GEOSYNTHETIC REINFORCED SOIL INTEGRATED BRIDGE SYSTEM

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Abstract: This paper describes the concept of a geosynthetic reinforced soil integrated bridge system. This simple method of bridge support blends the roadway into the superstructure to create a joint-less interface between the bridge and the approach way. The Federal Highway Administration (FHWA) developed the technology to meet the demand for efficiently constructed, cost-effective, and durable 21 to 27 metre single-span bridges.

Different from the "Integral Abutment," the Integrated Bridge System utilizes Geosynthetic Reinforced Soil (GRS) to support the superstructure without the use of a deep foundation or traditional spread footing. The Integrated Bridge System does not require an approach slab or construction joint at the bridge to road interface. The roadway and the bridge are designed to settle together to provide a bump free, smooth ride over the bridge.

The GRS abutments are built on a Reinforced Soil Foundation (RSF) over the subsoil. Prestressed concrete box beams fit well with this method because the beam-ends bear directly on the GRS abutments. The bridge can be built without cast-in-place concrete. Currently under development is an option for a steel girder superstructure. During the past several years, this technology has been used to build many bridges in Defiance County, Ohio.

The GRS Integrated Bridge System is a sound economical alternative to current bridge design. A bridge built with this technique can be constructed in less than two weeks for at least 25% less cost than a bridge supported on pile-capped abutments with 2:1 slopes. Other advantages include: the construction of this bridge system is less dependent on the weather; construction techniques can be easily modified to account for unexpected field conditions, design changes and unplanned construction issues. The bridge system is also expected to be easier to maintain because it has less parts.

Keywords: bridge abutment, bridge approach, geotextile, geosynthetic

INTRODUCTION

The need to build bridges faster, better and less expensive is essential in maintaining the transportation infrastructure in the United States. Current practice cannot meet the combined demand for the construction of new bridges and the replacement of existing bridges. The current methods of bridge construction is time consuming and costly in terms of design, labour, materials, and traffic delays. These factors, in combination with the reduction of construction budgets of many agencies, have created a situation that is insufficient to meet the demand for new bridges. The result is an unsustainable backlog of bridge replacement projects that will increase as the national highway system ages. To meet the demand for these new bridges, the Federal Highway Administration (FHWA) initiated the Bridge of the Future (BOF) program to develop new technologies to build better, more efficient bridge systems.

There are approximately 500,000 bridges in the national inventory. The majority, about 80%, are single span bridges 21-27m in length. For this reason, the BOF program is geared toward these basic, "bread and butter" bridges that comprise the vast majority of the inventory. The objective of the program is to develop cost-effective design and efficient construction techniques for these small bridge systems that deliver improved durability, maintenance, inspection accessibility and long-term performance.

GEOSYNTHETIC REINFORCED SOIL TECHNOLOGY

Geosynthetic reinforced soil technology (GRS) has been used in the United States for more than three decades; it was first used in the 1970's by the U.S. Forest Service (USFS) to support logging roads in steep mountain terrain. Many of these GRS walls were built with plain non-woven geotextiles. Shortly after the construction of these USFS walls, the Colorado Department of Transportation (CDOT) began investigating the technology as part of the Interstate 70 Glenwood Canyon expansion project. Later in the 1990s, the Colorado Transportation Institute (CTI) published a manual to design and construct low cost retaining walls (Wu 1994).

In the mid 1990s, the FHWA worked with CDOT to further improve the technology. During the past decade, the technology has been refined and successfully used to construct retaining walls, slopes, embankments, bridge abutments, culverts, rock fall barriers and foundations. To develop the technology for bridge support, the FHWA tested several full-scale GRS experiments at its Turner-Fairbank Highway Research Center in McLean, Virginia (Adams 1997, Koklanaris 2000). CDOT also constructed and performed a long-term load test on a full-scale GRS pier and abutment combination at the Colorado DOT Havana maintenance facility (Ketchart *et al*. 1997). The research has also been applied to economically build many bridges in the private sector; these bridges are performing well.

