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Geosynthetic reinforced soil (GRS) technology consists of closely-spaced layers of geosynthetic reinforcement and compacted granular fill material for supporting bridge abutments on low-volume roads. This method is being presented as a potential alternative to conventional concrete bridge abutments. GRS bridge abutments have been proven to cut both the time and cost of bridge construction by at least 50% compared to traditional abutments. The technology has been used to build over 50 bridges since its implementation in 2005. The purpose of this project was to develop a Pennsylvania-specific specification for PennDOT Publication 447, “Approved Products for Low-Volume Roads,” so that municipalities in Pennsylvania can begin to implement this technology.
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1. **Executive Summary**

**Overview:** Geosynthetic reinforced soil (GRS) technology consists of closely-spaced layers of geosynthetic reinforcement and compacted granular fill material for supporting bridge abutments on low-volume roads. This method is being presented as a potential alternative to conventional concrete bridge abutments. GRS bridge abutments have been proven to cut both the time and cost of bridge construction by at least 50% compared to traditional abutments. The technology has been used to build over 50 bridges since its implementation in 2005. The purpose of this project was to develop a Pennsylvania-specific specification for PennDOT Publication 447, “Approved Products for Low-Volume Roads,” so that municipalities in Pennsylvania can begin to implement this technology.

**Literature and Testing Review:** As part of the background research for development of this specification, an extensive literature review was conducted. The literature review focused on existing bridges and the monitoring data that has been recorded to date. Settlement has been monitored at several bridges in Ohio, Pennsylvania, and Iowa. Settlement data on these bridges, even when projected out to 100 years, was well within accepted tolerances. In addition to the literature review, several experts were consulted in the development of the specification. This included a visit to Defiance County, Ohio, where more than 25 GRS-IBS bridges have been constructed; a visit to the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center to meet with several of the authors of the GRS-IBS Implementation Guide; and continual collaboration with the PennDOT Bureau of Municipal Services.

**Specification Development for PennDOT Publication 447:** The goal in developing the GRS specification for Publication 447 was to keep the actual specification as simple as possible while making reference to the best available resources that exist. The standard resource for GRS-IBS bridges is a publication by the FHWA titled *GRS-IBS Interim Implementation Guide* (FHWA-HRT-11-026). The Pennsylvania specification was written in reference to the FHWA implementation guide. The purpose of developing this Pennsylvania specification was to: incorporate PennDOT materials and terminology into the GRS-IBS process; more clearly define materials and processes specifically for use in Pennsylvania; and create a brief and user-friendly specification with the end user, municipalities, in mind. The end result is a specification that, with reference to the FHWA implementation guide and in conjunction with sound engineering, can be used by municipalities in Pennsylvania to begin implementing GRS-IBS technology on local roads when site conditions allow.
2. **Literature Review and Case Studies / Testing**

2.1 **Introduction**

As defined by the Federal Highway Administration, Geosynthetic reinforced soil technology consists of closely-spaced layers of geosynthetic reinforcement and compacted granular fill material for supporting bridge abutments on low-volume roads. GRS-IBS is a fast, cost-effective method of bridge support that integrates the roadway and bridge superstructure to create a jointless interface between the two surfaces (Figure 1). It consists of three main components: the reinforced soil foundation (RSF), the abutment, and the integrated approach. The RSF is composed of granular fill material that is compacted and encapsulated with a geotextile fabric. It provides embedment and increases the bearing width and capacity of the GRS abutment. It also prevents water from infiltrating underneath and into the GRS mass from a river or stream crossing. This method of using geosynthetic fabrics to reinforce foundations is a proven alternative to deep foundations on loose granular soils, soft fine-grained soils, and soft organic soils. The abutment uses alternating layers of compacted fill and closely spaced geosynthetic reinforcement to provide support for the bridge, which is placed directly on the GRS abutment without a joint and without cast-in-place (CIP) concrete. GRS is also used to construct the integrated approach to transition to the superstructure that allows for a smooth changeover from the roadway to bridge surface. The use of GRS-IBS in Pennsylvania must consider site-specific factors such as appropriate soil pH, stream velocities, scour potential and other factors detailed in Section II of the attached GRS-IBS specification.

![Figure 1. Typical GRS-IBS cross section.](image)

2.2 **Advantages of GRS**

GRS bridges have several advantages over conventional reinforced concrete:

- GRS abutments are more flexible, hence more tolerant to foundation settlement.
• When properly designed and constructed, GRS abutments are remarkably stable and also have higher ductility (i.e., are less likely to experience a sudden catastrophic collapse) than conventional reinforced concrete abutments.

• When properly designed and constructed, GRS abutments can alleviate differential settlement between the bridge and the approach roadway, thus reducing "the bump at the end of the bridge" problem.

• GRS abutments do not require embedment into the foundation soil for stability. This advantage is especially important when an environmental problem such as excavation into previously contaminated soil is involved. Some soil conditions, such as low soil pH (acidity), can deteriorate geosynthetics. Varying environmental conditions should be considered when using geosynthetics.

• The lateral earth pressure behind a GRS abutment wall is much smaller than that in a conventional reinforced concrete abutment.

