INSTRUMENTATION OF GEOSYNTHETIC REINFORCED SOIL-INTEGRATED BRIDGE SYSTEM (GRS-IBS)

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ABSTRACT

Instrumentation is a vital tool to monitor and evaluate the behavior of Geosynthetic Reinforced Soil (GRS). The concept of GRS-IBS will be explained in this paper. Where GRS-IBS is a relatively new technology, measurements of internal strain, displacement, water and soil pressure and temperature provide an understanding to a GRS's geostructural performance. Different types of sensors are available to monitor these parameters. A case study will be presented which involves instrumentation with earth pressure cells, piezometers and geosynthetic fabric with fiber optic strain sensors to monitor the performance of a GRS-IBS in Barceloneta, Puerto Rico. Initially the specifications identified traditional geotechnical instrumentation, however fiber optic technology was ultimately utilized for all sensors. The audience will gain a basic understanding of design and construction issues related to GRS-IBS applications. Selecting appropriate instrumentation and technologies to monitor performance during construction and serviceability of GRS-IBS structures will be presented.

1. GRS-IBS TECHNOLOGY

GRS-IBS provides bridge support by using closely spaced alternating layers of compacted granular fill and geotextile reinforcing sheets. This technology was originally developed by the Federal Highway Administration (FHWA) under the Bridge of the Future Initiative. The goal was to combine common and well known building techniques with cutting-edge geosynthetics to produce an accelerated means of bridge support construction. Since GRS-IBS was first developed in 2010, nearly 200 bridges in 44 states, Puerto Rico and the District of Columbia have been selected for construction using GRS-IBS. As shown in Figure 1, GRS-IBS is comprised of three main design components - a reinforced soil foundation, a GRS abutment, and a GRS integrated approach.

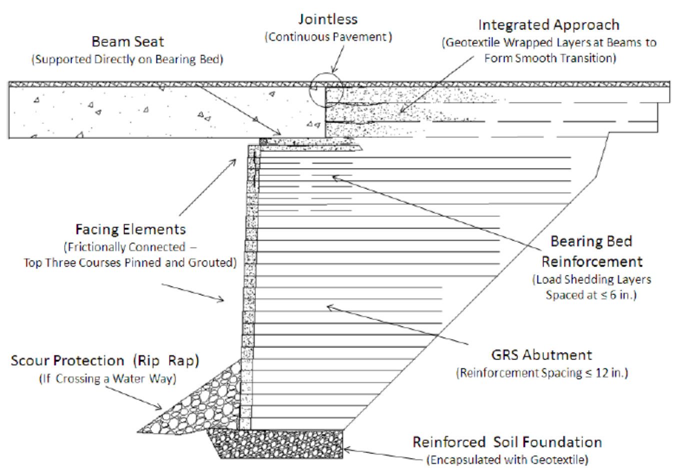

Figure 1: Typical GRS-IBS cross section components (Federal Highway Association , 2011)

GRS combines the compressive characteristics of the fill material and the tensile strength of the reinforcement to create a stronger composite material. With closely spaced reinforcement, the result is a stable abutment.

GRS-IBS is a promising replacement to conventional bridge support technology as it offers many unique benefits. The construction sequence is simple. The geotextile is placed, the granular fill is placed, spread and compacted. This process is repeated as the abutment is built up. As this is a simple procedure, commonly available equipment and non-specialized labor can be utilized. This design is flexible, and can be easily modified in the field for unseen or unexpected conditions such as obstructions, utilities or unfavorable weather conditions. As a result of the reduced construction time and costs, cost savings between 25 to 60 percent have been recorded on completed projects. (Federal Highway Association , 2011)

Another benefit of GRS-IBS is a seamless transition from the bridge to the approaching roadway. The alternating layers of reinforcement and fill eliminate the need for cast-in-place concrete or joints. This eliminates the need for slabs and joints which historically are the most costly maintenance issue for bridge owners.

