse sand was placed between the bottom of the settlement plate and the coarse gravel GRS backfill to facilitate horizontal installation of the plates. The threaded rods extended up to the top of the abutment through loose PVC sleeves, which prevented friction between the rod and backfill. The three settlement plates were installed above one another (i.e., along a vertical line) about 5 ft behind the north abutment wall, with the bottom plate about 2 ft above the reinforced soil foundation, middle plate about 6 ft above the foundation (i.e., mid-height), and top plate about 3 ft below the pavement. The upper two plates were slotted to allow the rod and pipe from the lower plate(s) to pass through the upper plates. Settlement plate measurements were collected via the land survey. The surveys were collected quarterly throughout the monitoring period.

An inclinometer system was used to measure lateral internal displacement of each GRS abutment. The inclinometer system consisted of a proprietary plastic casing and an inclinometer probe. The casing had four machined grooves at 90° angles running along its length. The casing was installed so that the bottom of the casing was fixed and the top was accessible at the ground surface. For Rustic Road, the bottom of each casing was fixed by grouting 12 in. of the casing into the limestone bedrock foundation. The probe had wheels that traveled along the casing grooves. As the probe was lowered down and the casing raised up, the probe recorded angle measurements with respect to gravity. Integration of the measurements results in an interpreted casing shape, and comparison of subsequent sets of readings, produced a change in casing shape, which was interpreted as lateral deflection of the abutment. Like the settlement plates, inclinometer casings were also located about 5 ft behind the abutment wall face. Inclinometer readings were collected by the research team during each monitoring site visit. The visits occurred monthly for the first year of monitoring and then every other month for the following six months.

Information regarding earth pressure or stress within the GRS backfill indicates how the load is distributed within the abutment. GRS-IBS loading primarily comes from self-weight (i.e., weight of the GRS backfill) and weight of the superstructure. Knowledge of stress distribution within the abutment helps explain performance since deformations depend on stresses and vice versa. For Rustic Road, six earth pressure cells were installed in the north abutment backfill as shown in Figure 37, with two cells near the bottom of the abutment and four cells near the top, beneath the center of each girder.

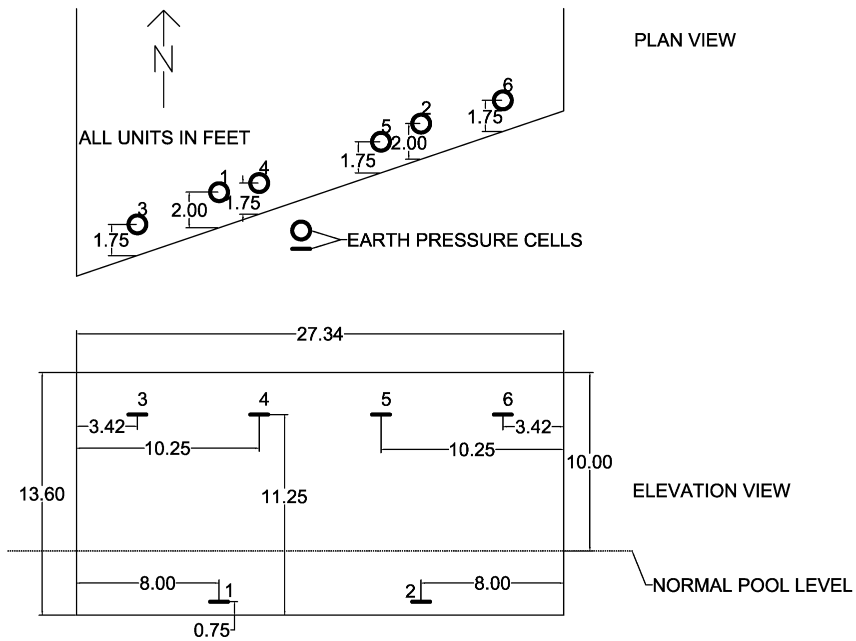


Figure 37. Earth pressure cell locations within north abutment of Rustic Road: plan view (top) and elevation view (bottom)

The two sensors installed near the bottom of the GRS-IBS backfill (EPC-1 and EPC-2) are intended to measure stress resulting from the total weight of the abutment and bridge girders. The four sensors installed in the bridge seat (EPC-3 through EPC-6) are intended to measure the load from the bridge girders. Of particular interest is the response of EPC-3 through EPC-6 during flood events that produce buoyancy forces on the bridge girders.

Vibrating-wire earth pressure cells were used. One of the instruments is shown in Figure 38.

Figure 38. Installation of EPC-1 near bottom of north abutment

The pressure recorded by earth pressure cells is typically somewhat different from the actual total stress within the soil, because the stiffness of the pressure cells is not equal to the stiffness of the soil, resulting in a redistribution of load. Earth pressure measurement difficulties associated with stiffness contrasts can be exacerbated by installation issues. The goal of the installation is to achieve a uniform stress distribution across the plates and above and below the cell. To achieve a uniform distribution, the instruments were installed horizontally and with a thin layer of fine sand above and below the cells. The sand is intended to prevent the uneven distribution that would result from angular pieces of gravel directly in contact with the cells. Installation of EPC-3 through EPC-6 was complicated by GRS-IBS details for the beam seat, which included two 4 in. thick layers of backfill wrapped in geosynthetic. EPC-3 through EPC-6 were installed in the bottom 4 in. thick layer.

One of the most important performance measures for any retaining wall system is how quickly the backfill drains. If the backfill is not freely draining, water pressure will develop on the face of the retaining wall, and pore pressures will reduce backfill shear strength. Measurement of pore pressures, and especially the response of pore pressure with time to water infiltration, is therefore an important indicator of abutment performance. Pore pressure measurement also provides information regarding the state of stress within the abutment backfill, complementing the earth pressure information described above and facilitating calculations of effective stress.

