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Geosynthetic Reinforced Soil for Low-Volume Bridge Abutments

tech transfer summary

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RESEARCH PROJECT TITLE

Geosynthetic Reinforced Soil for Low-Volume Bridge Abutments

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GRS abutment systems were studied from October 2010 through December 2011 as a potentially cost-effective and structurally-efficient alternative for supporting LVR bridge abutments.

Problem Statement

Iowa currently has approximately 25,000 bridges and about 80 percent of them are on low-volume roads (LVRs). Because many of these bridges are on rural county roads, funding is limited to replace deficient bridges.

Performance of substructure components (i.e., abutment and foundation soils) is believed to play a major role in the overall performance of the bridges. Use of geosynthetic-reinforced soil (GRS) abutment systems, which involves constructing engineered granular backfill material with closely-spaced alternating layers of geosynthetic reinforcement, can potentially be a cost-effective and structurally-efficient alternative for supporting LVR bridge abutments.

However, there are no documented case studies on GRS bridge abutments with performance monitoring information in Iowa. The feasibility of using this method needs to be investigated properly and documented for local conditions and materials with regard to several aspects, including internal and external stability during and after construction, construction methods, and performance monitoring.

Project Objectives

- Develop an instrumentation and monitoring plan to evaluate performance of newly-constructed GRS bridge abutment systems
- Develop a design approach and construction guidelines for GRS bridge abutment systems with shallow spread footings on LVR bridges
- Document and evaluate the cost and construction aspects associated with construction of GRS bridge abutment systems from detailed field observations on project sites
- Produce a research report and technology transfer materials that provide recommendations for use and potential limitations of GRS bridge abutment systems

Research Methodology

A review of literature on GRS abutment systems, material specifications, a newly-developed Federal Highway Administration (FHWA)-recommended design methodology and construction considerations, and results from two field demonstration projects are presented in the report.

The two projects included GRS abutment substructure and railroad flat car (RRFC) bridge superstructure, and were constructed in Buchanan County, Iowa. A woven geosynthetic material was used as the geosynthetic reinforcement in the fill material on both projects. Details of the two demonstration projects are provided below.



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Figure 1. Bridge 1 GRS abutment with grouted riprap facing

Bridge 1 – Olympic Avenue

Bridge 1 involved replacing an existing timber back wall abutment, with a GRS bridge abutment with flexible wrapped geosynthetic and grouted riprap facing (Figure 1), to support a 73 ft RRFC bridge on a reinforced concrete spread footing. No instrumentation or testing was performed by this research team on that project.

Bridge 2 – 250th Street

Bridge 2 involved replacing a 90+ year-old steel bridge supported on a concrete abutment with a 68.5 ft RRFC bridge supported on reinforced concrete spread footings founded on GRS fill material. The new bridge was longer, so the existing concrete bridge abutments, along with some existing fill, were left in place to serve as GRS facing (Figure 2).

The existing soil under the proposed new footing location was excavated and replaced with GRS fill material. Steel sheet piles were installed on the excavation sides for scour protection (Figure 2). Soil borings, in situ testing, laboratory testing, and instrumentation installation were conducted at this bridge site.

In situ tests included conducting nuclear gauge (NG) density tests and light weight deflectometer (LWD) tests on GRS fill material, live load (LL) tests (with a loaded test truck) monitoring bridge deflections and stresses in the GRS fill material, and bridge abutment settlement monitoring.

Instrumentation included installing inclinometers and piezometers in the ground, and semiconductor and vibrating wire earth pressure cells (EPCs) in the GRS fill material and under the footing.

Laboratory tests included characterizing the shear strength properties of GRS fill material from direct shear and consolidated drained (CD) triaxial tests on material with and without geosynthetic reinforcement. In addition, repeated load cyclic triaxial tests were conducted on material with and without geosynthetic reinforcement to evaluate differences in their permanent deformation characteristics.



Figure 2. Bridge 2 GRS fill material placed to support footing

Key Findings

Savings in Construction Costs

The construction costs of Bridges 1 and 2 were about \$49k and \$43k, respectively. These construction costs were about 50 to 60 percent lower than the estimated construction costs for building a conventional bridge with reinforced concrete abutments, piling, and concrete superstructure at these sites. The cost reductions using the GRS substructure with the RRFC superstructure are realized with the ease in construction, shortened construction time (one abutment per day), and reduced material and labor costs.