Today, GRS is often mistakenly lumped with Mechanically Stabilized Earth (MSE) systems. An effort is underway to differentiate these two wall systems (Wu 2001). The main differences between GRS and MSE are the design methodologies: a GRS mass consists of closely spaced alternating layers of geosynthetic reinforcement and a compacted granular fill, producing a composite mass with different material properties from that of soil (Wu *et al*.

2006). More recently the term, Geosynthetically Confined Soil ™ (GCS) was coined to describe close spaced GRS systems.

GRS is internally supported and can be designed without many of the factors governing the requirement of MSE systems. The behavioral differences are related to: 1) lateral earth pressure; 2) relationship between spacing and strength of reinforcement; 3) failure mechanism; and 4) safety factors. A GRS wall can be built without the MSE requirement for special block connections, reinforcement pullout, reinforcement creep reduction factors, specified wall embedment, specified wall base to height ratios, and lateral earth pressure at the face.

A GRS mass can be considered unique; a composite built with a particular compacted fill and reinforcement schedule producing a material with predicable properties. Research has been completed to develop test procedures used to evaluate the performance of a particular GRS mass (Ketchart *et al.* 2001).

There are two basic rules to assure acceptable performance of a GRS mass: 1) good compaction with quality granular fill; and 2) close reinforcement spacing. Bulging at the face or problems concerning the internal stability of a GRS mass indicates that either one or both of the two rules were not followed. Building a GRS mass is easy; a row of blocks, a layer of compacted fill to the height of the blocks (0.2m) followed by a layer of geotextile that extends between the layers of block. The 1-2-3 process is repeated until the wall height is reached.

Typically, the primary reinforcement is spaced at 0.4m for walls and 0.2m for load bearing, abutment applications. The spacing of reinforcement in the zone directly beneath a bearing area can also be reduced to less than 0.2m to provide additional confinement and mass stiffness. In recent years, the type of reinforcement most often used in GRS is polypropylene geotextile; this is because of its affordable price and suitable material properties. Another advantage of this type of geotextile is that it can be rolled out parallel to the face of the wall, as opposed to perpendicular, thus optimizing material quantities.

The requirements for the connection of the modular block to the GRS were based on the fact that GRS can effectively restrain lateral deformation of the soil without the requirement for mechanical connection. For the case of walls where the primary reinforcement layers are spaced at 0.4m, it is recommended that secondary layers or tails be placed between the primary layers to allow for better soil compaction at the face of the wall. The secondary reinforcement layers connect the facing block to the reinforced soil mass and reduce lateral loads against the modular block face.

The thrust against each course of the block can be described in terms of bin pressure as a function of the reinforcement spacing and not wall height (Wu 2007). A practical implication of this is that the facing block should only resist lateral movement such that an active condition can develop within the wedge soil confined between the layers of the reinforcement. For the case of a GRS mass consisting of reinforcement spacing of 0.2m and a soil, that has a unit weight of 2002 kg/m^3 (around 20.4 kN/m^3) and friction angle of 34 degrees, the lateral thrust produced is about 0.17 kN/m. The weight of the split face CMU (concrete masonry unit) is more than double this thrust value developed from the small wedge of soil at the face behind the facing block.

This simple method of connection is designed to allow the blocks to yield slightly against thrust to reduce pressures against the face. The lateral pressure within a GRS structure is a function of reinforcement spacing, and not wall height. The degree of frictional connection between the facing block and reinforcement is a function of the normal force due to the weight of the facing blocks and can vary between several hundred to more than a thousand pounds. Even though the modular block on a GRS wall provides some secondary confinement, the GRS structure is internally supported and the primary function of the block is a façade and form for each lift of fill during construction.

A GRS mass is a composite material with a distinctive stress-strain relationship depending on the type of reinforcement and backfill material. It has also been observed that both the reinforcement and the soil strain together to act as a composite GRS material when subjected to vertical stress. The strain compatibility of the soil and reinforcement has been observed to lateral strains of more than 2%. Creep rates of a GRS mass constructed with reinforcement spacing of 0.2m will typically accelerate at about 2.5% lateral strain. A GRS abutment will have a reinforcement strain less than 0.5% at an allowable bearing stress of 200 kN/m^2, (Adams 1997, Adams *et al*. 1999).