Providing instrumentation for GRS-IBS helps to understand the geostructural performance of this relatively new technology. The effectiveness of the closely spaced reinforcement can be evaluated, the design can be validated and helps to advance this new technology by providing assurance to the design standards and installation methods. Instrumentation can provide early warning signs of possible distress which could be immediately addressed. A case study will be introduced to explain the components of an instrumentation and monitoring program which has been deployed in Barceloneta, Puerto Rico on a GRS-IBS installation.

2. BARCELONETA, PUERTO RICO CASE STUDY

2.1 Introduction

In 2011, U.S. Transportation Secretary LaHood announced a $9.5 million grant aimed at reducing congestion and creating long-lasting roads and bridges throughout 13 states and Puerto Rico using innovative technologies. Fifteen projects were identified which would use proven technologies that are not widely used with the goal to encourage and spread knowledge relative to innovative practices. The grants provide the states the ability to use these technologies, which can reduce life cycle costs, reduce construction time and increase structure life and safety, which they may not normally consider. Bridge No. 1828 on PR 140 in Barceloneta using geosynthetic reinforced soil system technology (GRS-IBS) was partially funded by such a grant. Initially the specifications identified traditional geotechnical instrumentation, however fiber optic technology was ultimately utilized for all sensors. Prima Facie out of Guaynabo, PR was selected as the prime contractor. Geocomp was brought into the team for the instrumentation and monitoring portion due to past experience and current relationship with Tencate as the lead installer for their intelligent geotextile, Geodetect® and as a systems integrator for MicronOptics, the manufacturer of the fiber optic interrogator data acquisition system.

2.2 Project Description

Barceloneta is located about 40 miles to the west of San Juan, Puerto Rico. PR 140 is a main highway running north to south from Barceloneta to Ponce. Figure 2 identifies the project location.

Figure 2: Project Location

The construction of the Bridge No. 1828 abutments followed the approach outlined in FHWA Publication No. FHWA-HRT-11-026 “Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide.” For Bridge No. 1828 alternating layers of Huesker Comtrac P105 woven polypropylene geotextile fabric and 8 in. lifts of granular clean gravel No. 18 were used to build up the reinforced abutment. Compaction was completed at each 8 in. lift. Most GRS-IBS utilize a block facing which serves as an aid during construction. As shown in Figure 3, the existing abutment face was utilized for the GRS-IBS facing component for this project.

Figure 3: Construction of GRS abutment utilizing existing abutment face

2.3 Instrumentation

This project was bid with an instrumentation and monitoring package included with construction to assess the GRS-IBS design and performance with time. The instrumentation in the specifications included standard geotechnical instruments including piezometers and pressure cells complimented by the innovative product Geodetect® which serves as a geosynthetic strain meter.

The project team initially planned to use vibrating wire piezometers and pressure cells but made the decision to switch all of the instrumentation to fiber optic. There were a few reasons why they switched to fiber optic. Yearly flooding is typical at the project site. The owners were concerned with electric surcharge causing a short in the system because of heavy rain and lightning storms. Additionally, due to a high rate of copper theft in the area the switch to fiber optic posed less of an appeal for crime.

As shown in Figure 4, the instrumentation program was comprised of 16 pressure cells, 2 piezometers (not pictured) and 6 geosynthetic strips with embedded fiber optic strain sensors.

