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Applied bearing pressure beneath a reinforced soil foundation used in a geosynthetic reinforced soil integrated bridge system

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ABSTRACT

Geosynthetic reinforced soil integrated bridge system (GRS-IBS) design guidelines recommend the use of a reinforced soil foundation (RSF) to support the dead loads that are applied by the reinforced soil abutment and bridge superstructure, as well as any live loads that are applied by traffic on the bridge or abutment. The RSF is composed of high-quality granular fill material that is compacted and encapsulated within a geotextile fabric. Current GRS-IBS interim implementation design guidelines recommend the use of design methodologies for bearing capacity that are based around rigid foundation behavior, which yield a trapezoidal applied pressure distribution that is converted to a uniform applied pressure that acts over a reduced footing width for purposes of analysis. Recommended methods for determining the applied pressure distribution beneath the RSF for settlement analyses follow conventional methodologies for assessing the settlement of spread footings, which typically assume uniformly applied pressures beneath the base of the foundation that are distributed to the underlying soil layers in a fashion that can reasonably be modeled with an elastic-theory approach. Field data collected from an instrumented GRS-IBS that was constructed over a fine-grained soil foundation indicates that the RSF actually behaves in a fairly flexible way under load, yielding an applied pressure distribution that is not uniform or trapezoidal, and which is significantly different than what conventional GRS-IBS design methodologies assume. This paper consequently presents an empirical approach to determining the applied pressure distribution beneath the RSF in GRS-IBS construction. This empirical approach is a useful first step for researchers, as it draws important attention to this issue, and provides a framework for collecting meaningful field data on future projects which accurately capture real GRS-IBS foundation behavior.

1. Introduction

Geosynthetic reinforced soil integrated bridge system (GRS-IBS) technology has seen recent adoption across many regions of the United States, as a cost effective solution for constructing small- to medium-span bridges (e.g., Adams et al., 2011; Talebi et al., 2014b; Warren et al., 2014; Boeckmann et al., 2016; Ngo, 2016; Saghebfar et al., 2017). A typical GRS-IBS utilizes closely spaced layers of geosynthetic reinforcement and compacted granular fill material to provide direct bearing support for structural bridge members (Fig. 1a). An “integration zone” comprising additional alternating layers of geosynthetic reinforcement and compacted backfill (overlain by a pavement layer) is utilized to allow vehicles to transition smoothly between the reinforced soil abutment and the bridge superstructure (Adams et al., 2011). Interim implementation guidelines for GRS-IBS technology (Adams et al., 2011) recommend the use of a reinforced soil foundation (RSF) to support the dead loads that are applied by the reinforced soil abutment, integration zone, and bridge superstructure, as well as any live loads that are applied by traffic on the bridge or abutment. In conventional practice, the RSF is composed of high-quality granular fill material that is thoroughly compacted on top of a geotextile fabric; the fabric is then wrapped around and on top of the fill layer to completely encapsulate it (Fig. 1b). The resulting geosynthetic “mattress” supports the applied loads above it, increasing the structure's bearing capacity and reducing its settlement under working load conditions relative to what would be observed if the structure was constructed directly on the native soils (Leshchinsky and Marcozzi, 1990).

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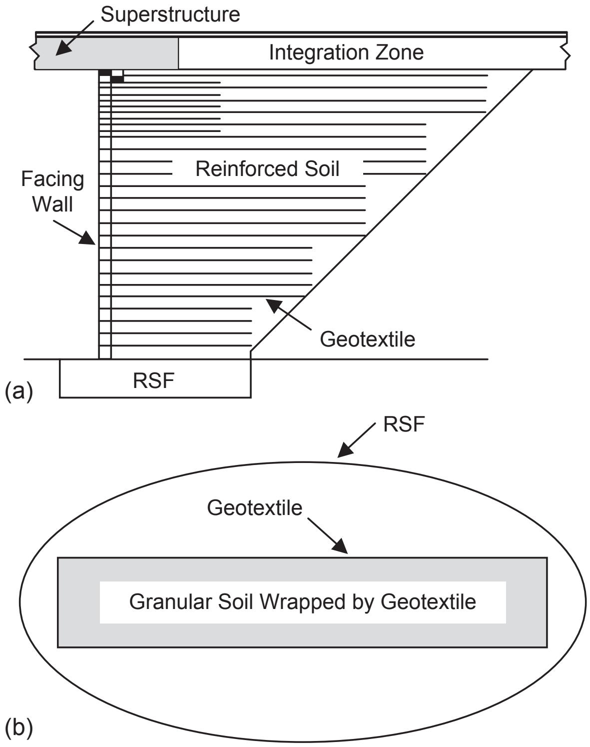

Fig. 1. GRS-IBS structure: (a) Typical section view through a GRS bridge abutment, and (b) Reinforced soil foundation (RSF).