For Rustic Road, ten vibrating wire piezometers were installed to measure pore pressure within the north abutment backfill. The piezometers were distributed as shown in Figure 39 to obtain a representative sampling of the pore pressures throughout the abutment.

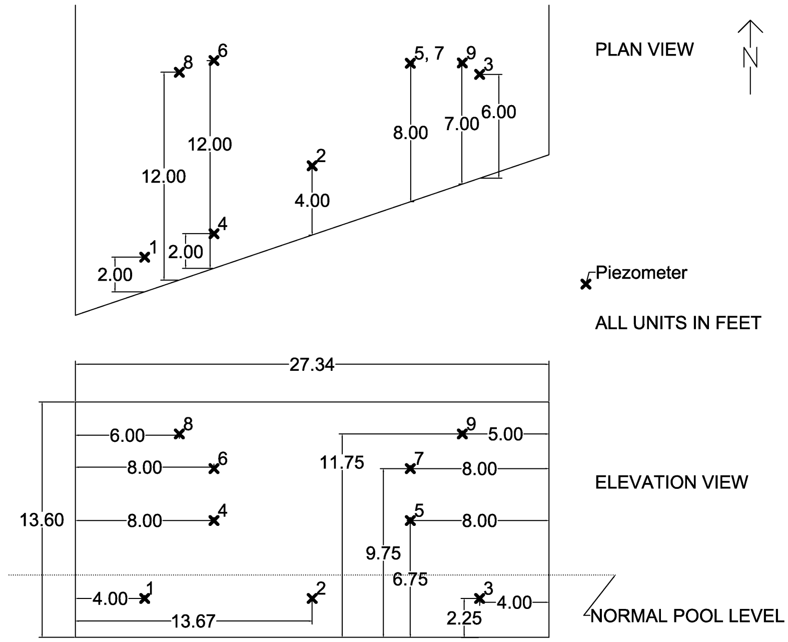


Figure 39: Piezometer locations within north abutment: plan view (top) and elevation view (bottom)

Figure 40 shows a piezometer during installation. The piezometers were installed inside sand pockets within the GRS backfill to stabilize pore pressure measurements.

Figure 40: Piezometer PZ-1: installation in sand pocket within GRS backfill (left) and close-up view of vibrating wire piezometer (right)

Performance

Details of each monitoring system component were summarized in Table 1. During the course of the 19-month monitoring period (March 2015 through September 2016), 15 site visits were conducted, one per month for the first year and every other month thereafter. For each site visit, the research team documented visual observations with notes and photographs, recorded crack gage data, performed inclinometer readings, and collected data that had been logged for the vibrating wire piezometer and earth pressure cells. In addition to research team site visits, the City of Columbia survey crew visited the site every three months during the monitoring period and surveyed the abutment face targets, corners of the bridge, and settlement plate rods.

Visual Observations

Visual observations were documented with each site visit. Most of the observations were consistent with a bridge performing well in its early service life; “No apparent change since last site visit” was a common note. However, three sets of observations are noteworthy: (1) a high water event in early July 2015, (2) potential shifting of the scour protection at the downstream (west) corner of the south abutment, and (3) cracks that developed at the top of all four wing walls. Each set of observations is discussed next.

In late June and early July 2015, a series of rain events in Boone County led to a significant water level increase in the North Fork of Grindstone Creek, as shown in Figure 41.

Figure 41. Rustic Road GRS-IBS during July 2015 high water event: looking upstream from on top the bridge showing creek high up its banks (upper left) and looking at north abutment (right) with close-up view (lower left)

During the site visit several days after rain had stopped, the creek level was observed near the top of the rip rap, approximately 3 ft above the normal level, which is just above the reinforced soil foundation. The water marks on the CMU blocks (shown in Figure 41) indicated that the creek level had been several feet higher. The marks indicate the maximum water level was just below the abutment mid-height.

During a site visit in August 2015, one month after the high water event, a gap was observed between the downstream (west) corner of the south abutment and the rip rap scour protection as shown in Figure 42 (left). No changes in the gap were observed throughout the course of subsequent monitoring (Figure 42 center and right).

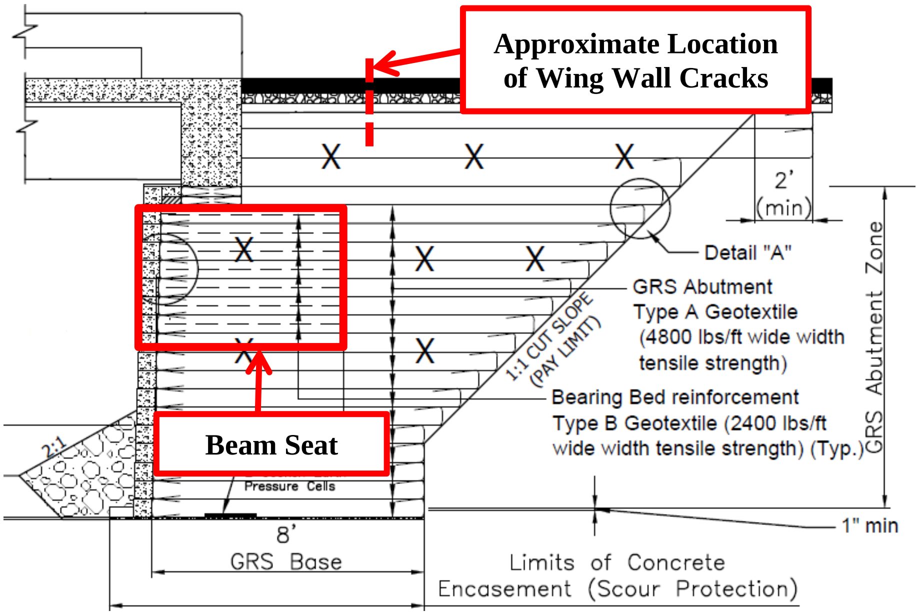
Figure 42: Downstream corner of south abutment: August 31, 2015 (left), February 25, 2016 (center), and September 22, 2016 (right)

It is possible that the gap formed in response to the high water event; it is also possible the gap was present from the first placement of the scour protection in May 2015, since that portion of the scour protection was underwater during the June and July 2015 site visits. Regardless, observations during subsequent site visits did not indicate any growth in the size of the gap nor any significant shifting in the rip rap.