Since a particular GRS mass is considered unique based on its components, a large-scale model (mini-pier) was constructed with the same geotextile and fine gravel used to build the GRS integrated bridge system. Figure 1 is a photo of the mini-pier test specimen. Figure 2 shows the vertical strain of the GRS composite as a function of applied stress. While this test was not initially performed to aid in the design of the abutments, it shows how the test can be used to validate a particular GRS mass (Adams *et al.* 2002, Adams *et al.* 2007). The results of the experiment show the integrity of the GRS mass is maintained to vertical strains between 2.5% to 3%, or a stress of 850kN/m^2. This stress also corresponds to the intersection of tangents technique used to determine the ultimate load capacity. The maximum load applied to the specimen was 1250 kN/m^2. The true maximum load was not obtained because of insufficient capacity of the hydraulic loading system. It is important to note that the deformation was nearly a straight line, and additional load increments would have been useful to verify the ultimate capacity of this composite which may have been greater than 850 kN/m^2. After this load, the acceleration of creep initiates and the specimen is near its ultimate capacity. Based on the results for this particular GRS composite, a 98kN/m^2 working load for Bowman Road Bridge translates to a factor of safety around 8.6.

Figure 1. Defiance Mini Pier test speciment

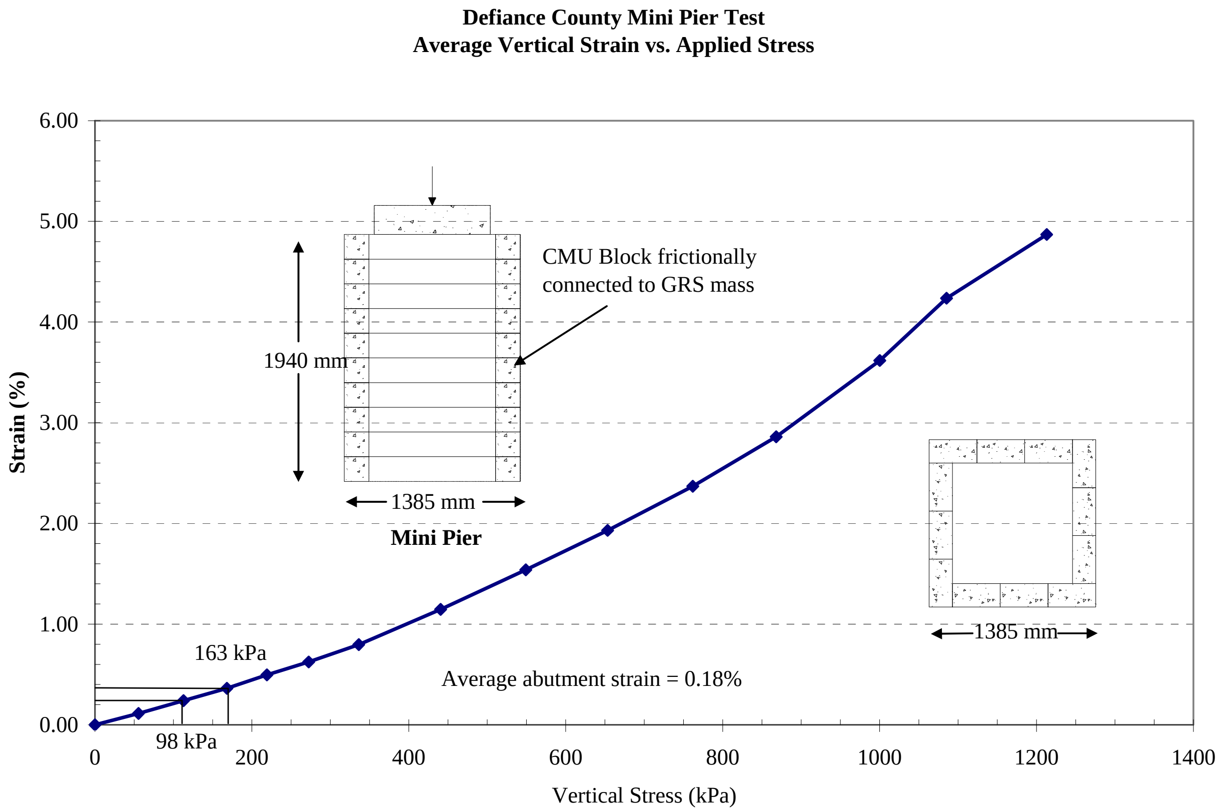

Figure 2. Vertical Strain Mini Pier

THE FHWA GRS INTEGRATED BRIDGE SYSTEM.

In the past, GRS technology had been used to support the bridge directly on the abutment wall (Abu-Hejleh *et al.* 2001, Wu *et al.* 2001, Devins *et. al.* 2001). There are also numerous undocumented applications of this technique in the private sector. In these cases, the beams were supported on an intermediate concrete foundation, or sill perched on top of the abutment wall.

The method is similar to the placement of traditional spread footings on an approach fill embankment. Some obvious differences are that the allowable bearing stress on GRS is greater than the stress allowed on compacted fill and the span length for the bridge supported on GRS is shorter because the wall can be constructed vertically, where as an approach embankment typically has a 2:1 fill slope.

Additionally, the more traditional method would include a stem wall cast into the back of the spread footing to retain the approach fill behind the beam. The approach detail also frequently includes an approach slab to smooth the transition for the approach onto the bridge (DiMillio 1982).