Laboratory Test Results

CD triaxial test results showed an increase in effective shear strength parameters when the granular material was reinforced with geosynthetic (Figure 3). Cyclic triaxial test results showed a decrease in total permanent strain at the end of 70,000 cycles when the granular material was reinforced with geosynthetic (Figure 4). These improvements in geosynthetic reinforced samples are believed to be due to the lateral restraint effect at the soil-geosynthetic interface in the sample.

Field Test and In-Ground Instrumentation Results

- Bridge 2: Total vertical stress readings in the EPCs located at about 2.2 and 3.8 ft below the footing indicated that the dead load vertical stress applied under the footing (about 2,120 lbs/ft²) was almost fully transferred down to the bottom of the GRS fill material. The horizontal dead load stresses along the excavation walls were about 600 lbs/ft² or less. The horizontal to vertical stress was less than 0.25, thus indicating low lateral stress on the soil surrounding the GRS fill material.
- Bridges 1 and 2: Bridge abutment elevation monitoring since end of construction to about 1 year after construction indicated maximum settlements of ≤ 0.7 in. with transverse differential settlements of ≤ 0.2 in. at each abutment.

- Bridge 2: Static LL tests indicated non-uniform deflections transversely across the bridge at the center span (with a differential deflection of up to 0.8 in.) when the truck was positioned along the edge. This suggests poor load transfer across the RRFCs. A maximum deflection of about 0.9 in. was measured during static LL testing. The maximum measured deflection was close to but less than the AASHTO allowable deflection. However, it must be noted that the AASHTO allowable limits are based on a 72 kip three-axle test truck, while the test truck used in this study weighed about 52 to 53 kips.
- Bridge 2: Peak increase in vertical stresses in the GRS fill material was observed when the test truck was positioned directly above the footing, as expected. Peak increase in horizontal stresses in the excavation at the GRS/existing soil interface was observed when the test truck was positioned either directly above or within 20 ft of the footing. The estimated vertical stress increase under LL using elastic solutions compared well with the measured vertical stress increase values from EPCs. The horizontal stress increase under LL were lower than the estimated values from elastic solutions, as the elastic solutions used do not account for the lateral restraint effect in the reinforced soil layers, which causes a reduction in the horizontal stresses.
- Bridge 2: EPC results indicated that the ratio of vertical stress increase in the GRS fill due to dynamic (with test truck traveling from 5 to 40 mph) and static loading varied from about 0.8 to 1.2, with an average of about 1.0. The increase in vertical stresses in the GRS fill material under a 1,000 bushel load semi-truck and a loaded grain cart was about 1.3 and 1.6 times higher than the increase in vertical stresses under the loaded test truck, respectively (Figure 5).

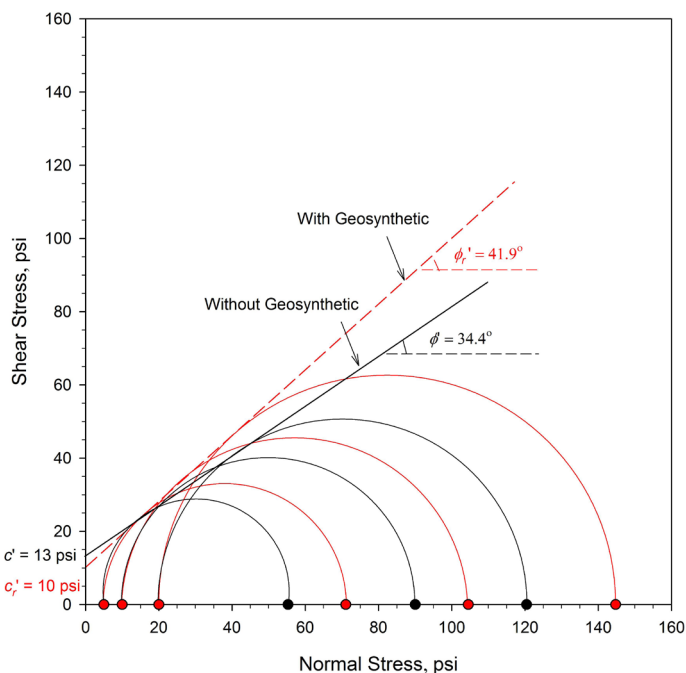


Figure 3. Mohr-Coulomb failure envelopes from CD tests on granular materials with and without geosynthetic reinforcement