Shortly after construction, cracks were observed in the CMU blocks at the top of each wing wall. All four cracks developed approximately 10 ft back from each abutment corner. The cracks extended from the top of the wing wall down two or three rows of CMU blocks, as shown in Figure 43.

Figure 43. Crack on east wing of north abutment wall

The location of the cracks corresponds to the back end of the beam seat (Figure 44).

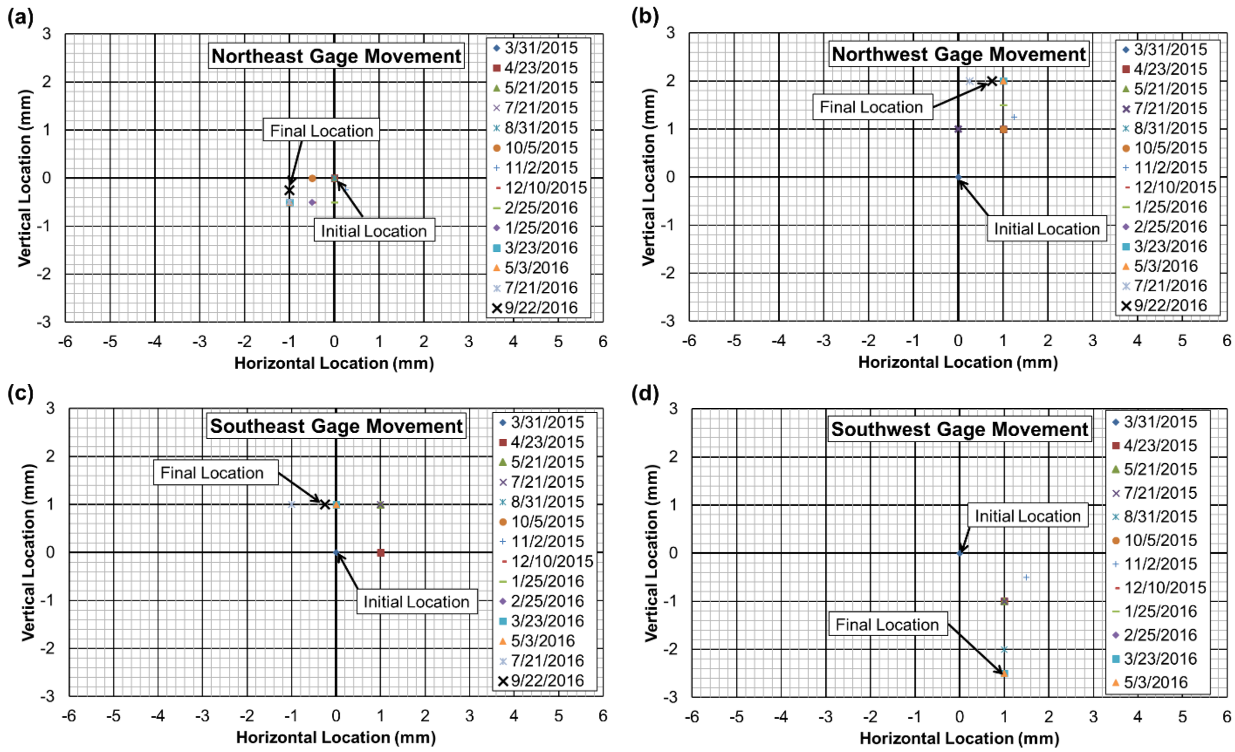


Rustic Road plans, original annotations

Figure 44. Crack location relative to bearing bed showing as-constructed cut slope steeper than 1:1

It is possible that the cracks are related to the stiffness contrast between the beam seat and the surrounding GRS backfill. It is also possible that the cracks are a results of differential settlement associated with the front of the wall bearing directly on rock while the sloping backfill rested on soil, but the constructed cut slope was steeper than 1:1.

As described in the rest of this chapter, the survey data indicated little external movement, and the settlement plate and inclinometer data indicated little internal movement. Crack gage data is shown in Figure 45.



For each gage, initial (installed) and final (September 22, 2016) locations of the gage crosshair

Figure 45. Crack gage data for each wing wall: northeast (top left), northwest (top right), southeast (bottom left), and southwest (bottom right)

Survey Results

Survey results indicated that vertical and lateral movement of both abutment wall faces was negligible during the monitoring period. For both abutments, settlement was less than 0.25 in. for all survey markers on the abutment faces, while survey results for points near the ground surface indicated about 1 in. of settlement. However, the survey data for surface points varied considerably with time, especially compared to the survey markers on the face of the abutments. It is possible that the surface of the bridge did indeed settle about 1 in., but it is more likely 1 in. is within the accuracy of the surface measurements since the bridge corners were not marked with permanent survey markers. The latter possibility is supported by the results of settlement plates, which settled only 0.25 in. If the surface had in fact settled 1 in., additional settlement would be expected for at least the top settlement plate. Settlement plate results are discussed in further detail in the next section.

