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Experimental study on performance of geosynthetic-reinforced soil model walls on rigid foundations subjected to static footing loading

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A B S T R A C T

Geosynthetic-reinforced soil (GRS) walls have been increasingly used to support bridge foundations as abutment walls. On the GRS abutment wall, large footing loads are applied adjacent to the wall facing. However, so far limited studies have been conducted to investigate the performance of GRS abutment walls subjected to static or dynamic loading. This study presents a series of model tests on the GRS walls to evaluate the effects of several influence factors, including the offset distance of a strip footing, the width of the strip footing, the length of geogrid reinforcement, and the connection mode between geogrid and facing, on the ultimate bearing capacities of the strip footings on the GRS walls. The settlements of the loading plate and the lateral displacements of the wall facing during loading were monitored. Thin colored sand layers were placed in the backfill sand to observe possible failure surfaces developing in the GRS walls. The experimental results showed that the footings on the GRS walls with 0.7H (H is the wall height) long reinforcement reached the maximum bearing capacities at the offset distances of 0.3*H* and 0.4*H* in the wall tests with mechanical and frictional connections, respectively. When the GRS walls had the geogrids with longer reinforcement length (2H), the ultimate bearing capacity increased with the offset distance of the footing and became constant when the offset was greater than 0.4H. It was observed that the failure surface started from the edge of the footing and exited from the facing of the wall. Based on the limit equilibrium analyses, under the footing loading, the slip surfaces by Spencer's two-part wedge method had a good agreement with those observed in the model tests.

1. Introduction

Geosynthetics-reinforced soil (GRS) walls have been successfully used for many applications under static and dynamic loading (for example, Tatsuoka et al., 1997; Leshchinsky and Han, 2004; Berg et al., 2009; Ling et al., 2009; Han and Leshchinsky, 2010). In the recent years, GRS walls have been increasingly used to support bridge abutments (for example, Ketchart and Wu, 1997; Abu-Hejleh et al., 2000; Tatsuoka et al., 2009). Bridge abutments are often supported by pile foundations in GRS walls (Pierson et al., 2009, 2011; Huang et al., 2011, 2013, 2014). Recently, GRS walls with shallow footings are increasingly used to support bridge abutments. Fig. 1 illustrates a GRS bridge abutment on a shallow footing. On the GRS abutment wall, large footing loads are often applied close to the wall facing, which is different from the typical and traditional applications of GRS walls. GRS bridge abutment walls with shallow footings eliminate the use of pile foundations and reduce bridge bumps at the interface between an approaching embankment and a bridge. As a result, they create a more economic and safer solution (Koerner, 1996; Helwany et al., 2003). A few field GRS abutment walls have been constructed and demonstrated their excellent performance with small deformation and high load-carrying capacity (Adams, 1997; Abu-Hejleh et al., 2000).

One of the well-documented GRS abutment wall projects was a 6 m high GRS abutment constructed by the Colorado Department of Transportation at Founders/Meadows, Colorado, in the United States (Abu-Hejleh et al., 2001). After construction, a series of load tests were conducted to carefully investigate the performance of the earth structure. The tests showed satisfactory results with a 10 mm maximum lateral deformation of the wall facing and a

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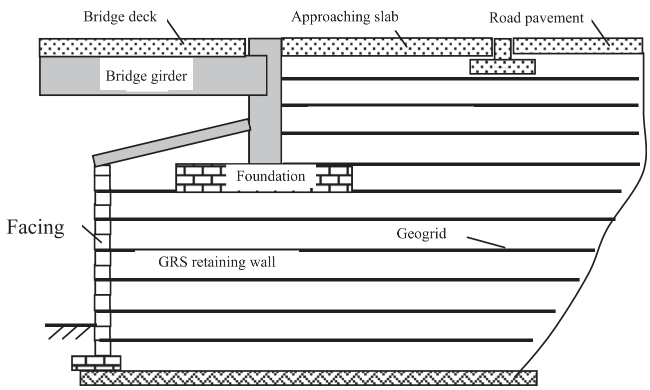

Fig. 1. Typical cross section of a GRS bridge abutment (modified from Abu-Hejleh et al., 2000).

14 mm settlement of the bridge footing. In addition, Adams and Collin (1997) and Ketchart and Wu (1997) carried out large or field loading tests on geosynthetic-reinforced foundations and GRS abutment walls. At the design pressure of 200 kPa, the GRS walls performed well (Elias et al., 2001). So far, the majority of GRS abutment walls have been founded on the competent foundations and they performed well under service loads. However, a few GRS walls have been constructed on relative weak foundations. Field test data and numerical analysis results also showed satisfactory performance of these walls despite the existence of the unfavorable foundation conditions (Wakai et al., 1996; Rowe and Skinner, 2001; Skinner and Rowe, 2005; Hara et al., 2004).