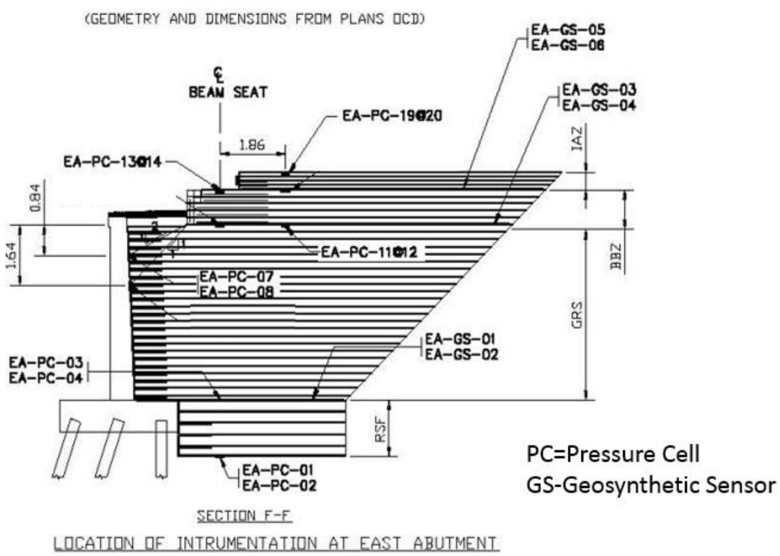

Figure 4: Instrumentation Layout Plan

The earth pressure cells provide a direct way to measure total sub soil pressures including both the effective soil stress and pore water pressures. The piezometers measure pore water pressures and ground water elevations. The geosynthetic strips with embedded strain sensors (Geodetect®) directly measure horizontal strain in the reinforced soil mass. The pressure cells and piezometers are fabry-perot based sensor technology and the Geodetect® strips use fiber Bragg grating (FBG) strain sensors. The main difference between the two being that FBG technology allows for multiple sensors to run in series on the same channel whereas fabry-perot technology are a single channel sensor.

Geodetect®, manufactured by Tencate, is considered one of the first “intelligent geotextiles.” During the manufacturing process fiber optic sensors are embedded into the geotextile, as shown in Figure 5.

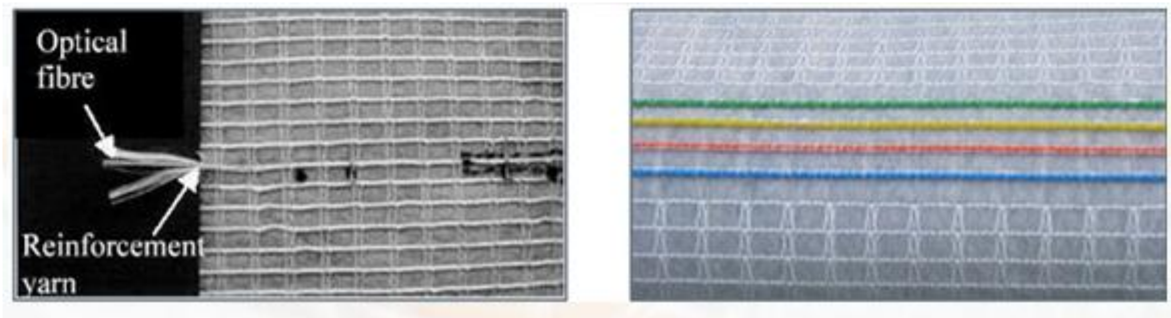

Figure 5: Optical Fiber Integration with geotextile (Tencate, 2012)

Since the geotextile is in direct contact with the soil, strain in the soil can be measured. The geotextile sensors communicate though the data acquisition system and logger. A Micron Optics 8 channel interrogator was used for this application. Each Geodetect® strip contains 11 sensors. The continuous fiber can be read from either end. This is a useful feature of the product because if a break in the senor fiber occurs during installation or during the lifetime use of the sensors, the sensor data can be acquired from either end of the fiber.