• Construction of GRS abutments is rapid and requires only "ordinary" construction equipment and workers with moderate construction skills.

• GRS abutments are generally much less expensive to construct than their conventional counterparts.

2.3 National GRS Guidelines

The FHWA has established national guidelines for the construction of GRS-IBS bridges. These guidelines are as follows: (1)

• Vertical height of less than 30 feet.
• Maximum span length of 140 feet.
• Reinforcement layer spacing less than 12 inches.
• FHWA policy that the AASHTO Load and Resistance Factor Design methodology be conducted for all projects receiving Federal aid.
• Depth of excavation for the RSF:
  o One-quarter of the total width of the base of the GRS abutment including the block face.
  o Engineer design recommendations may require deeper excavations.
• Scour potential:
  o FHWA Hydraulic Engineering Circulars, (HEC) 23 – for smaller, more culvert-like structures where flow length through the structure is longer than the structure width.
  o FHWA Hydraulic Engineering Circulars, HEC 18 and 20 – for more bridge-like structures where the opening length is greater than the flow distance through the structure.

2.4 Case Studies

As of 2010, 45 bridges utilizing GRS abutments had been built in the United States. Of these bridges, IBS had been employed on 28 bridges, all built over water crossings.(1) The hydraulic environments at these locations is such that scour is shallow, making the system
feasible for these sites. For the purposes of this literature review and testing summary, several case studies are highlighted.

### 2.4.1 Defiance County, Ohio (4 & 5)

From 2005-2011, Defiance County, located in northeastern Ohio, completed 26 GRS-IBS projects at a cost of $3,513,484. Of these completed projects, 15 were built entirely with a county crew, seven structures with abutments were built by the county with the superstructure by a contractor, and three structures were built entirely by a contractor. Although initially the cost of construction was similar to traditional deep-foundation bridges, current construction is generally half the cost or less, while construction time is twice as fast with a standard abutment construction time of 3 days. A variety of superstructure types have been utilized in the construction of the GRS-IBS bridges. These include adjacent pre-stressed box beams with waterproofing and overlay, adjacent and spread pre-stressed box beams with composite concrete deck, steel beams with composite concrete deck, cast in place slabs, and fiberglass box beams. Note that fiberglass beams or adjacent pre-stressed box beams without a composite deck are not permitted on projects with state funding in Pennsylvania.

Of the 26 completed GRS-IBS bridges, 5 have current monitoring to measure vertical and lateral deformations. These bridges were built between 2005 and 2009 and have been monitored for a minimum of 1.5 years to 3.2 years. A summary of these five bridges is included in Table 1.

#### Table 1. Defiance County, Ohio bridge information summary.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Date Built</th>
<th>Abutment</th>
<th>Abutment Height (ft)</th>
<th>Dead Load (kips/ft²)</th>
<th>Span Length (COB to COB) (ft)</th>
<th>Width of Bridge (ft)</th>
<th>Monitoring Length (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vine Street</td>
<td>October 2006</td>
<td>North</td>
<td>12.36</td>
<td>2.37</td>
<td>50.0</td>
<td>32.67</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>10.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glenburg Road</td>
<td>May 2006</td>
<td>North</td>
<td>13.22</td>
<td>4.53</td>
<td>30.6</td>
<td>28</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>12.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huber Road</td>
<td>August 2007</td>
<td>North</td>
<td>17.3</td>
<td>1.53</td>
<td>28.0</td>
<td>28</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>16.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bowman Road</td>
<td>October 2005</td>
<td>East</td>
<td>16.91</td>
<td>3.46</td>
<td>79.0</td>
<td>34</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>West</td>
<td>16.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tiffin River</td>
<td>July 2009</td>
<td>North</td>
<td>20.52</td>
<td>3.69</td>
<td>134.0</td>
<td>36</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

COB = Center of bearing.

Vertical deformation was measured for each of the bridges using either the standard survey level and rod system or an electronic distance measurement (EDM) survey referenced off a permanent survey pole and benchmarks. Table 2 provides a summary of the vertical movement for each bridge. Over the various monitoring periods for each bridge, the maximum bridge differential settlement was 0.033 ft at the Tiffin River Bridge. The average total settlement ranged from -0.175 to -0.004 ft and the average GRS settlement ranged from 0.015 to 0.106 ft (Table 3).
### Table 2. Defiance County movement information summary.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Abutment</th>
<th>Abutment Height (ft)</th>
<th>Abutment Differential Settlement ($\Delta S_{abut}$) (ft)</th>
<th>Uniformity of Abutment Settlement ($\Delta S_{abut}$/width of bridge)</th>
<th>Bridge Differential Settlement ($\Delta S$) (ft)</th>
<th>Angular Distortion ($\Delta S$/span length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vine Street</td>
<td>North</td>
<td>12.36</td>
<td>0.024</td>
<td>0.0007</td>
<td>0.009</td>
<td>0.00018</td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>10.36</td>
<td>0.015</td>
<td>0.0005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glenburg Road</td>
<td>North</td>
<td>13.22</td>
<td>0.02</td>
<td>0.0006</td>
<td>0.012</td>
<td>0.00039</td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>12.8</td>
<td>0.008</td>
<td>0.0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huber Road</td>
<td>North</td>
<td>17.3</td>
<td>0.011</td>
<td>0.0004</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>16.16</td>
<td>0.021</td>
<td>0.0008</td>
<td>0.01</td>
<td>0.00036</td>
</tr>
<tr>
<td>Bowman Road</td>
<td>East</td>
<td>16.91</td>
<td>0.022</td>
<td>0.0007</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>16.47</td>
<td>0.003</td>
<td>0.0001</td>
<td>0.019</td>
<td>0.00024</td>
</tr>
<tr>
<td>Tiffin River</td>
<td>North</td>
<td>20.52</td>
<td>0.003</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>18</td>
<td>0.005</td>
<td>0.0003</td>
<td>0.033</td>
<td>0.00025</td>
</tr>
</tbody>
</table>

