Geotextiles and Geomembranes 45 (2017) 34–47

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Performance monitoring of Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS) in Louisiana

Milad Saghebfar [a], Murad Abu-Farsakh [a, *], Allam Ardah [a], Qiming Chen [a], Benjamin A. Fernandez [b]

[a] *Louisiana Transportation Research Center, Louisiana State University, Baton Rouge, LA, 70808, United States*
[b] *Louisiana Department of Transportation & Development, Baton Rouge, LA, 70808, United States*

ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form
14 November 2016
Accepted 16 November 2016

Keywords:
Geosynthetic
Reinforced soil
GRS-IBS
Instrumentation
Monitoring
Abutment

ABSTRACT

The Geosynthetic Reinforced Soil (GRS) Integrated Bridge System (IBS) is an alternative design method to the conventional bridge support technology. Closely spaced layers of geosynthetic reinforcement and compacted granular fill material can provide direct bearing support for structural bridge members if designed and constructed properly. This new technology has a number of advantages including reduced construction time and cost, generally fewer construction difficulties, and easier maintenance over the life cycle of the structure. These advantages have led to a significant increase in the rate of construction of GRS-IBS structures in recent years. This paper presents details on the instrumentation plan, short-term behavior monitoring, and experiences gained from the implementation of the first GRS-IBS project in Louisiana. The monitoring program consisted of measuring bridge deformations, settlements, strains along the reinforcement, vertical and horizontal stresses within the abutment, and pore water pressures. In this paper, the performance of instrumentation sensors was evaluated to improve future instrumentation programs. Measurements from the instrumentations also provide valuable information to evaluate the design procedure and the performance of GRS-IBS bridges. The instrumentation readings showed that the magnitude and distribution of strains along the reinforcements vary with depth. The locus of maximum strains in the abutment varied by the surcharge load and time that did not corresponds to the $(45+\phi/2)$ line, especially after the placement of steel girders. A comparison was made between the measured and theoretical value of thrust forces on the facing wall. The results indicated that the predicted loads by the bin pressure theory were close to the measured loads in the lower level of abutment. However, the bin pressure theory under predicted the thrust loads in the upper layers with reduced reinforcement spacing. In general, the overall performance of the GRS-IBS was within acceptable tolerance in terms of measured strains, stresses, settlements and deformations.

1. Introduction

Over the decades, soil mass reinforced by layers of geosynthetics has been widely used successfully in a variety of earth structures such as mechanically stabilized earth retaining (MSE) walls, embankments, slopes and shallow foundations. Due to the proven benefits such as cost-effectiveness, simple and fast construction, and tolerance of differential settlements, the geosynthetic-reinforced soil (GRS) technology has been extensively used for transportation infrastructure to support bridge structures, the self-weight of backfill materials, and the traffic load.

The application of the geosynthetic reinforced soil (GRS) technology to bridge-supporting structures, particularly for bridge abutments has been recently gaining popularity due to its proven advantages over the traditional bridge abutments (Abu-Hejleh et al., 2000a, 2000b; Adams, 1997; Mohamed et al., 2011; Wu et al., 2001, 2006; Xie and Leshchinsky, 2015; Nicks et al., 2016; Xiao et al., 2016). Recognizing the potential benefits of using GRS for abutments, some state and local agencies have been proactive in adopting the GRS abutment technology (Adams et al., 2007a, 2007b). The FHWA has also been promoting the GRS abutment technology and included the GRS abutment in the Every Day Counts (EDC) initiative to accelerate its nation-wide implementation.

The GRS technology typically involves using alternating layers of

* Corresponding author.
E-mail address: cefars@lsu.edu (M. Abu-Farsakh).

http://dx.doi.org/10.1016/j.geotexmem.2016.11.004
0266-1144/© 2016 Elsevier Ltd. All rights reserved.

geosynthetics, mainly woven geotextiles or geogrids, and granular geo-materials. Because of the close spacing between geosynthetics (equal or less than 0.3 m), the GRS is deemed to behave as a composite mass, meaning the geosynthetics closely interact with the backfill materials (Pham, 2009; Wu et al., 2014). These studies indicate that for larger-spaced reinforced soil systems, the composite behavior diminishes with increased reinforcement spacing. However, the transition into GRS behavior is not dependent solely on reinforcement spacing; the aggregate size and friction angle are also contributing factors. Through both laboratory tests on large-scale or full-scale GRS abutments and field studies on in-service GRS abutments, the behavior and characteristics of GRS abutments have been investigated to reveal the benefits of using GRS for bridge abutments. Factors influential on the behavior of the GRS mass include the spacing between the geosynthetics, the geosynthetic strength/stiffness and embedded length, the interaction characteristic between geosynthetics and backfill materials, among others (Adams et al., 2007a; 2007b; Pham, 2009; Wu and Yang, 2014; Wu et al., 2014).