In the "FHWA GRS Integrated Bridge System," the adjacent concrete box beams are supported directly on the GRS abutments, without a concrete footing or elastomeric pads. The bridge has no cast-in-place concrete or approach slab. Figure 5 illustrates a typical cross section of a GRS integrated abutment to show that GRS is compacted directly behind the bridge beams to form the approach way and to create a smooth transition from the roadway to the bridge.

The reinforcement layers behind the beam-ends are wrapped to confine the compacted approach fill against the beam-ends and the adjacent side slopes to prevent lateral spreading. Since the wrapped faced GRS fill behind the beam-ends is free standing, the active lateral pressure against the beam-ends is considered negligible. The wrapped face fill also prevents migration of fill during thermal bridge cycles and vehicle live loads.

Similarly, the placement of GRS behind the stem wall on a traditional bridge abutment would reduce lateral pressure and the rotational force against the wall. This detail would also confine the fill and prevent the loss of the material that can create a bump (White 2005).

In the integrated system, GRS is also compacted against the beam sides on the wing walls. Guardrail posts are installed with a 1.1m setback distance from the face of the GRS wall. Asphalt pavement is placed on the bridge and approach without a conventional joint system at the bridge ends. A layer of paving fabric is extended from the concrete box beams onto the approach fill to bridge the transition. The integrated bridge system is designed for the bridge and the adjacent road to settle together providing a bump free, smooth ride for drivers on and off the bridge. The system is also expected to reduce maintenance requirements.

This type of abutment is not suitable for every bridge building assignment; however, the technology is well suited for single span bridges of less than 36.6m, but not for water crossings where the potential for scour is high.

DESIGN BACKGROUND

The Bowman Road Bridge, in Defiance County, Ohio, was the first production bridge to use GRS technology to integrate the bridge substructure and superstructure with a jointless pavement. State of the practice in this region is to build typical bridges with concrete box beams on pile cap abutments with 2:1 side slopes. As shown in Figure 3, placement of the Bowman Road Bridge on GRS abutments reduced the beam length from 40.8m to 25m.