### Table 3. Defiance County vertical settlement and strain information summary.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Average Abutment Height (ft)</th>
<th>Average Total Settlement (ft)</th>
<th>Average Total Vertical Strain (percent)</th>
<th>Average GRS Settlement (ft)</th>
<th>Average GRS Vertical Strain (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vine Street</td>
<td>11.36</td>
<td>-0.035</td>
<td>0.31</td>
<td>0.023</td>
<td>0.2</td>
</tr>
<tr>
<td>Glenburg Road</td>
<td>13.01</td>
<td>-0.107</td>
<td>0.82</td>
<td>0.083</td>
<td>0.64</td>
</tr>
<tr>
<td>Huber Road</td>
<td>16.73</td>
<td>-0.004</td>
<td>0.24</td>
<td>0.015</td>
<td>0.09</td>
</tr>
<tr>
<td>Bowman Road</td>
<td>16.69</td>
<td>-0.07</td>
<td>0.42</td>
<td>0.047</td>
<td>0.28</td>
</tr>
<tr>
<td>Tiffin River</td>
<td>19.26</td>
<td>-0.175</td>
<td>0.91</td>
<td>0.106</td>
<td>0.55</td>
</tr>
</tbody>
</table>

A log-time scale was used to forecast long-term settlement for Bowman Road Bridge over its expected service life (100 years). The average predicted creep settlement was calculated at 0.09 ft for the bridge and 0.035 ft for the abutment walls. The GRS abutment creep distance, 0.055 ft, was defined as the difference between the two average predicted creep settlement values.

Due to difficulties in obtaining accurate long-term measurements and the fact that GRS walls and abutments have performed as expected, theoretical calculations to determine lateral deformation are commonly used. Lateral deformation testing was performed on the Tiffin River Bridge. The results of theoretical calculations that determine the lateral deformation and strain based on an assumption of a zero loss of volume are shown in Table 4. For the Tiffin River Bridge, the theoretical calculations had only an error of ±0.005 ft when compared to the measured lateral deformation.
Table 4. Defiance County predicted lateral deformations summary.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Average Abutment Height H (ft)</th>
<th>Width of Bridge Bearing Area + Setback b + ab (ft)</th>
<th>Average GRS Mass Settlement Dv (ft)</th>
<th>Calculated Lateral Deformation DL = (2(b + ab)*Dv)/H (ft)</th>
<th>Calculated Lateral Strain eL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vine Street</td>
<td>11.36</td>
<td>2.64</td>
<td>0.023</td>
<td>0.011</td>
<td>0.004</td>
</tr>
<tr>
<td>Glenburg Road</td>
<td>13.01</td>
<td>2.14</td>
<td>0.083</td>
<td>0.027</td>
<td>0.013</td>
</tr>
<tr>
<td>Huber Road</td>
<td>16.73</td>
<td>2.64</td>
<td>0.015</td>
<td>0.005</td>
<td>0.002</td>
</tr>
<tr>
<td>Bowman Road</td>
<td>16.69</td>
<td>3.64</td>
<td>0.047</td>
<td>0.02</td>
<td>0.005</td>
</tr>
<tr>
<td>Tiffin River</td>
<td>19.26</td>
<td>5.14</td>
<td>0.089</td>
<td>0.047</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Thermal cycles based on daily temperature fluctuations can affect the expansion and contraction of a bridge. Through the monitoring of in-service GRS-IBS bridges with spans up to 140 feet, thermal cycles do not affect bridge performance. GRS-IBS bridges are designed to minimize thermal cycle-related movement through the integrated transition behind the beam ends.

The 140-ft Tiffin River Bridge has been monitored since its construction. Through daily and seasonal thermal cycles, the average lateral earth pressure changed in magnitude. Although the monitoring after one thermal cycle indicated that the lateral pressure is nonlinear with temperature and displays hysteretic behavior, additional monitoring is being carried out to determine the effect of multiple thermal cycles.