Lateral movement values were calculated as the Pythagorean sum of changes in northings and eastings, as shown in equation (3):

$$\text{Lateral Movement} = \sqrt{(x - x_0)^2 + (y - y_0)^2}, \quad \textbf{(3)}$$

where x = northing, x_0 = initial northing, y = easting, and y_0 = initial easting.

Lateral movement results followed a trend similar to the one observed for vertical movement: Variable results at the ground surface indicating significantly more movement than was observed for the abutment face markers. For both abutments, lateral movement for survey targets installed on the abutment faces was less than 0.5 in. for all surveys. However, for both abutments, survey results for points near the ground surface indicated as much as 5 in. of lateral displacement, although values were generally between 1.0 and 1.5 in. Variability of the surface data is considerable, likely a result of the survey accuracy for surface points as discussed above, especially since the inclinometer probe data near the surface for both abutments indicated less than 0.2 in. of movement. Inclinometer results are discussed in greater detail in the next section.

Settlement Plate Results

Figure 45 is a plot of settlement plate results based on surveying the settlement plate rods.

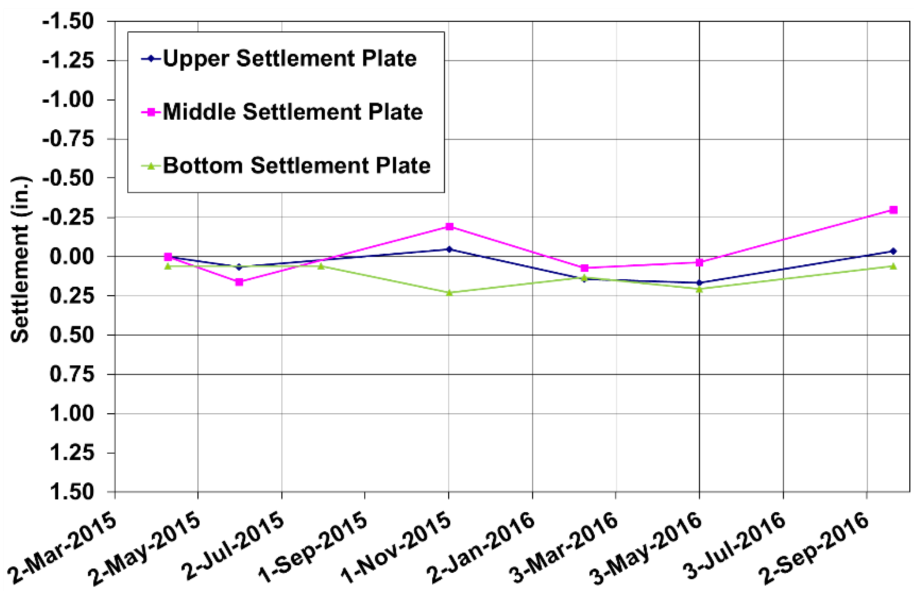


Figure 45. Settlement of settlement plates, as determined by survey results

The data fluctuated between 0.25 in. of settlement and 0.25 in. of upward movement. Based on these results, it is reasonable to conclude there is negligible settlement within the GRS backfill and 0.25 in. is the approximate accuracy of surveying the settlement plate rods. These conclusions are supported not only by the magnitude of settlement values but also by the lack of any trend toward movement in one direction and by inconsistencies between the different plates. For instance, the middle plate indicated upward movement while the bottom plate indicated settlement, and the upper settlement plate was moving less than either of the other plates.

Inclinometer Results

Internal lateral deflection results interpreted from the inclinometer probe for the north and south abutments are shown in Figure 46. The data represents the change in casing shape relative to the installed shape; all data indicates negligible movement.