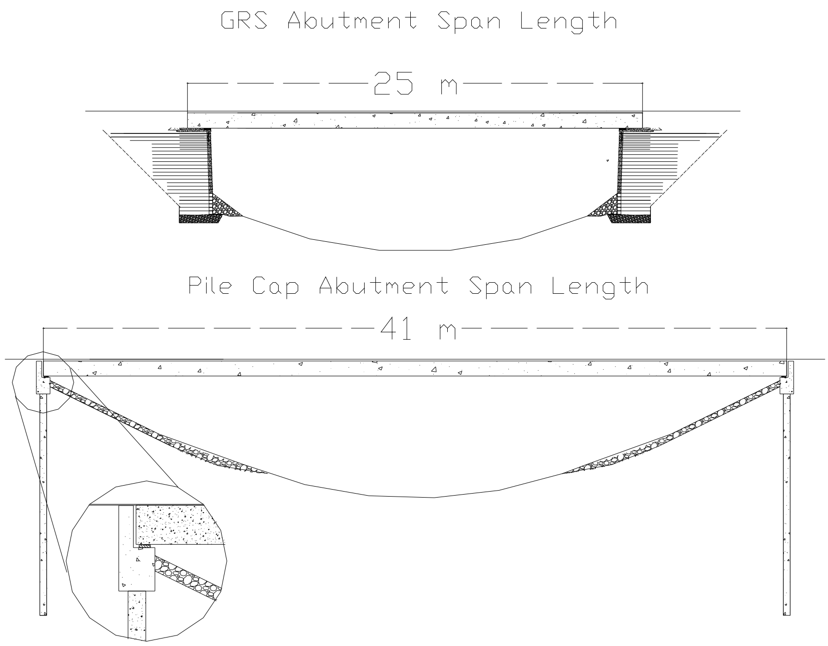

Figure 3. Illustration of Bridge Span Length for GRS and Pile Cap Abutments

The centre of bearing was 0.6m behind the back of the concrete modular facing block. The width of the bridge seat was 0.91m. The setback distance or gap between the back of facing block and bridge seat was 0.15m.

Typical concrete box beams were used to form the 10.4 m wide superstructure. The weight of the beams and asphalt produced an equivalent bearing stress of 163 kN/m^2.

The economics of this method is apparent when comparing the cost of the main components of these two bridge systems. The cost of building the GRS abutments more than offsets the cost for the longer span and installation of the deep foundation.

A cost comparison of the two abutment types shows a savings of 25% using GRS abutments over conventional pile cap abutments. Actual cost of the GRS abutment bridge was $226,000, compared to a contractor's bid quote of $338,000 for a pile cap bridge. Further examination of the cost components show the cost difference of the abutments is only $10,000, the real savings are incurred due to the decreased beam length allowed using GRS. The beams used were 9m shorter in length, producing a price difference of $62,000.

Another advantage to GRS abutment type is that the bridge can be constructed in less time than the conventional abutment. The Bowman Road Bridge was built in about 6 weeks versus a construction time of several months if the bridge was supported on a conventional abutment. The county has since streamlined the GRS construction process and is now capable of completing a bridge in about 2 weeks, with a cost savings of nearly 30 percent depending on the span length and abutment height. The typical labour crew consisted of four labourers and one equipment operator.

During the past two construction seasons, Defiance County has switched from installation of stubby pile cap abutment to the integrated GRS abutments because of cost and flexibility of construction. In addition, the county has also elected to use GRS abutments instead of box culverts.

The Bowman Road Bridge in Defiance County was built in the fall of 2005 with design and construction guidance from the FHWA. Design of the abutments was based on the first author's knowledge of GRS for load bearing applications in combination with recommendations provided in NCHRP Report 566.

The computer program MSEW was also used to check for external global stability and reinforcement strength against the development of an active failure wedge. The MSE design requirements for eccentricity, reinforcement pullout and connection were not applied because MSE design methodology does not account for geosynthetic soil interaction exhibited with GRS.