2.4.2 FHWA's Turner-Fairbank Highway Research Center

FHWA’s Turner-Fairbank Highway Research Center (TFHRC) performed a 12-year settlement study of a GRS-IBS abutment. A tunnel was constructed within the abutment to serve as a monitoring point. This tunnel had an overburden (3,800 lb/ft²) equivalent to a typical bridge load. The abutment and embankment sides had differing reinforcement strengths of 4,800 lb/ft geotextile and 2,100 lb/ft geotextile, respectively. Even with these differences, settlement measurements indicated that the settlement difference was nearly identical, with a difference of about 0.0024 ft. A log-time scale plot predicted a vertical deformation settlement after 100 years at 0.033 ft on the abutment side and 0.030 ft on the embankment side.

Short-term testing was completed on five concrete box beam GRS bridges. The Cecil Creek, Big Lake, and Cut Off Creek bridges are typically submerged under water for 6 months per year. After 147 days of testing, the settlement performance of these bridges was well within acceptable criteria. The average total settlement ranged from -0.098 to 0.078 ft (Table 5).
### Table 5. Turner-Fairbank concrete box beam bridge settlement information summary.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Date Built</th>
<th>Bridge Span (ft)</th>
<th>Abutment</th>
<th>Average Total Settlement (ft)</th>
<th>Differential Settlement (ft)</th>
<th>Uniformity of Abutment Settlement ($\Delta S_{abut}$/ width of bridge)</th>
<th>Angular Distortion ($\Delta S$/ span length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Mamie</td>
<td>Fall 2000</td>
<td>67</td>
<td>Both</td>
<td>-0.013</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>at 3 days</td>
<td>No data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twin Lake</td>
<td>Fall 2000</td>
<td>71</td>
<td>Both</td>
<td>-0.021</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>at 6 days</td>
<td>No data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cecil Creek</td>
<td>June 2005</td>
<td>76</td>
<td>A</td>
<td>-0.098</td>
<td>0.013</td>
<td>0.0007</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>-0.02</td>
<td>0.002</td>
<td>0.0001</td>
<td>0.002</td>
</tr>
<tr>
<td>Big Lake</td>
<td>June 2005</td>
<td>76</td>
<td>A</td>
<td>0.007</td>
<td>0.040</td>
<td>0.002</td>
<td>0.0005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>-0.029</td>
<td>0.075</td>
<td>0.004</td>
<td>0.0005</td>
</tr>
<tr>
<td>Cut Off Creek</td>
<td>June 2005</td>
<td>76</td>
<td>A</td>
<td>0.078</td>
<td>0.050</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>0.072</td>
<td>0.001</td>
<td>0.0006</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

#### 2.4.3 Mt. Pleasant Road Bridge in Huston Township, Clearfield County, Pa. (6 & 7)

The Mount Pleasant Road bridge in Huston Township, Clearfield County, Pa. was completed in late 2011 at a cost of $101,893.91. Due to the fact that the bridge was in poor shape and along a school bus route, construction time had to be kept to a minimum. Through the implementation of GRS-IBS, the entire project took just 36 days to complete.

The construction details of the Mount Pleasant Road bridge are as follows:

- Depth of footing = 4 ft
- Materials used: timber superstructure, concrete blocks, geotextile, 2RC and AASHTO #8 coarse aggregate, riprap (scour countermeasure), bituminous paving, guide rail
- Facing wall: Concrete Masonry Units (CMUs) utilized; top three rows grouted along with all corners

The bridge was constructed with local forces except for a rented excavator and guide rail contractor. An adjacent local municipality paved where applicable. All equipment was township owned or locally rented. The excavator work was subcontracted due to the reach requirements. Comparable PennDOT, local, and contracted box culvert and bridge beam projects for District 2 range in cost from $150,000 to $500,000+.

Bridge settlement monitoring was implemented in December 2011. Two nails in a utility pole used as benchmarks and the elevations for 17 individual bridge locations were recorded. Through July 2012 there had been nominal settlement, with an initial average bridge elevation of 995.20 ft and an average bridge elevation through July 2012 of 995.19 ft (Table 6). Figure 2 provides a schematic of the bridge structure and of the 17 monitoring points shown in Table 6.
Table 6. Clearfield County GRS bridge vertical settlement summary.

<table>
<thead>
<tr>
<th>Point</th>
<th>Elevation (ft)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>993.85</td>
<td>NE Top of GRS Block Row</td>
</tr>
<tr>
<td>B</td>
<td>996.09</td>
<td>NE Top of Cap</td>
</tr>
<tr>
<td>C</td>
<td>994.16</td>
<td>NE Top of Sill Plate</td>
</tr>
<tr>
<td>D</td>
<td>993.82</td>
<td>SE Top of GRS Block Row</td>
</tr>
<tr>
<td>E</td>
<td>996.07</td>
<td>SE Top of Cap</td>
</tr>
<tr>
<td>F</td>
<td>994.14</td>
<td>SE Top of Sill Plate</td>
</tr>
<tr>
<td>G</td>
<td>993.87</td>
<td>SW Top of GRS Block Row</td>
</tr>
<tr>
<td>H</td>
<td>996.11</td>
<td>SW Top of Cap</td>
</tr>
<tr>
<td>I</td>
<td>994.20</td>
<td>SW Top of Sill Plate</td>
</tr>
<tr>
<td>J</td>
<td>993.88</td>
<td>NW Top of GRS Block Row</td>
</tr>
<tr>
<td>K</td>
<td>996.12</td>
<td>NW Top of Cap</td>
</tr>
<tr>
<td>L</td>
<td>994.21</td>
<td>NW Top of Sill Plate</td>
</tr>
<tr>
<td>M</td>
<td>996.38</td>
<td>NW Top of Deck</td>
</tr>
<tr>
<td>N</td>
<td>996.35</td>
<td>NE Top of Deck</td>
</tr>
<tr>
<td>O</td>
<td>996.34</td>
<td>SE Top of Deck</td>
</tr>
<tr>
<td>P</td>
<td>996.36</td>
<td>SW Top of Deck</td>
</tr>
<tr>
<td>Q</td>
<td>996.41</td>
<td>Center of Deck</td>
</tr>
</tbody>
</table>