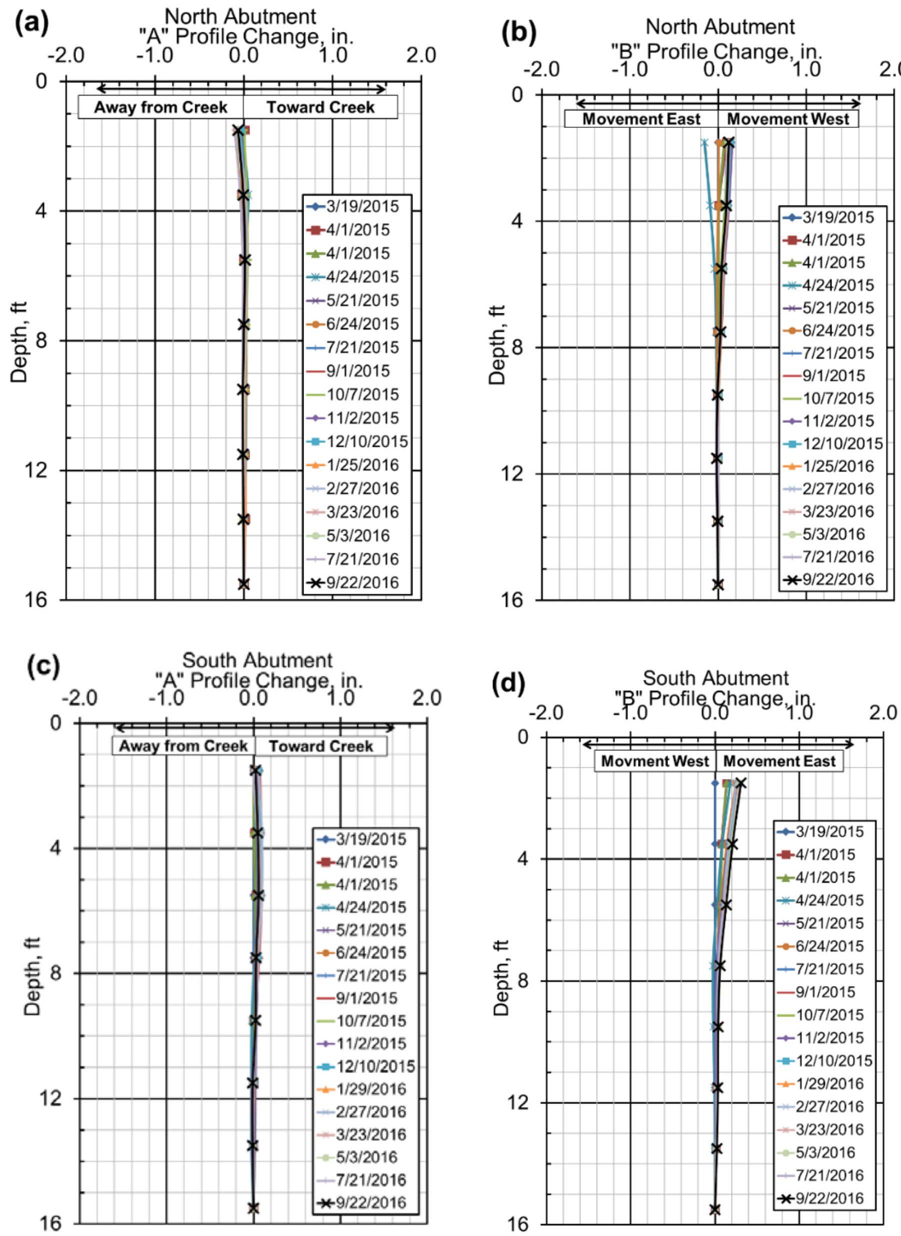
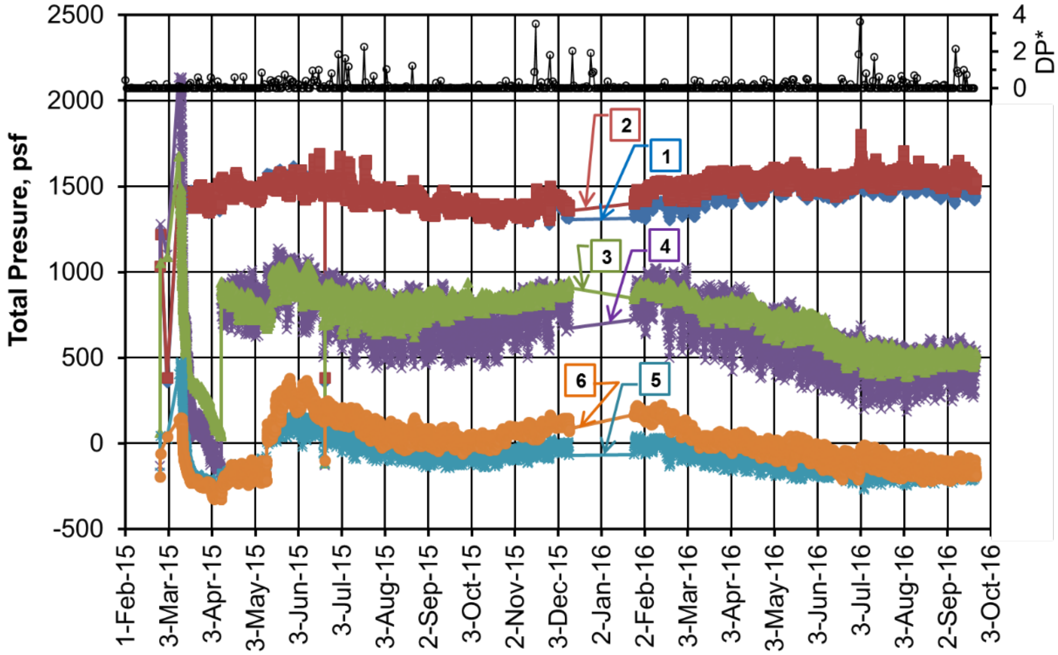


Figure 46. Inclinometer results: north abutment change in casing profile in direction toward creek (top left), north abutment change in casing profile in east-west direction (top right), south abutment change in casing profile in creek direction (bottom left), and south abutment change in casing profile in east-west direction (bottom right)

The left two plots show the change in casing shape in a plane perpendicular to the creek (i.e., parallel to the centerline of the roadway); the right two plots show the change in casing shape in a plane parallel to the creek (i.e., perpendicular to the centerline of the roadway). The results of Figure 46 indicated that the lateral deflection that occured during the monitoring period was negligible. For the north abutment, the casing shape did not change significantly throughout the monitoring period; the greatest change in profile occurred at the top of the casing and was less than 0.2 in. Similar results were obtained for the south abutment. The greatest change in profile for the south abutment casing also occurred at the top of casing and was less than 0.4 in.

Earth Pressure Cell Results

Total stresses from the earth pressure cells throughout the monitoring period are plotted in Figure 47.



DP = Daily precipitation in inches, based on average of three nearby weather stations

Figure 47. Daily precipitation and earth pressures (total stresses) in north abutment from vibrating wire earth pressure cells

Cells EPC-1 and EPC-2 were installed near the bottom of the abutment backfill; each of the other cells were installed beneath one of the bridge girders (see Figure 37). The earth pressure results were corrected for the effect of temperature using the observed pressure-temperature slopes based on internal thermistor data. For more information, see Boeckmann et al. (2016).

The results have been corrected for temperature effects by using the slopes of the pressure-temperature data for each instrument (each earth pressure cell contains an internal thermistor). Uncorrected earth pressure cell results and additional information regarding the temperature corrections are included in Boeckmann et al. 2016. After removing temperature effects, the observed total stresses from all six cells are all relatively constant during the monitoring period, except for a gradual decrease in EPC-3 and EPC-4 during the last six months of monitoring. Other observations regarding the earth pressure data are noteworthy:

- Earth pressure measurements were not strongly influenced by precipitation events. As noted in the visual observations section previously, the creek level was never high enough to result in buoyancy forces on the bridge girders.