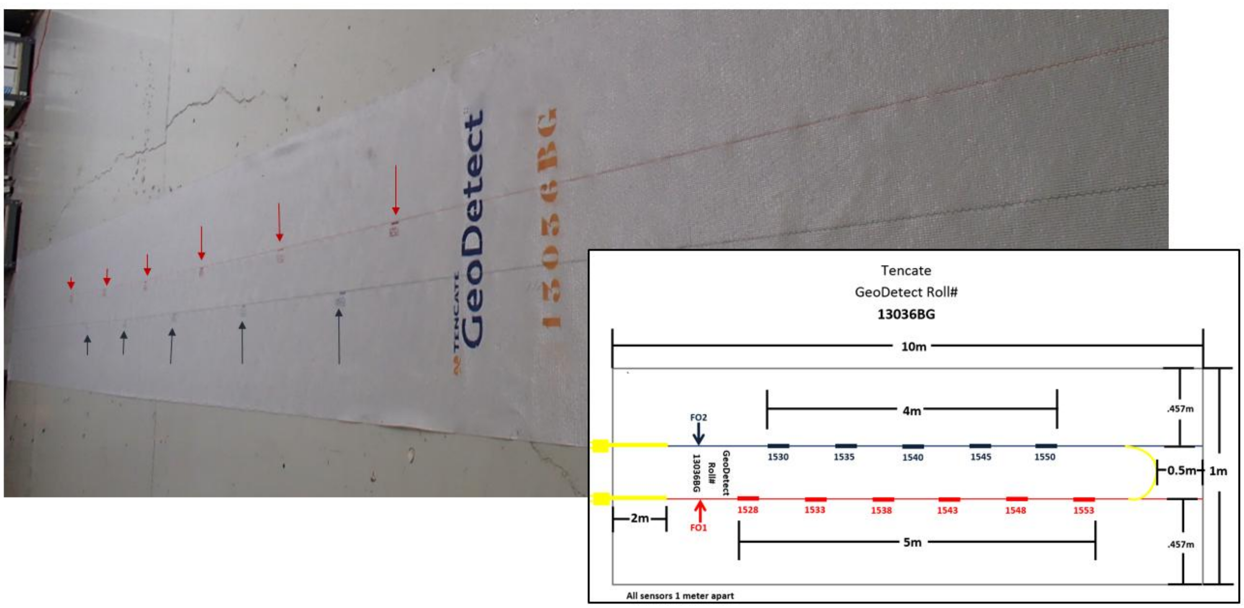

Figure 6: Geodetect® and calibration sheet

Data from the sensors will be collected through a uniquely designed system which has its own power, and can be remotely accessed or accessed directly through a laptop connection. Data will be collected continuously in 3 minute intervals, stored and transmitted wirelessly through an IP phone connection to a remote data storage location. The system is connected to 12V batteries which are powered by solar panels. Figure 7 shows the Data Acquisition System (D.A.S) components and enclosure. At the time of this paper, the system is yet to be fully commissioned.

Figure 7: Data acquisition system

2.4 Discussions and Lessons Learned

Geodetect® will be a useful tool to monitor stress in the reinforced structure as it provides the user with the same information that would typically be gathered from an array of traditional geotechnical instrumentation, commonly strain gauges affixed to geosynthetics.

In order to monitor magnitude and axis of the stresses within the reinforced zone, strain gauges would commonly be deployed. Strain gauges are more difficult to install in the field. They are more time consuming to install than Geodetect®, which can replace multiple strain gauges simplifying installation and speeding up construction.

A big benefit of Geodetect® is that it is less intrusive than a traditional instruments. To get the most accurate measurements using a soil pressure cell, they should be re-calibrated in the in-situ material. Pressure cells and strain gauges produce a more disturbed environment adding rigidity to the reinforced system that would not normally be there. Geodetect® is a flexible material, very similar to the material being used for reinforcement, while it does add some strength to the system it does not add the level of disturbance that typical geotechnical instruments do.

Although the system on Bridge No. 1828 is yet to be fully commissioned, we have worked on a similar project in Aurora, Colorado as the Geodetect® installation specialists, where we have obtained data from the Geodetect® sensors. Figure 8 displays data obtained from a Colorado Department of Transportation (CDOT) GRS-IBS project which was constructed in the summer of 2014.