Note: 10/20/11 was during construction.

Figure 2. Mount Pleasant Road GRS bridge schematic; letters relate to measured elevation points in Table 6.
2.4.4 Buchanan County, Iowa

The Center for Earthworks Engineering Research at Iowa State University evaluated two GRS-IBS in Buchanan County, Iowa. These GRS-IBS bridges were found to be 50%-60% lower in cost when compared to traditional bridges. The first bridge, located on Olympic Avenue, is a 73-ft Railroad Flat Car (RRFC) bridge on a reinforced concrete spread footing and had a GRS bridge abutment with flexible wrapped geosynthetic and grouted riprap facing. The total cost was approximately $49,000. Field observations showed that the grouted riprap installed over the wrapped geosynthetic facing for erosion protection was intact. The average settlement was about 0.7 inches for the north abutment footing and 0.4 inches for the south abutment footing. No transverse differential settlement was observed at either abutment.

The second bridge, located on 250th Street, is a 68.5-ft RRFC bridge that used existing concrete bridge abutments along with some existing fill, which were left in place as GRS facing. Sheet piling was used as scour protection and the total cost was approximately $43,000. In-situ bridge abutment settlement monitoring was conducted for roughly 1 year after bridge construction. The monitoring results found an average settlement of about 0.4 inches with a transverse maximum differential settlement of about 0.2 inches. Monitoring indicated that most of the settlement occurred within the first 2 months after completion of construction. Lateral ground movements monitored during the 1-year monitoring period showed minimal movements.

2.5 Summary of Literature Review and Testing

Over 50 GRS bridges have been constructed in the United States since 2005. The technology has proven to be time saving, cost effective, and reliable. In general, GRS bridges have seen a cost and construction time savings of at least 50% over conventional bridges. The monitoring data outlined above has shown that settlement has been minimal and that even the 100 year settlement projections are well within acceptable tolerances. It should be noted that Pennsylvania’s only GRS bridge in Clearfield County, built utilizing a township workforce and PennDOT-specified materials, has performed extremely well, with an average settlement of only 0.01 ft over the first year after construction.
3. **Specification Development & Review of PennDOT Resources**

Center for Dirt and Gravel Road Studies staff employed a variety of strategies in the development of the GRS specification for Pennsylvania. These included site visits to many existing GRS structures and gathering of information from experts in the field of GRS bridge construction. The Center also adapted existing GRS guidelines and construction materials to make a “Pennsylvania-specific” specification that references existing PennDOT-approved materials, practices, and standards where possible.

### 3.1 Site Visits

Site visits were conducted in Defiance County, Ohio, at the Turner-Fairbank Highway Research Center in Washington D.C., and at the Mt. Pleasant Road GRS bridge in Pennsylvania. The purpose of these site visits was not to simply see the bridges, but to interact with the GRS experts at these various locations.

#### 3.1.1 Defiance County, Ohio

On July 1-3, 2012, Center staff visited Defiance County, Ohio. Defiance County is nationally recognized as the leader in GRS-IBS implementation, with over 26 bridges completed using the technology from 2005 through 2011. Center staff met with Warren Schlatter (Defiance County Engineer), and visited a dozen completed GRS-IBS bridges. Mr. Schlatter proved to be an extremely knowledgeable and valuable resource during the visit. Center staff visited GRS-IBS bridges ranging from 2005 to 2011 in time of construction, 11 ft to 130 ft in span length, and 5 ft to 25 ft in GRS height. All bridges and GRS abutments were in excellent condition and functioning well. Many of the abutments had been completely submerged since their construction with no detrimental effects (Figure 5). There was no evidence of scour or erosion around the GRS structures of any of the bridges. Several of these bridges were used in long-

![Figure 3](image1.png)  
**Figure 3.** Under the 74-ft length Bowman Road Bridge, the first GRS-IBS bridge in Defiance County, OH, completed in 2005.

![Figure 4](image2.png)  
**Figure 4.** A small 11-ft span GRS bridge on Flory Road (west) in Defiance County, OH, completed in 2011.
term monitoring and assessment studies of the GRS-IBS concept. Much of this data was
presented in the Literature Review/Testing section of this document.