Another deviation from MSE design policy is the selection of the reinforcement strength reduction factor. The allowable reinforcement strength was set at 0.3 the reinforcement's ultimate strength, instead of the recommended reduction factor of 0.03 for polypropylene reinforcements as outlined in the FHWA design guidance for MSE walls (Elias, *et al.* 2001). The reinforcement spacing in a GRS wall is close, is internally stable and does not creep when properly constructed. For this reason, the reduction factor for creep is essentially omitted in the calculation of the allowable strength from the reinforcement ultimate strength.

A GRS structure is internally supported and can be efficiently built with a lightweight simple CMU block that is frictionally connected to the geotextile reinforcement layers. GRS structures may also be built with MSE blocks. Proprietary MSE systems are built with a distinctive MSE block-reinforcement combination. Each unique MSE segmental wall system has a connection method that specifies special pins, keys or block shapes that mechanically connect geosynthetic reinforcement to a particular block. Incorporated into the design of these systems (many of which are proprietary) is a technique to resist shear between each course of block.

A simple standard split-faced CMU is representative of the products available for modular block wall construction are an economical alternative to a MSE block. The manufacturing process and mix design for split-faced CMU block is often identical to segmental retaining wall (SRW) block. Both are dry-cast concrete products that can be made to a particular performance specification depending on geographic location or application (Chan *et. al* 2007). A standard CMU is 0.2m deep, whereas SRW units are most commonly 0.3m deep. Other than size and weight of the block, one difference between a CMU and SRW block is the allowable height tolerance across the length of the block, 3 mm and 1.5 mm, respectively.

Figure 4 shows the abutment face for the Bowman Road Bridge. The Bridge was skewed approximately 24.5 degrees and super elevated about 0.88m.

Figure 4. Face View of GRS Abutments to Show Bridge Super Elevation

GRS ABUTMENT CONSTRUCTION

The fill material used to build the abutments was 10mm diameter crushed limestone aggregate, classified between a fine gravel and coarse sand. This material was easy to spread and compact. Direct shear box tests on the fine gravel indicated that the friction angle was 37 degrees. Two types of woven polypropylene geotextiles were used to build the GRS abutments; the wide width strength of the fabrics was a 70 kN/m and 30 kN/m, strength material.

Figure 5 shows the cross section for the abutment wall, using 0.2m spacing. As explained in the previous section, the primary reinforcement spacing for a GRS wall application is 0.4m, which was used for the wing walls. Short lengths of reinforcement tails, typically about 1 m were also used to allow proper compaction at the face of the wall behind the block. The tails ensure that the facing block is connected adequately to the GRS mass. A tail roll can be quickly made by cutting a 1 m section from a roll of geotextile with a chainsaw.

The Bowman Road Bridge spans Powell Creek that frequently floods but does not produce sufficient water velocity to scour. Never the less, the abutments were protected against scour by building them on a reinforced soil foundation (RSF) wrapped in geotextile. The first course of the concrete modular block was placed directly on a sheet of geotextile that encapsulated the RSF.

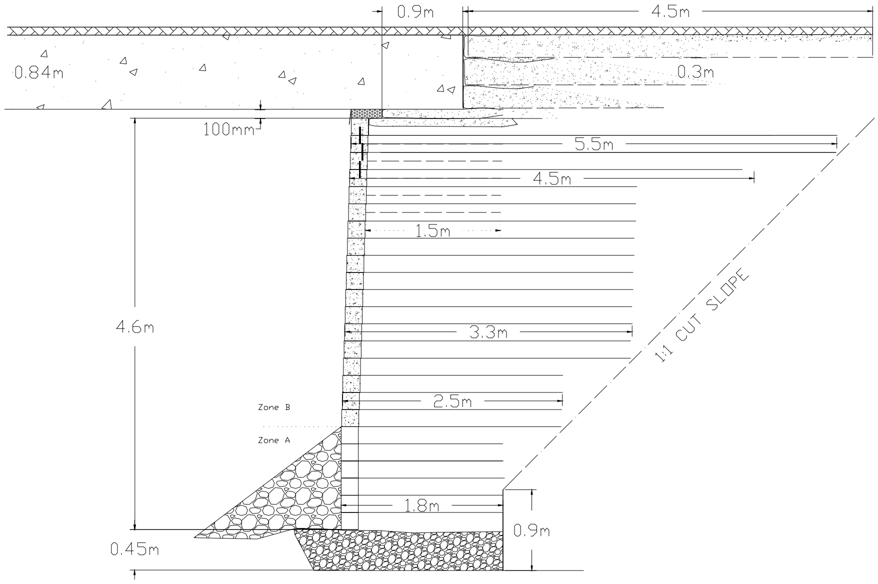

Figure 5. Reinforcement Schedule (Abutment and Approach Way)