Literature review reveals that there are two design philosophies for bridge abutments built with geosynthetic-reinforced soil; the design procedure specifically developed for the closely spaced geosynthetic reinforced soil (GRS) and the tie-back design philosophy used in most design procedures for mechanically stabilized earth structures using geosynthetic (GMSE). For many years, the geosynthetic-reinforced structures had been considered as a simple subset of mechanically stabilized earth (MSE) structures. While there are a number of details that vary between the two design methods, there is a distinct difference in the design premise used in the development of these two approaches (Xie, and Leshchinsky, 2015; Ambauen et al., 2015; Xie et al., 2016). The GRS design method outlined by FHWA is specifically developed for small bridges with GRS abutment that acts as composite load bearing support structure (Adams et al., 2011, 2012). On the other hand, in the second method the geosynthetic reinforced abutment is designed similar to GMSE wall. The GMSE wall design was essentially developed for free standing structures, to which surcharge loads could be applied. A primary difference between these two approaches is that the reinforcement layers are spaced differently. Vertical spacing between reinforcement layers in GRS is much less than GMSE. The tightly spaced reinforcements in GRS structures imparts an elevated confining stress on soil and influence the fundamental particle-to-particle interaction of the soil. The soil mass and reinforcement layers in GMSE structures are considered as one component and designed similar to tied-back wall systems (Lin et al., 2016); while the GRS design approach treats the soil and the reinforcement in a composite manner. The GRS mass usually shows higher strength due to suppression of dilation (Wu et al., 2014). Within a properly designed and constructed GRS, the fabric spacing would be sufficiently close such that the fabric resists dilation of the soil particles at the strength limit. Another fundamental difference between the GRS and GMSE is the function of facing wall. The facing unit in GMSE is provided to resist the loading imposed by the soil between the embedded tensile elements, and failure of facing wall may make the GMSE wall unworkable. The reinforcement in GMSE is secured to the facing units to hold the facing in place. On the other hand, the facing units within the GRS are purely a construction aid and a façade for the wall face. As the facing only needs to resist the construction-induced compaction loads (Adams et al., 2012).

While the use of a unified framework for reinforced soil wall has served the transportation industry well, additional advantages can be realized by incorporating the benefits of closely-spaced reinforcement. In order to address these benefits, FHWA developed a design method specifically for GRS-IBS bridges. The design methods and construction techniques for GRS abutments have been evolved along with the numerous research and studies conducted on the GRS abutments. The Federal Highway Administrative (FHWA) has recently released one synthesis and one implementation manuals covering the background, design, construction, and performance of GRS abutments (Adams et al., 2011, 2012). The current design for a GRS bridge is largely empirical-based and requires validation for local materials and subsurface conditions and practice. This method addresses the advantages of closely-spaced geosynthetic reinforcement such as higher confinement, lower lateral deformation, suppression of dilation, and reduction in connection stress (Nicks et al., 2013a). FHWA also calibrated the reliability of these models using performance test data, which have been correlated against results from laboratory and field monitoring programs (Nicks et al., 2013b). However, the results of those studies are only deemed valid for the conditions specifically simulated in that research. Additionally, important design parameters such as stresses and deformations of GRS abutment need to be measured and verified against the current FHWA design method. These limitations provide a motivation to monitor the performance of the GRS abutment. Undoubtedly, a successful instrumentation program is necessary to achieve this goal. An extensive instrumentation program was designed to provide insight into the mechanical responses and deformation characteristics of GRS-IBS.

2. Maree Michel GRS-IBS bridge

Recognizing the potential benefits of using GRS-IBS for local bridges, the Louisiana Department of Transportation and Development (LA DOTD) decided to build GRS-IBS abutments for one single-span bridge at Maree Michel bridge site. The Maree Michel bridge is located in Route LA 91 Vermilion Parish. The new bridge is a replacement for an existing bridge that was nearing the end of its design life. The existing bridge was a 7.3 m by 18 m treated timber trestle, which was replaced by a 19.8 m steel girder span bridge. The new GRS-IBS bridge had the same general footprint area as the previous bridge, carrying two lanes of traffic. The Average Daily Traffic (ADT) count on the bridge in 2013 was about 375, and it was estimated to be 450 vehicles in 2033.

For proper design, several site exploration tests consisting of boreholes, soil sampling, and associated laboratory soil testing were performed to determine the foundation soil conditions. Soil borings were drilled from the ground surface elevation of the existing bridge prior to its removal, which is similar to the elevation of the constructed GRS-IBS, to a depth of 30.5 m below the surface. Filed exploration indicates that the foundation soil predominantly consists of high plasticity clay (CH) according to Unified Soil Classification method. Laboratory testing of representative soil samples indicated that wet in-place density ranged from 1.74 to 1.76 g/cm^3, natural moisture content ranged from 23% to 49%, liquid limit (LL) ranged from 45% to 84%, and the plasticity index (PI) ranged from 35% to 56%. The geosynthetic used was a woven polypropylene geotextile with an ultimate tensile strength of 80 kN/m and tensile strength at 2% strain of 17 kN/m. The groundwater table was encountered at about 1.5 m below the existing ground surface.

The height of the GRS abutment is approximately 4.3 m, the width of the abutment is 13 m, and the girder span is 22 m. The overall width of the bridge superstructure is 9.1 m. This bridge was built with seven steel girders. The width of the beam seat bearing area on each abutment was determined to be 1.5 m using the FHWA design procedure. The vertical space between the reinforcement layers of GRS was 20 cm. However, for the top 5 layers of abutment, secondary reinforcement was added in the middle of each layer to increase the load carrying capacity.

The three primary materials for GRS construction are a high