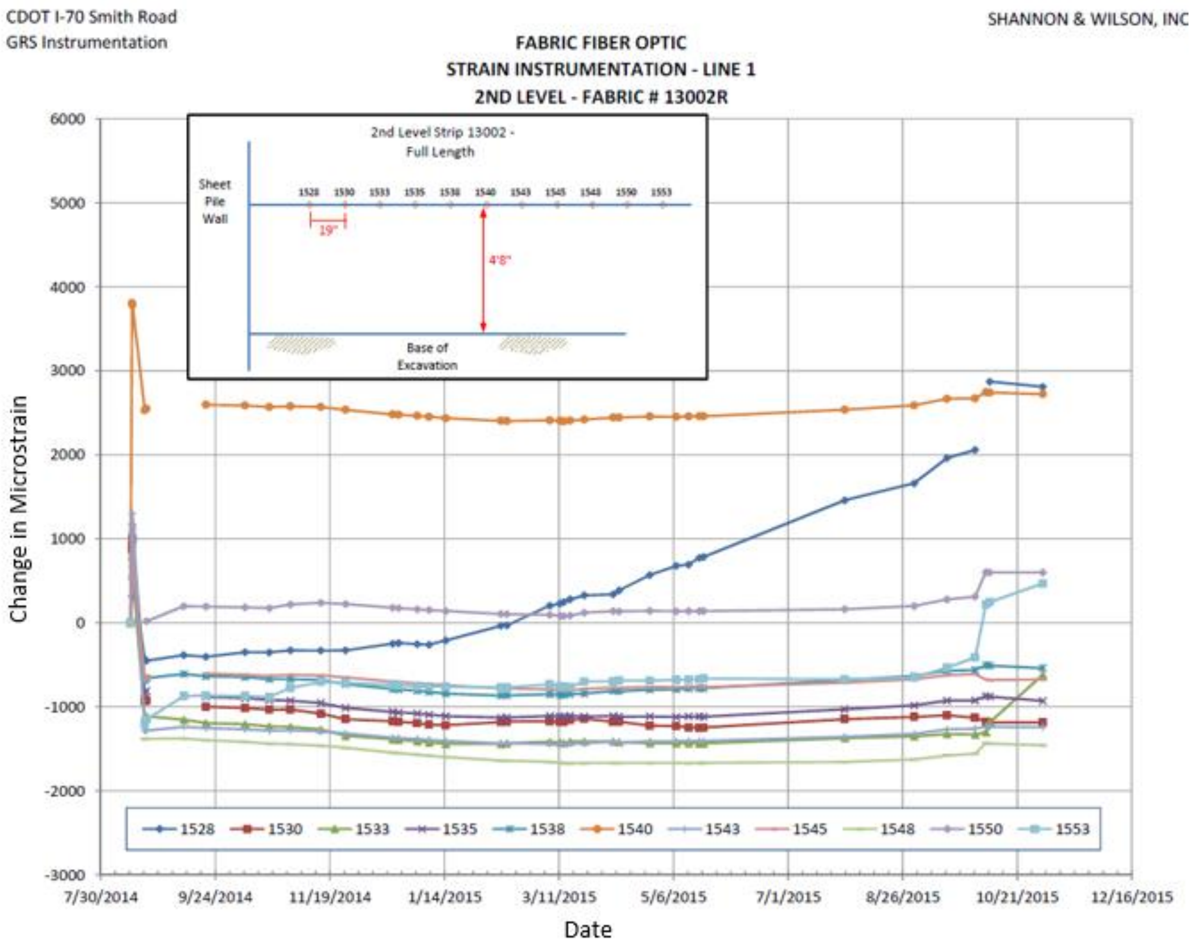

Figure 8: Data from Geodetect® on CDOT GRS-IBS project

We are optimistic that the Geodetect® on Bridge No. 1828 in Puerto Rico will also present very stable geosynthetics strain readings as we see in Figure 8. On both projects, dissipation of strain and pressures with depth will be evaluated and compared against construction records for different loading conditions. These studies will help evaluate the long-term performance of the different instrument types to determine if Geodetect® could become a replacement system for early warning signs of problems evolving within the reinforced mass or a complimentary system to traditional geotechnical instrumentation.