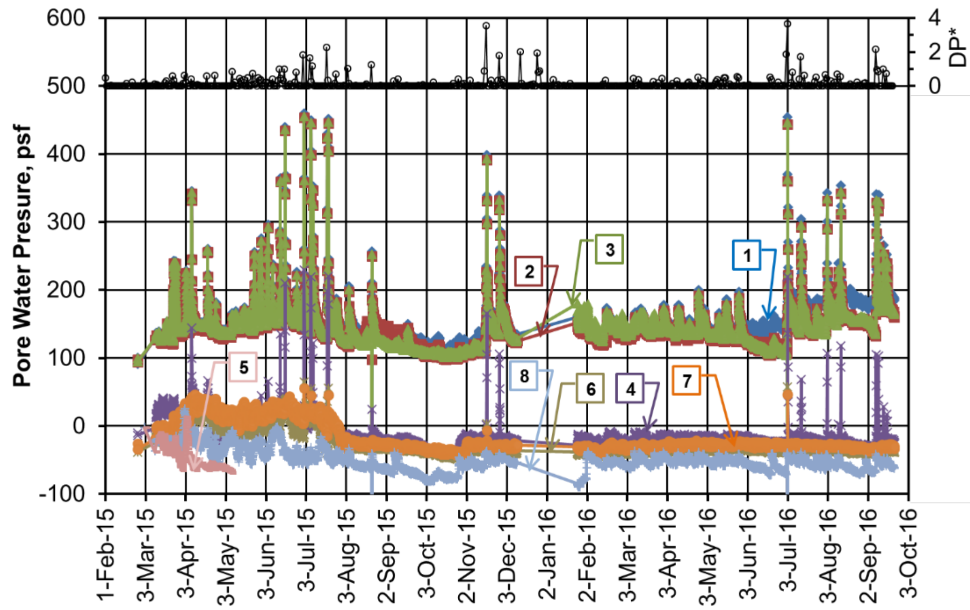
- Two sudden increases and one sudden decrease in earth pressure were observed for EPC-3 and EPC-4 in the first two months of operation. It is difficult to explain the cause of the sudden changes. The stresses in EPC-3 and EPC-4 are approximately 1000 psf greater than those in EPC-5 and EPC-6 (both before and after the changes).

- EPC-3 through EPC-6 are each loaded by the weight of half of one of the bridge girders, which corresponds to a stress of approximately 1200 psf. After correcting for temperature effects, the observed stresses in EPC-3 through EPC-6 were all lower than the anticipated stress from the weight of the girders, although EPC-3 and EPC-4 measured stresses of approximately 800 psf.

- After accounting for the effect of temperature, the pressure recorded in EPC-1 and EPC-2 was greater than the pressure recorded in EPC-3 through EPC-6. This is consistent with the anticipated stress profile within the abutment: EPC-1 and EPC-2 should be subjected to loading from the weight of the girders as well as the weight of the overlying GRS abutment. Boeckmann et al. (2016) considered the effect of stress distribution with depth for the girder weight and concluded that EPC-1 and EPC-2 indicated lower-than-anticipated stresses, similar to the observations for EPC-3 through EPC-6.

Piezometer Results

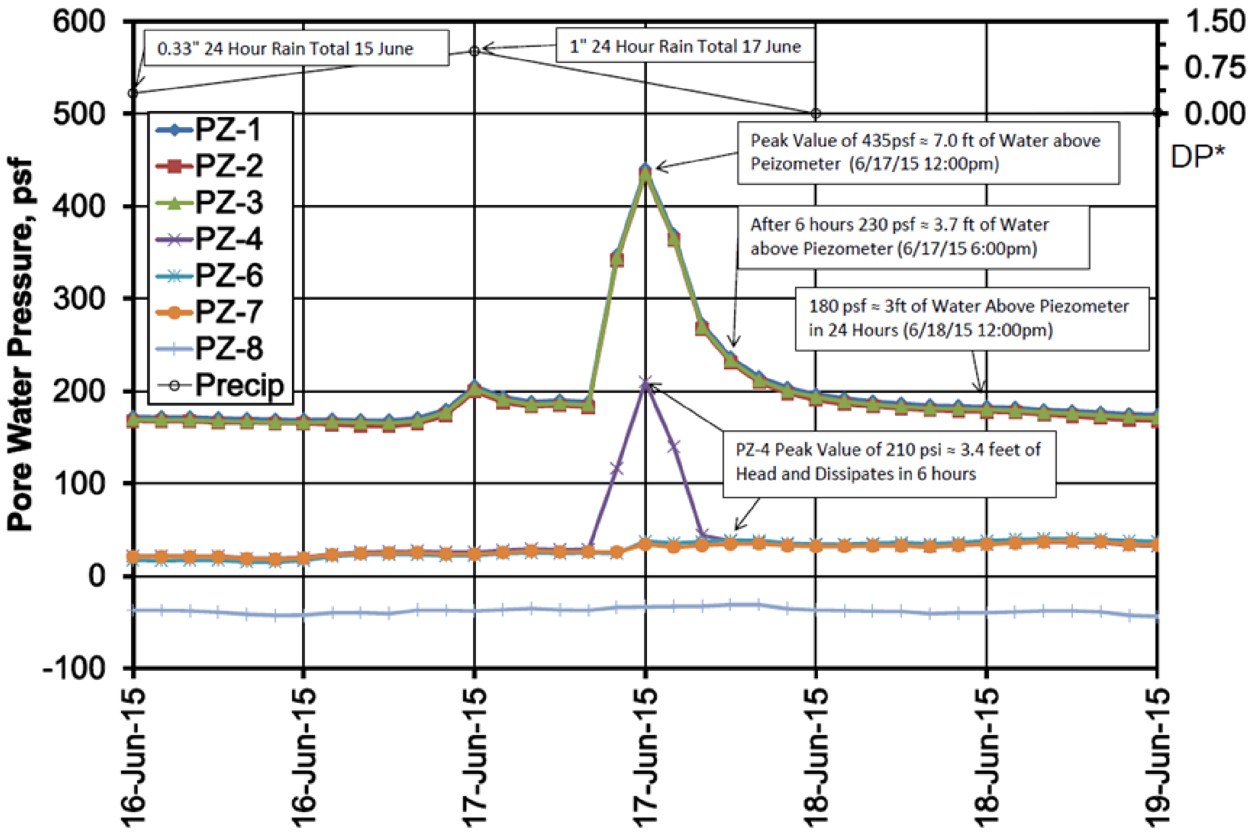
Pore water pressure results from the vibrating wire piezometers are plotted in Figure 48. For instrument locations, refer to Figure 39.