Bearing Capacity and Slope Stability Analysis Results – Bridge 2

- Bearing capacity analysis was conducted for three potential failure modes: A – bearing capacity failure within the foundation soil, B – bearing capacity failure within the GRS fill material, and C – punching shear failure through the GRS fill material and bearing capacity failure in the foundation soil. Analysis results indicated lowest factor of safety (FS) values (1.8 to 2.6) for failure mode B and they were lower than the minimum recommended value ($FS_{GRSBearing} \geq 3.5$) by the FHWA. For failure modes A and C, a case with the water table at the surface of the GRS fill material showed the lowest FS values in case of deadload + liveload and were lower than the recommended value ($FS_{Bearing} \geq 2.5$) by the FHWA.
- The ultimate strength of geosynthetic reinforcement, T_f , plays a critical role in determining the ultimate bearing capacity of the foundations over GRS fill material. The T_f of the geosynthetic product used in this study was about 1,200 lbs/ft, which is lower than the FHWA recommended minimum $T_f = 4,800$ lbs/ft. This resulted in lower FS values than recommended, as indicated above (failure mode B).
- Global stability analysis was conducted using three water table scenarios: A – water level at the base of the GRS fill material, B – water level during flooding, and C – water levels in a rapid draw down condition. The analysis indicated that the FS values for both rapid draw down and flooding cases (1.2 to 1.4) were lower than the recommended minimum ($FS_{Stability} = 1.5$) by the FHWA. The potential failure surfaces were at the interface of the GRS fill material and the underlying weaker foundation layer.

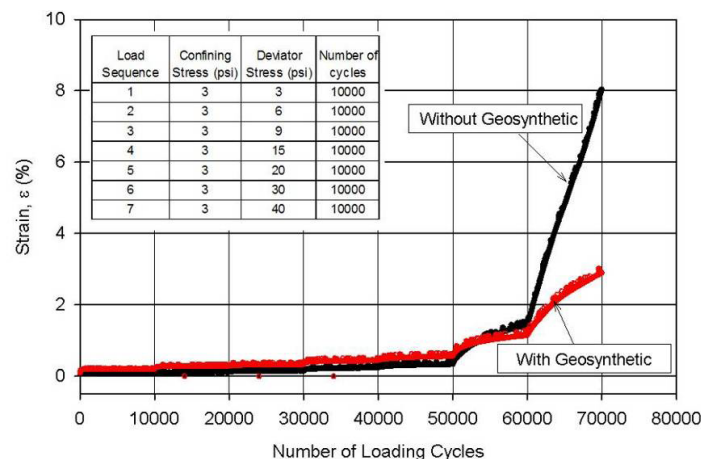


Figure 4. Comparison of permanent strain versus load cycles on granular materials with and without geosynthetic reinforcement