The sheets of geotextile fabric were used to encapsulate the RSF. They were overlapped so that the top piece was upstream similar to the way roof shingles shed water. The depth of the RSF was about 0.46m. It was built with two layers of compacted, well-graded gravel layered with geotextile in the middle.

The concrete modular blocks used to face the abutment were split-faced concrete masonry units (CMUs). The blocks were frictionally connected to the GRS mass with a layer of reinforcement between the rows of modular blocks. The height of each abutment wall was about 4.6m. The walls were built with two different colours and types of CMU block; a red solid core block in the lower base section of the wall and a grey hollow core block in the upper 2/3 section. A riprap talus was built against the red block to armour the face of the wall against scour. Exposure of red block during inspection is a visual indication that erosion or scour may have occurred.

GRS INTEGRATION

As shown in Figure 5, at the top of the wall, the spacing of the reinforcement was reduced in the area beneath the bridge beams to significantly increase the strength of the GRS composite. This detail allows load to be placed directly behind the face with insignificant lateral deformation. On top of the wall, a 0.1m thick bridge seat was constructed with a layer of fine gravel encapsulated in a sheet of the 70 kN/m geotextile reinforcement.

To form the Integrated Abutment the box beams were placed directly on the GRS abutments. The bridge was built without cast-in-place concrete. The bridge does not have an approach slab; instead, GRS was compacted directly behind the bridge beams to form the approach way and create the smooth transition from the roadway to the bridge as illustrated in Figure 5 and Figure 10.

As explained above, the GRS was compacted against each beam end and was layered to create a gradual transition from the abutment to the road. The layers behind the beam-ends were wrapped to confine the compacted approach fill against the beam-ends and the adjacent side slopes to prevent lateral spreading. Since the wrapped faced GRS fill behind the beam ends is free standing, the active lateral pressure against the beam ends is considered to be negligible. The wrapped face fill also prevents migration of fill during thermal bridge cycles and vehicle live loads.

PERFORMANCE MONITORING

The bridge and abutments were instrumented by FHWA to evaluate performance and GRS-bridge interaction. A survey station was installed to record bridge settlement and movement of the GRS abutments. Earth pressure cells were installed to measure stress beneath the beams and at the base of the GRS abutments. Several earth pressure cells were also installed behind the beams to measure passive earth pressures against the approach fill due to the thermal cycles of the beams. Strain gauges were installed in the beams during casting to correlate thermal expansion and contraction cycles to the pressure at the beam ends.

The instrumentation and settlement will be monitored for a 2 to 3 year period. Based on observations and collected data to date, the bridge is performing very well. There has been very little movement or settling and no pavement cracking at the approach. The stress due to thermal cycles of the beam ends against the approach fill is in the range of about 25kN/m^2.

Figure 6 is a graph that shows the settlement of each abutment with time. Included in each graph is the settlement of both the abutment wall and bridge beams. The weight of the bridge on the GRS abutments is equivalent to bearing stress of 163 kN/m^2. The results indicate how the performance test can be used to predict vertical deformation of the GRS mass due to a surcharge.