![Figure 5. Under the Tiffin River Bridge, the longest span to date at 130 ft, completed in 2009. Note the debris stuck under the bridge, indicating total flooding of the GRS structure.](image)

![Figure 6. Unbroken pavement (no bump) over the 20-ft span Flory Road (east) bridge in Defiance County, OH, completed in 2008.](image)

### 3.1.2 Turner-Fairbank Highway Research Center, Washington D.C

On August 15, 2012, Center staff visited the Federal Highway Administration’s Turner-Fairbank Highway Research Center in McLean, Virginia. Center staff met with three of the authors of the FHWA GRS-IBS Implementation Guide: Michael Adams, Jennifer Nicks, and Jonathan Wu. The purpose of the meeting was to receive feedback and input that would help in the creation of the GRS specification for Pennsylvania. The visit proved to be invaluable, as it answered many questions previously raised by several parties about the potential GRS specification for Pennsylvania. FHWA staff continue to be in contact and have offered any assistance they can provide in the creation of a GRS specification for Pennsylvania.

### 3.1.3 Mt. Pleasant Road, Clearfield County, Pennsylvania

The Mt. Pleasant Road Bridge is located just North of Pennfield in Clearfield County, Pa. It is currently the only modern GRS bridge in Pennsylvania. It was built in the fall of 2011 by a township crew at a total cost of ~$100,000. This represented a significant cost savings over standard bridge alternatives. The GRS abutments were constructed in 6 days and the entire bridge, including paving, was done in 36 days. The Center had made several visits to the Mt. Pleasant Bridge. In September of 2012, the Center used

![Figure 7. The 26-ft span Mount Pleasant Road Bridge constructed in Clearfield County, PA, in 2011.](image)
the bridge as a tour stop as part of the 2012 Annual Maintenance Workshop. More than 150 conservation and road maintenance professionals from around Pennsylvania toured the site. The Center has also been working closely with project supervisor Randy Albert, of PennDOT BMS District 2, in the development of the GRS specification. Previously unpublished monitoring data from the Mt. Pleasant Road Bridge is also included in the Literature Review/Testing section of this document.

3.2 Testing

As outlined in the Center’s proposal, actual testing of GRS structures was not within the scope of the Center’s work. Instead, monitoring and testing data from existing sources has been summarized. This data is presented in Section 2 of this report.

3.3 Specification Development

GRS-IBS bridges are a much more complicated practice than many of the products and practices typically included in PennDOT Publication 447. The goal in developing the GRS specification for Publication 447 was to keep the actual specification as simple as possible while making reference to the best available resources that existed for the bulk of the guidance. This proved to be the Geosynthetic Reinforced Soil Integrated Bridge System—Interim Implementation Guide, published by FHWA. This extensive guide outlines the GRS-IBS process in detail and includes specifications for materials to be used.

The goal of developing the GRS specification for PennDOT Publication 447 was to incorporate PennDOT-approved materials, testing methods, and practices into the existing GRS Implementation Guide. Based on feedback received from various sources, the Center also incorporated several guidelines into the Publication 447 GRS specification that are more conservative than FHWA guidelines. Center staff also met with the authors of the FHWA implementation guide to assist in developing the Pennsylvania specification.

Maintenance and protection of traffic must be considered during construction. The road may need to be closed or a realignment may be necessary since this type of construction is typically not conducive to a phased construction environment. (PennDOT Publication 408, Section 901)
I. DESCRIPTION – This work consists of designing and constructing an Integrated Bridge System (IBS) using Geosynthetically Reinforced Soil (GRS) technology on a Reinforced Soil Foundation (RSF). GRS technology consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. GRS-IBS is a fast, cost-effective method of bridge support that blends the roadway into the superstructure. GRS-IBS includes an RSF, a GRS abutment, and an Integrated Approach (IA). Designers must utilize the design and construction specifications provided as follows:

A. Federal Highway Administration:

B. Guidelines in this document provide additional information to **FHWA-HRT-11-026** and **FHWA-HRT-12-051**. In instances where guidelines differ between the sources, this document takes precedence.

C. PennDOT current and applicable design standards, including, but not limited to **PennDOT Publication 15M, Design Manual Part 4** on structures.


II. GRS-IBS DESIGN GUIDELINES (in accordance with: **FHWA-HRT-11-026 and FHWA-HRT-12-051**)

A. SITE LIMITATIONS
   1. GRS-IBS is limited to bridges with simple plan structures.
   2. GRS-IBS is limited to span lengths up to 70 feet.
   3. GRS-IBS is limited to bridges with GRS abutment heights up to 30 feet.
   4. GRS-IBS is limited to sites with low scour potential.
   5. GRS-IBS is limited to streams with a 100 year storm maximum allowable stream velocity of:
      1. \( \leq 7 \text{ fps} \):
         a. Conventional GRS construction utilizing Standard CMUs (8” x 8” x 16”) with friction connection.
      2. 7-10 fps:
a. Complete concrete fill with rebar on Standard CMUs.

3. 10-12 fps:
   a. Large CMUs (24” x 24” x 72”) with intermediate layers of geotextile wrap-faced at 8” intervals.