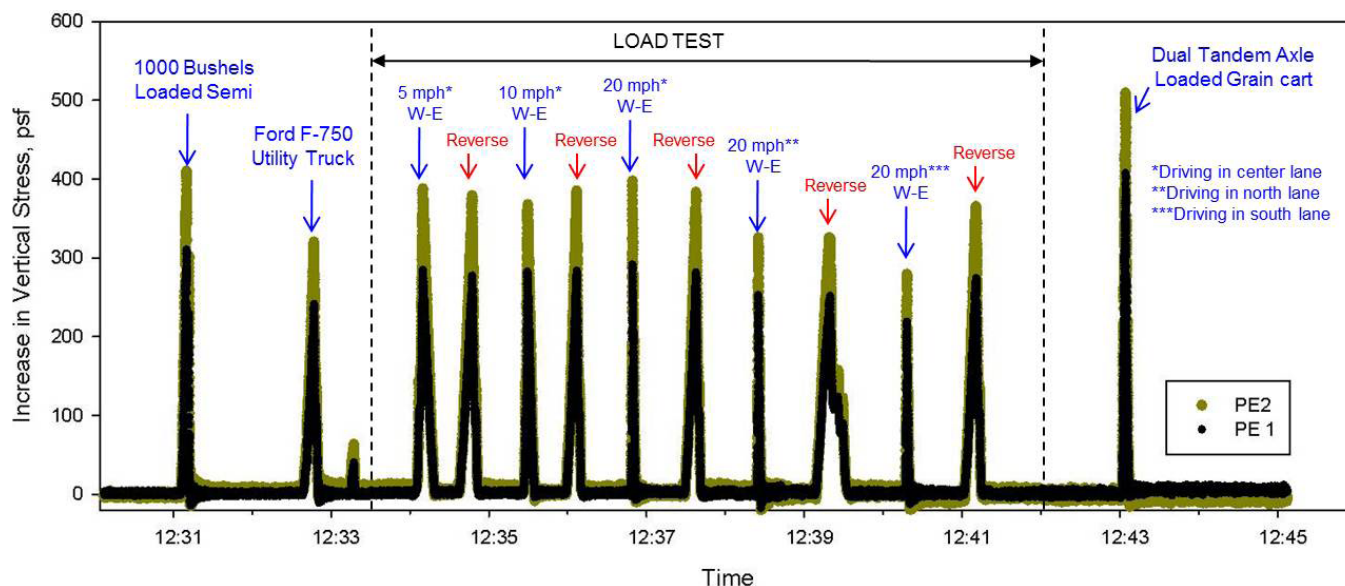


Figure 5. Bridge 2 increase in total vertical stresses at 3.8 ft (PE1) and at 2.2 ft (PE2) below footing during dynamic loading under husbandry traffic and load test vehicle

Recommendations for Future Projects

- The T_f of geosynthetic reinforcement must be selected to meet the minimum FHWA requirements. Typically, the T_f values are provided by the manufacturer as part of the product technical data sheets. Consideration must also be given to selecting a geosynthetic product that has good infiltration capacity so that the GRS fill material is easily drained during flooding. As an example, according to the manufacturer, Mirafi® HP570 woven geosynthetic or higher grade has $T_f \geq 4,800$ lbs/ft and also has good permeability (30 gal/min/ft²).
- Bridge 1 construction involved installation of rock fill for erosion protection at the toe of the GRS abutment slopes. The installation of rock fill material at that project site was performed by excavating a trench after the fill slopes were constructed. Excavation at the toe of slopes can contribute to slope instability and must be avoided. Any excavations at the toe of the slope must be performed before the fill layers are constructed, and should be properly backfilled and compacted.
- Neither bridge evaluated in this study included a drainage design. Field observations indicated that flood water levels reached nearly up to the bottom of the superstructure at Bridge 2. Draining the water entered into the GRS fill materials is critical to the long term performance of these structures. Drainage in critical areas, including behind the wall, base of the wall, and locations where a fill slope meets a wall face, must be incorporated into the design.
- Slope stability analysis on the Bridge 2 abutment indicated potential failure surfaces at the interface of the GRS fill material and the underlying weaker foundation layer. Obtaining subsurface soil information prior to bridge construction is recommended, so that excavation depths to determine any weak foundation layers can be determined prior to construction. If soil boring information is not available, at least testing at the bottom of excavation must be conducted to determine if the foundation layers are stable.

Implementation Benefits

The primary benefits of using GRS bridge abutments for low volume road bridges include (1) cost savings due to lower material costs than conventional reinforced concrete bridge abutments and piling, less need for highly skilled labor, and less construction time; (2) ease in construction; and (3) less disruption to traffic due to short construction times.

Implementation Readiness

GRS bridge abutments were constructed using existing abutment wall and grouted riprap as facing elements in this research study. In situ test results from the two demonstration projects in this study indicated that the bridges performed well within the monitoring phase of the project. Performance of these structures over a long period must be investigated. Long-term performance of GRS abutments with different facing elements (e.g., sheet piles, concrete masonry units, and timber-faced walls), must be evaluated.

Future research should also include an experimental study to evaluate the bearing capacity of GRS fill materials with different granular fill materials used commonly in Iowa and geosynthetic materials (woven and non woven) with varying ultimate strengths. The bearing capacity evaluations must include performance test evaluation with full-scale field testing to failure, to determine the ultimate bearing capacities.