The installation of the Geodetect® product is very simple. For protection, a layer of sand is added on top of the granular fill, the Geodetect® is placed on the sand and then covered with another layer of sand before continuing to add the granular fill used for the GRS. In Figure 9, the Geodetect® is being placed over a protective layer of sand.

Figure 9: Geodetect® installation over layer of sand

Due to the fragile nature of fiber optics, extra caution must be taken in the field to try to protect the fiber during transportation, installation, and through the active construction sequence. The Geodetect® strips for this project measure 1 m. in width by 10 m. in length. The Geodetect® product can be "folded" over if the necessary length is not available. If the installer must produce a fold over, the radius of the fold should be as large as possible. There should never be a 90 degree bend through the fiber or the chance of a break or a block in light transmission increases. The fold should not be directly on the sensor. To create a radius for a fold, adequate sand should be placed. Figure 10 shows a fold completed on this project. The fold over location should be documented in the project notes in order to relate the calibration documents and reading locations.

Figure 10: Geodetect® fold over

It is important to read the sensors during the installation stages. Ideally they should be read immediately prior to installation, once unrolled and placed in their designated location, after they are covered with the sand layer and during subsequent layers of granular fill placement and compaction. The project team and all laborers on site need to be educated about the presence of the fiber in the geosynthetics material so that they can avoid stepping on the fibers, lead wires and refrain from compacting directly on top of the fibers and reduce the chance of a break in the fiber. Installing the Geodetect® is relatively quick and does not slow down the construction process by much, however, obtaining frequent readings during the installation process proves to be invaluable to refine the process for future projects.

On this project, even with very careful placement and an adequate sand coverage, breaks in the fiber occurred. These breaks occurred in the strips which were installed at the deepest layers in the abutment. Since the fiber is imbedded into the geotextile as a continuous loop, the user has access to both ends of the fiber and all 11 sensors on the fiber were able to provide useful data, despite having a break. In the planning stage, there should be a consideration to the possibility of a break which would require additional channels on the interrogator to be able to read all sensors (potentially from each end of the fiber strip). We selected an 8 channel interrogator, which allowed one channel for each of the 6 strips and 2 extra channels. If additional channels are required due to breaks, it may not be necessary to read all sensors as the arrangement of multiple sensors provides an adjacent pair for each sensor on the 1 meter width strip.

3. SUMMARY

The advantages of GRS-IBS are clear: The system can be easily designed and employed with common materials and equipment and readily available laborers. The bump which is usually common at the approach and bridge is eliminated. The simple construction sequence saves time and money in both the planning and execution stages. The accelerated construction time reduces traffic disruptions.

Developing an instrumentation and monitoring system comprised of fiber optic technology provides the project team with benefits over traditional instrumentation such as protection against lightning or electrical interference, allowance for longer sensors cable runs and resistance to corrosive effects seen in copper wire instrumentation systems. The use of fiber optic technology for structural health monitoring has been used for many years. However, the advancement of intelligent geosynthetic products utilizing this technology has only recently been providing more efficient ways to monitor. Geodetect® has been used successfully to monitor internal strain of a reinforced mass. The next step is to evaluate the performance of the Geodetect® as a component of the entire instrumentation program on Bridge No. 1828 when the system is fully deployed.

As GRS-IBS is becoming a more popular construction technique, applied research projects (such as Bridge No. 1828) focused on understanding the lifetime performance become a vital tool to aiding widespread use of the new system. Collecting and analyzing data from an instrumentation program like the one developed for this bridge will be a tool to evaluate the effectiveness of the closely spaced reinforcement. Innovative technologies such as Geodetect® enhance the instrumentation and monitoring program, which in turn advances the growth and acceptance of new technology and design guidelines for accelerated bridge construction.

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