DP = Daily precipitation in inches, based on average of three nearby weather stations

Figure 48. Daily precipitation and pore water pressures in north abutment from vibrating wire piezometers during monitoring period

The signal for one of the piezometers, PZ-5, became unstable about two months after the end of construction. The observed pore pressures were mostly consistent with time, but several locations showed peaks that appear to be in response to precipitation events. The peaks dissipated quickly. To examine the drainage more quickly, pore pressure data during one precipitation event was plotted in Figure 49. Indeed, the pore pressures generated in response to the precipitation event dissipate within six hours of the event.



DP = Daily Precipitation, in.

Figure 49. Close examination of change in pore pressures during one precipitation event

The measured pore pressures appeared to mostly be a function of the vertical location of the piezometer within the backfill. (Locations of the piezometers were shown in Figure 39.) PZ-1 through PZ-3 are located near the bottom of the abutment, approximately at the normal creek water elevation. These instruments typically recorded pore pressures of approximately 100 psf, a relatively small value corresponding to about 1.6 ft of water. The other piezometers were located above the normal creek water level and, as expected, recorded pore pressures around zero. The responses to rain events were also influenced by instrument height, with PZ-1 through PZ-3 showing strong responses to precipitation events, PZ-4 (6 ft above the bottom of the abutment) showing less strong and less frequent responses, and PZ-7 (9 ft above the bottom of the abutment) responding slightly to one precipitation event.

Summary

Design of the bridge replacement was completed largely in accordance with the FHWA *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (Adams et al. 2012). As another innovative design measure, the superstructure consists of four tub girders with attached precast bridge deck sections (as previously shown in Figure 6). The girders were placed in one day. To counter buoyancy forces on the tub girders, each girder was anchored to plates embedded in the GRS.

The first letting of Rustic Road GRS-IBS produced a single bid that was significantly greater than the engineer's estimate. The overwhelming cause of the overage was cost of the GRS abutments, which came in nearly 150 percent greater than the engineer's estimate. The bid was rejected. Prior to a second letting, the county revised the bid documents to allow a more flexible construction calendar and to improve constructability of the GRS-IBS plans. The county also actively advertised the project to potential contractors and held a pre-bid meeting with potential contractors to present information on GRS-IBS construction. The meeting, and also a SHRP2 GRS-IBS showcase, featured a FHWA expert on GRS-IBS. The second letting resulted in four bids; the lowest bid was still greater than the engineer's estimate but significantly less than the first round of bidding. The GRS portion of the low bid was only 10 percent greater than the engineer's estimate.

During the SHRP2 showcase, a local contractor offered an informative hypothesis for high GRS-IBS bids. He noted that small bridges like those for which the GRS-IBS is typically applied are mostly built by contractors without MSE experience, and that MSE walls are often built by contractors without experience building bridges. Large contractors experienced with both bridge and MSE construction are unlikely to bid on a contract for a single, small bridge (i.e., GRS-IBS). As a result, the pool of potential bidders for GRS-IBS projects is composed of contractors who are unfamiliar with at least part of the GRS-IBS construction process. This unfamiliarity likely increases bid prices.

The construction progress was documented with the images captured and shown in Figures 7–34 and generally followed the sequence and procedures outlined in the FHWA *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (Adams et al. 2012), with a few deviations. Limestone bedrock was encountered at depths shallower than anticipated, requiring excavation via a rock chipping hammer (see Figures 7 and 8) to achieve adequate abutment embedment. The construction crew experienced difficulty with the facing blocks creeping outward during vibratory compaction. To reduce the displacement, the crew clamped lumber to the reinforcement extending out in front of the wall from just beneath the course being compacted (see Figures 20 and 21).

During an interview after completion of Rustic Road GRS-IBS, the contractor indicated that the movement of the blocks during compaction was the most significant challenge of the project. The skew of Rustic Road presented another significant challenge, partly by exacerbating the facing block sliding problem and partly by complicating alignment of the facing blocks at the corners. Leveling the blocks at the limestone base of the wall was also difficult. A final significant challenge was winter weather, which several times resulted in snow cover and freezing of the aggregate stockpile. The contractor's project manager stated the company would likely increase its unit prices for construction of another GRS-IBS, primarily to account for time with the small modular block wall facing.

Monitoring activities during the 19 month monitoring period included visual observations and land surveying as well as measurements from settlement plates, inclinometers, earth pressure cells, and piezometers. Visual observations included documentation of a significant high water event, some potential shifting of scour protection that was deemed minor, and cracks that developed at the top of each wing wall. The cracks were monitored with crack gages, which all indicated limited further movement after the initial observation. Land surveying results indicated that external movement of the survey targets on the abutment wall faces was negligible during the monitoring period. Internal movement of the GRS backfill was also negligible, as measured via settlement plates and inclinometers. The response of earth pressure cells appears to be dominated by temperature effects, but the measured pressures are otherwise reasonable and were not strongly influenced by precipitation events. Piezometers indicated that pore pressures near the bottom of the GRS backfill spiked during precipitation events but dissipated within six hours.