Plotted on the curve in figure 2 is the dead load stress for the Bowman Road Bridge; 163kN/m^2 with a corresponding strain of 0.3%. The graph in figure 6 indicates that the average total settlement at the end of the beams is about 22 mm. The calculation of the 163kN/m^2 was based on a 0.9m wide beam seat as shown in figure 5. The average measured strain for both abutments was actually 0.18%. An explanation for the reduction in strain is that the very close (0.1m) reinforcement layers beneath the beam seat increases the effective bearing area width to 1.5m. Plotted in Figure 2 is the recalculated stress for an effective bearing width of 1.5m is 98kN/m^2. This corresponds to a strain of 0.21%; much closer to the measured value, suggesting that there is considerable load shedding into the secondary layers beneath the beam seat. The settlement of the bridge is the result of deformation within the GRS mass and consolidation of the foundation soil beneath the abutments. As indicated in the graph, consolidation of the foundation soil is equal to the settlement of the abutment walls (face), 13.7mm. The average settlement difference between the beam and the face of each GRS abutment wall is the result of deformation within the GRS mass caused by the surcharge weight of the superstructure is about 8.5mm.

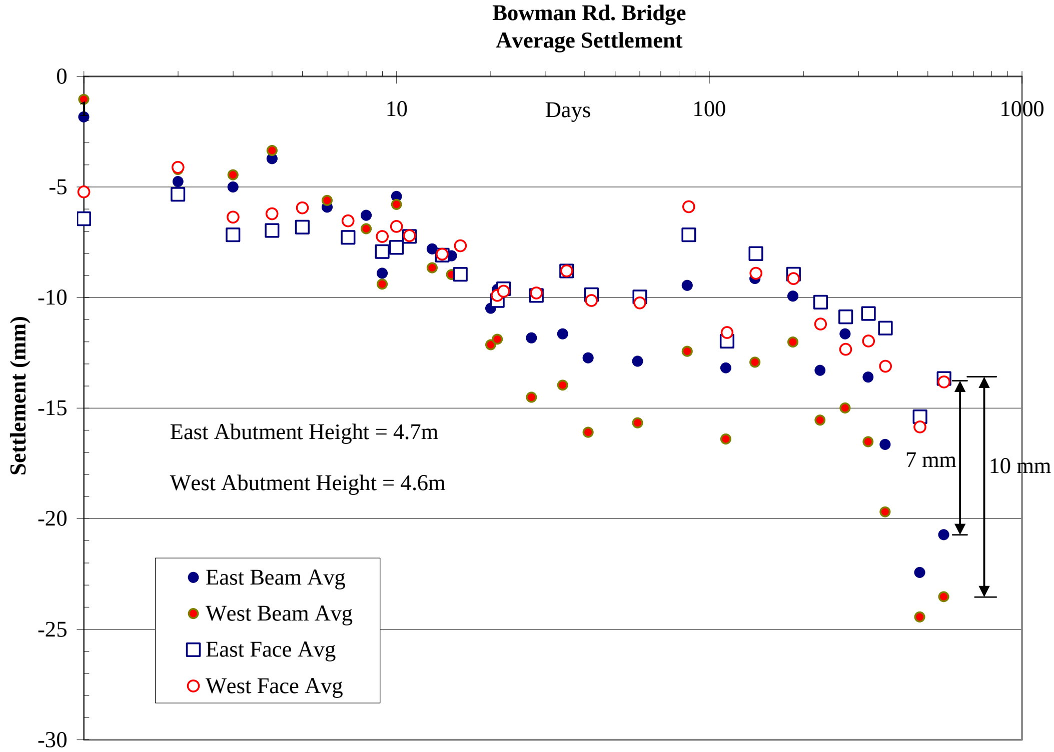

Figure 6. Bowman Road Bridge (Post Construction Settlement)

The differential settlement between each end of the bridge, 2.7 mm, is negligible. The pavement overlay on this joint-less bridge system has not cracked to date. Defiance County has built 11 additional bridges supported on GRS abutments. All are performing excellently.

Figure 7. Construction of GRS Abutment

Figure 8. Completed Bowman Road Bridge

Figure 9. Placement of Concrete Box Beams Directly on the GRS Abutment (note absence of concrete footing)

Figure 10. Integration of Approach Way for the Glenberg Bridge, next day after beam placement

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