6. GRS-IBS is limited to sites with soil pH between 5 and 9.

7. Outlet pipes through the GRS-IBS are not permitted.

B. SITE EVALUATION
   A site evaluation shall be performed in accordance with FHWA-HRT-11-026, Section 4.3.2.

C. SCOUR
   1. Scour Depth:
      1. Footings are to be designed based on the total scour depth obtained from a scour design flood. The scour design flood is defined as a 100 year flood, the flood of record (if available), or the overtopping flood (if less than the 100 year flood), whichever results in the worst-case scour condition in accordance with PennDOT Publication 15M Section 7.2.2.
      2. The reinforced soil foundation shall be placed below this calculated depth in accordance with Hydraulic Engineering Circular 18 (HEC-18) or PennDOT Publication 15M Section 7.2.4.

   2. Scour Protection:
      1. A properly designed scour countermeasure shall be placed to protect against local scour in accordance with FHWA-HRT-11-026, Section 4.3.3. Riprap protection shall be sized appropriately for the class of stone specified in accordance with PennDOT Publication 15M Section 7.2.5. It is recommended that CMU blocks which are solid be used at the bottom of the GRS wall for reinforcement, and CMU blocks of a different color be used to indicate scour as per FHWA-HRT-11-026, Section 6.4.
      2. Potential for channel migration shall be evaluated. The effect of lateral channel movement on abutments may be mitigated by providing abutment setback or providing wingwalls that extend beyond the estimated channel migration distance. The RSF shall be protected from scour. In all cases, wingwall height and length shall be constructed to adequately protect the reinforced fill from channel scour and undermining from surface drainage.

D. BEAM SEAT:
   1. The maximum Service I Bearing Pressure on the GRS beam seat shall be limited to 4,000 lb/ft².
2. A cast-in-place or precast beam seat with a concrete end diaphragm is required for concrete girders, steel/timber superstructure elements, or other similar superstructures without backwall support.

III. MATERIAL (in accordance with: FHWA-HRT-11-026 and FHWA-HRT-12-051) Materials must be obtained from a manufacturer listed in Bulletin 15 for projects with state or Federal funding and conforming to the following requirements:

A. FACING ELEMENTS

1. Concrete Masonry Unit (CMU):  PennDOT Publication 408, Section 713.2 and ASTM C1372, and conforming to the following requirements:
   1. Class A concrete (PennDOT Publication 408, Section 704).
   2. Water absorption limit ≤ 5%.
   3. Freeze thaw testing in accordance with ASTM C1262-10.
   4. “Standard CMUs” with nominal dimensions of 8” x 8” x 16”.
   5. “Large CMUs” with nominal dimensions of 24” x 24” x 72”.

2. Existing Abutments: GRS structures can be constructed behind existing bridge abutments, subject to PennDOT approval. In these cases, the existing bridge abutments effectively become part of the facing element of the GRS structure. The GRS shall be wrapped-faced using geotextile fabric against the existing abutment in accordance with FHWA-HRT-11-026, Section 7.3.3.

3. Other Facing Elements: Other facing materials may be used with District Bridge Engineer approval.

B. BACKFILL MATERIAL:

1. All backfill material shall consist of sound crushed durable particles, fragments of stone gravel free from organic matter or other deleterious material, with a minimum friction angle of 38 degrees.

   1. Reinforced Soil Foundation (RSF) Backfill: PennDOT 2A coarse aggregate with a maximum Plasticity Index value of 6 (PennDOT Publication 408, Section 703.2) -or- Driving Surface Aggregate (DSA) with a maximum Plasticity Index value of 6. (PennDOT Pub 447, MS-0450-0004)

2. GRS Abutment Backfill: AASHTO #8 is the preferred abutment backfill. Backfill may also consist of coarse aggregate conforming to AASHTO #8, #57, #67, or a combination thereof. All backfill aggregates must be Type A. (PennDOT Publication 408, Section 703.2)

3. Integrated Approach Backfill: PennDOT 2A coarse aggregate with a maximum Plasticity Index value of 6 (PennDOT Publication 408, Section 703.2) -or- Driving Surface Aggregate (DSA) with a maximum plasticity index value of 6. (PennDOT Pub 447, MS-0450-0004)
C. GEOSYNTHETICS (Geotextiles)

1. Geosynthetic Reinforcement in Abutment, Reinforced Soil Foundation and Integrated Approach: Biaxial geotextiles with Ultimate Tensile Strength = 4,800 lb/ft as determined by ASTM D 4595 (woven geotextiles). Geotextile reinforcement tensile strength at 2 percent strain shall be greater than the calculated required reinforcement strength in the direction perpendicular to the abutment wall face as outlined in FHWA-HRT-11-026, Section 4.3.7. The design requirement may call for a Geotextile with higher strength. Geosynthetics shall conform to PennDOT Publication 408, Section 212.

D. Concrete (Block Wall Fill and Wet Cast Coping): Class A cement concrete with 3,000 psi compressive strength. (PennDOT Publication 408, Section 704.1)

E. Reinforcement Bars: Deformed #4 rebar (0.5” diameter), epoxy coated in accordance with PennDOT Publication 408, Section 1002.