SUMMARY AND CONCLUSIONS

A review of the technical literature, interviews with agency and contractor personnel, and a detailed examination of the Rustic Road GRS-IBS project from design through early service life, revealed many valuable conclusions that could advance implementation of GRS-IBS technology. The conclusions below are organized into three categories: technical and performance observations, construction insights, and lessons learned. A standalone Implementation Aid document is loosely organized under these headings as well and contains similar information.

Technical and Performance Observations

The case histories reviewed largely confirm the information contained in the FHWA *Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide* (Adams et al. 2012) and *Composite Behavior of Geosynthetic Reinforced Soil Mass* report (Wu et al. 2013). No major problems were reported for any of the GRS-IBS case histories reviewed. Reported values of settlement were all negligible, and no "bump at the end of the bridge" was observed for any of the GRS-IBS. Cracking of CMU blocks used for wall facing appeared to be common, but in all reported cases the cracks were considered mainly an aesthetic problem since the facing is not a structural element.

- Performance of Rustic Road GRS-IBS in Boone County, Missouri was monitored closely for 19 months after construction, with regular visual observations, land surveys, and measurements from telltales, inclinometers, earth pressure cells, and piezometers. The Rustic Road GRS-IBS performed as intended: external and internal displacements were negligible and the backfill was typically dry and drained quickly after precipitation events. Cracking of some CMU wall facing blocks was observed atop the wing walls shortly after construction, but the cracks did not expand in the ensuing 19 months. The project site has experienced water levels that approached the bottom of the bridge girders.

- Other reports of good performance included several bridges built using GRS-IBS technology that were subjected to inundation. PennDOT reported surveying two such bridges, and no significant displacement was observed for either of them. The Rustic Road GRS-IBS was also subjected to partial inundation.

- A Defiance County, Ohio field study (Warren et al. 2014) found that GRS-IBS provided flexible end constraints for thermal stresses. This was noted as advantageous compared to conventional integrated abutments, for which thermal stresses can build up with time.

GRS-IBS Construction Insights

Interviews with agency and contractor personnel provided several important insights regarding the construction of GRS-IBS:

- All of the agencies and contractors interviewed agreed that FHWA guidance regarding construction of GRS-IBS, including the number of personnel and recommended equipment, was generally accurate, although some project-specific considerations required deviations from the guidance.

- For cost and schedule success, it is important contractors find a “rhythm” to the GRS-IBS construction procedure. The rhythm is associated with the repetitive nature of constructing bridge abutments with thin (typically 8 in.) lifts.

- The majority of GRS-IBS had been constructed with open-graded backfill, which is generally compacted in accordance with method specifications requiring a certain number of passes with a vibratory compactor. One project completed with well-graded backfill reported difficulty satisfying performance specification criteria (95 percent of maximum dry density) using a vibratory compactor similar to those typically used for the open-graded backfill. To satisfy the requirements, the contractor switched to heavier equipment and wetting the well-graded backfill.

- Congested project sites present challenges for most construction projects, but they can be particularly problematic for GRS-IBS projects, which require space for a large volume of backfill and facing materials.

- Based on the experience of the Rustic Road GRS-IBS contractor, working with the modular wall facing blocks for this bridge design was likely the most significant challenge of their GRS-IBS construction learning curve. The facing blocks can be difficult to level (especially for bottom rows on rock foundations), to align (especially at skewed corners), and to stabilize (especially during vibratory compaction). Other MoDOT projects used wet-cast blocks, which are generally larger and more durable than the dry-cast blocks used on Rustic Road. However, the contractors reported difficulty handling and leveling the heavy wet-cast blocks and stated dry-cast would have been preferable. Other GRS-IBS projects have avoided facing blocks altogether. For example, a project in Buchanan County, Iowa used a sloped abutment with grouted rip-rap facing (Vennapusa et al. 2012).

Cost Savings and Implementation Lessons Learned

Interviews with agency and contractor personnel also resulted in important insights regarding cost and implementation of the GRS-IBS:

- Several agencies reported that the technology is a useful tool for achieving cost savings and schedule efficiency, especially for bridge replacements on low-volume roads.

- Several agencies reported that prices decreased with the number of applications as engineers and contractors became more familiar with the technology.

- The cost savings and simplicity of construction operations make the technology particularly well suited for local agencies, which also generally own a relatively high proportion of small bridges. The embrace of GRS-IBS by Defiance County, Ohio is evidence of the value of the technology for local agencies. Furthermore, achieving widespread implementation will require participation by local agencies. Experience with GRS-IBS in Pennsylvania indicates that promotion by state transportation agencies can accelerate implementation.

- Specifying GRS-IBS backfill that is readily available locally was reported to be important for achieving cost savings.

- Several important lessons were encountered during bidding and construction of the Rustic Road GRS-IBS:

    - Allowing a flexible construction calendar can improve bid competition. Some contractors are unlikely to bid if construction must be completed during a limited time window. The effect of such restrictions is likely worse for small bridges, which have smaller payoffs than other potential contractor projects.

    - Actively educating contractors about GRS-IBS construction procedures through pre-bid meetings and open "showcase" events can improve bid competition and lower bid prices.

    - As a relatively new technology, GRS-IBS will likely be associated with a "learning curve" for contractors. As observed by one local contractor, the learning curve might be especially steep for small contractors that have construction experience with either bridges or MSE walls, but not both types of construction. Bid prices will likely be greater than engineer's estimates until contractors have mastered the learning curve.

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