The GRS-IBS structure that is described in the current paper was designed and constructed following conventional practice in the United States, in accordance with guidance documents and terminology that have been developed by the U.S. Federal Highway Administration (e.g., Adams et al., 2011). This technology is conceptually quite similar to the “GRS bridge abutment” structure that is described in Tatsuoka et al. (2009, 2014, 2016) and Yonezawa et al. (2014). In U.S. practice, existing GRS-IBS design methodology does not recommend structurally integrating (i.e., connecting) the bridge girder or bridge deck to either the reinforcement facing elements or the reinforcement itself, as has been done for other similar construction of this type in other countries. Moreover, the reader should be aware that this type of structure is very different from a traditional structural integral (or integrated) bridge abutment.

In some countries, GRS bridge abutments are constructed following established codes of practice that have been developed for various types of reinforced earth structures, which often include reinforced walls or embankments. In U.S. practice, construction of GRS bridge abutments for highway applications has evolved following a more experience-driven approach, and some aspects of current design are consequently semi-empirical in nature (e.g., Adams et al., 2011). Following U.S. design procedures, numerous potential mechanisms of failure must be assessed as part of the GRS-IBS design process, comprising both internal (within the abutment or structure) and external (global, outside of the abutment or structure) failure modes (Adams et al., 2011; Mirmoradi and Ehrlich, 2014; Wu and Pham, 2014; Saghebfar et al., 2017). This paper will focus on two vertical failure mechanisms of potential concern: (1) catastrophic bearing capacity failure of the GRS abutment(s) via shear in the underlying foundation soils, a vertical ultimate limit state failure mechanism, and (2) excessive settlement of the GRS abutment(s), a vertical serviceability limit state failure mechanism. Either of these failure mechanisms can occur as a result of excessive loading (dead load, live load) via the GRS abutment or bridge superstructure, sufficiently weak or overly compressible foundation soils, or some combination of these two conditions.

Current U.S. GRS-IBS design methodologies recommend a Meyerhof-type approach for performing bearing capacity analysis of an eccentrically loaded footing, which is based upon an underlying assumption of rigid body mechanics; this assumed behavior yields a trapezoidal applied pressure distribution beneath the RSF that is converted to a uniform applied pressure that acts over reduced RSF dimensions for purposes of analysis (Meyerhof, 1953; Adams et al., 2011). For performing settlement analyses, little direct guidance is given in the GRS-IBS interim implementation guide, with the reader instead being told that: “The settlement of the underlying foundation soils is determined separately using classic soil mechanics theory for immediate (elastic) and consolidation settlement.”, and “Nevertheless, settlement of the foundation soil should be assessed as with any other spread footing according to FHWA guidance.” (Adams et al., 2011). Both of these statements generally imply that, for settlement purposes, the applied pressure distribution beneath the foundation is uniform. Following classical elastic theory approaches that are commonly used in settlement analyses, such as those extrapolated from Boussinesq (1885) or Westergaard (1938), the changes in stress that are induced by GRS-IBS construction are applied directly to the foundation soil (the elastic medium) in the analysis process.

The recommended methods for vertical ultimate limit state (ULS) analysis and serviceability limit state (SLS) analysis of GRS-IBS structures consequently make some significant assumptions about the applied pressure distribution beneath the RSF, which correspond to methodologies that were originally developed for rigid concrete foundations. However, RSF behavior can reasonably be expected to be more flexible than the behavior of traditional concrete foundations (e.g., Leshchinsky and Marcozzi, 1990). This flexible foundation behavior has the potential to change the applied pressure distribution beneath the RSF significantly, which can have effects on the bearing capacity and settlement analyses of these structures.

The current study presents measurements of applied bearing pressure beneath a RSF for a GRS-IBS constructed over a fine-grained soil foundation. Four total pressure transducers were utilized to measure values of applied bearing pressure directly beneath the RSF, with pressure values being measured at various intervals during the GRS-IBS construction process, after bridge superstructure placement, and with various levels of live load upon the bridge superstructure. In general, the load levels that were applied to the instrumented GRS-IBS in this study correspond to an “in-service” level of loading that was less than SLS and ULS loading; that is, the applied loads were small enough such that they did not induce any deformation-related problems (SLS failures) or catastrophic failure events (ULS failures). Even at this lower level of loading, it is quite evident that rigid foundation behavior was not observed for the instrumented GRS-IBS. Consequently, an empirical approach for predicting foundation behavior was developed from the actual data that was measured, which can be used to predict values of applied pressure at different load levels. The proposed empirical methodology provides a framework for data collection for future GRS-IBS studies, from which an improved understanding of GRS-IBS field behavior can be developed.

2. Ultimate limit state analysis of a GRS-IBS – vertical bearing capacity

The current approach to vertical bearing capacity analysis of GRS-IBS structures assumes rigid foundation behavior, a fully

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