F. Aluminum Flashing: Flashing, such as 4” x 1.5” aluminum fascia or equivalent, may be used to serve as a drip edge under the superstructure to shed potentially corrosive fluids off the dry cast block and to prevent animals from burrowing into the abutment.

G. Preformed Cellular Polystyrene: A durable foam board, such as expanded polystyrene filler or equivalent, having a compressive strength >10 psi as defined in PennDOT Publication 408 Section 516.2. Total thickness of the foam board shall be 4 inches or greater depending on the abutment height.

H. Asphaltic (bitumen) Coating: An asphaltic coating shall be shop installed on the concrete beam ends where it will be embedded between the GRS abutment and the wing wall to seal the embedded concrete.

J. Rip-rap Scour Countermeasure: Rip-rap as defined in PennDOT Publication 408, Section 850. Rip-rap scour countermeasures shall be sized according to Hydraulic Engineering Circular 23 (HEC-23).

IV. CONSTRUCTION (in accordance with: FHWA-HRT-11-026 (Chapter 7), and FHWA-HRT-12-051, Section 3)

A. Equipment: Use equipment that produces the completed GRS-IBS and maintain all equipment in a satisfactory operating condition as specified in PennDOT Publication 408, Section 108.05(c).

1. Compaction Equipment: Rollers and other compaction equipment as described in PennDOT Publication 408, Section 108.05(c).3,4

B. Excavation: Construct embankments and/or cut existing grade to the bottom of footing elevations. Excavate and backfill foundation areas as specified in PennDOT Publication 408 Section 204.3 and compact using a mechanical tamper. If unsuitable foundation material is encountered, remove all unsuitable material at least 12” or as specified or directed below the bottom of the RSF elevation and backfill with compacted No. 2A...
Coarse Aggregate or DSA as specified or directed. No additional payment shall be made if rock is encountered during excavation.

C. Compaction of Backfill (RSF, Abutment, and Integrated Approach): Hand-operated compaction equipment as specified above is required within 3 ft of the front of the abutment wall face.

1. Compaction of Open-Graded Backfill in Abutment: Compact to non-movement or no appreciable displacement with compaction equipment specified above and assess with visual inspection (minimum of 4 vibratory passes per lift). Abutment backfill is to be placed at a maximum compacted depth of 4 inches per lift.

2. Compaction of Well-Graded Backfill in Reinforced Soil Foundation and Integrated Approach: Compact well-graded backfill to not less than 100% of the determined dry-weight density. Dry-weight density for material in place in the field will be determined, in accordance with Pennsylvania Testing Method (PTM) No. 106, Method B. In-place density or compaction will be determined, in accordance with PTM No. 402 where directed. At the time of compaction, maintain the material's moisture content not more than 2 percentage points above optimum moisture for that material. Backfill is to be placed and compacted in lifts shallow enough to achieve 100% compaction, not to exceed 8 inches (loose) in a single lift.

D. GRS Abutment

1. Reinforcement of Facing-wall/Wing-wall Corners for Flows \( \leq 7 \) fps Velocity During 100 year Storm:

   1. The top three courses of Standard CMU block shall be filled with Class A cement concrete (PennDOT Publication 408, Section 704) with one #4 epoxy coated reinforcement bar of sufficient length to engage all three courses of block, embedded with a minimum of 2” cover, and provided with a wet-cast cap in accordance with FHWA-HRT-11-026, Section 7.7.7.

   2. All courses of hollow CMU blocks on the facing-wall/wing-wall corners shall be filled as described in Section 1.1 above. This shall include a minimum of 3 block columns comprised of the corner unit, and one unit on each side of the corner unit.

2. Reinforcement of Facing-wall/Wing-wall for Flows of 7-10 fps Velocity During 100 year Storm:

   1. All courses of hollow Standard CMU blocks on the facing-wall and wing-walls shall be filled with Class A cement concrete (PennDOT Publication 408, Section 704), #4 epoxy coated reinforcement bars of sufficient length to engage all courses of block, and embedded with a
minimum of 2” cover and provided with a wet-cast cap in accordance with *FHWA-HRT-11-026, Section 7.7.7.*

3. **Construction of Facing-wall/Wing-wall for Flows of 10-12 fps Velocity During 100 year Storm:**
   1. Large CMUs (24” x 24” x 72”) shall be used. In addition to horizontal geotextile layers between blocks, two additional intermediate layers of geotextile shall be used behind each block, wrap-faced against the GRS wall so that geotextile spacing is at 8” intervals.

E. **Site Drainage**
   All GRS structures shall include consideration for surface drainage both during and after construction in accordance with *FHWA-HRT-11-026, Section 7.1.1 and Section 8.2.*

V. **MEASUREMENT AND PAYMENT** – Lump Sum. Includes all excavation required for GRS-IBS placement, the Reinforced Soil Foundation (RSF), the GRS abutments, the integrated approach, geotextile, backfill material, CMUs, and scour protection. Does not include the beam seat (when required), superstructure, removal of the existing structure as defined in the contract drawings, temporary shorings, dewatering, maintenance and protection of traffic, or approach roadway items.
References