As compared with typical and traditional GRS walls, the GRS abutment walls are generally subjected to high footing loads that are close to the wall facing. Under such a condition, not only the stability of the GRS wall but also the bearing capacity and settlement of the bridge footing should be considered in design. The stability of the GRS wall is affected by the applied load through the footing. In addition to the magnitude of the load, the location or offset distance of the footing to the wall facing can affect the stability of the GRS wall, the bearing capacity as well as the settlement of the bridge foundation when the footing is located adjacent to the facing.

The interaction between the GRS wall and the footing is a complicated problem, which has not been well investigated. Wu et al. (2006) investigated the effect of bridge sill type, sill width, soil stiffness/strength, reinforcement spacing, and foundation stiffness on the load-carrying capacities of GRS abutment sills. Based on the limiting displacement and shear strain criteria, Wu et al. (2006) determined the allowable bearing pressures of the GRS abutments. Bourgeois et al. (2011) analyzed the mechanical response of earth structures reinforced with steel strips to traffic loads. El Sawwaf (2007) carried out a series of reduced-scale model tests to examine the behavior of strip footings on geogrid-reinforced sand over a soft clay slope. The test results indicated that the inclusion of geogrid layers in sand not only significantly improved the footing performance but also led to a great reduction in the depth of the reinforced sand layer required to achieve the allowable settlement. Bilgin (2009) investigated the effect of reinforcement length on the failure mechanism of GRS walls. Leshchinsky (2014) recently investigated the effects of footing location, reinforcement strength, and reinforcement spacing on the bearing capacity of the footing on the GRS wall and the failure mode using the limit analysis of plasticity. Although several studies have been conducted to investigate the behavior of footings on stabilized sandy slopes (Huang et al., 1994; Yoo, 2001; Alawaji, 2001; El Sawwaf, 2005), the performance of a footing on a GRS abutment wall has not yet been well investigated and understood. Prior to development of a design method for this application, it is necessary to understand the behavior of the GRS abutment wall under static loading of different magnitude and offset distance to the wall facing. Geosynthetics can be connected to wall facing by the friction between the geosynthetic and blocks or a mechanical connector. Nicks et al. (2013) demonstrated that the wall facing had an apparent effect on the load-carrying capacity of the footing on the GRS pier. In other words, the geosynthetic-facing connection has an effect on the performance of the GRS pier. Wu and Pham (2013) treated closely-spaced geosynthetic-reinforced soil mass as a composite and developed a solution to calculate the load-carrying capacity of the GRS mass. This solution is suitable for isolated GRS piers under uniform axial loads, but may not be appropriate for GRS walls with retained soil under localized loads.

The main objectives of this study are to evaluate the relationship between the ultimate bearing capacity of the strip footing and the offset distance of the strip footing to the wall facing, identify possible failure modes of the wall, and investigate the effect of the mode of connection between geosynthetic and wall facing. To achieve these objectives, model GRS walls with a reduced size by a factor of 1/5 to a typical field scale were constructed and tested under strip footing loads in the laboratory. This study investigated the following influence factors: the offset distance of the footing, the length of geogrid reinforcement, the connection mode between geogrid and facing blocks, and the width of the footing.

The composite behavior of GRS walls is important for a system with close reinforcement spacing under a working load when it is used to support bridge footings to meet the serviceability requirement. Our study, however, is focused on the ultimate bearing capacity and stability (i.e., limit states) of the GRS wall. Under such conditions, the composite behavior is not that important. To achieve the limit states, the strengths of the fill and the geogrid have to be reduced. This method, so-called the strength reduction method, has been commonly used for theoretical development and model tests and was adopted in this study by using reduced-strength backfill and geogrid. More importantly, our model test results were verified by the limit equilibrium method.

2. Model tests

2.1. Test apparatus

A series of reduced-scale model tests were conducted to investigate the behavior of the GRS walls on rigid foundations subjected to static loading at different offset distances to the wall facing. The sizes of model walls were designed at a scale ratio of 1/5 to those of typical field walls. The main components of the experimental apparatus included a loading frame with a platform, an air cylinder, a test box, loading plates, and dial gauges. The box with inside dimensions of 1.5 m (length) × 0.4 m (width) × 0.8 m (height), was made of wood in three sides. The front side of the box was made of 20 mm thick toughened glass and was placed directly on the platform, as shown in Fig. 2. The glass wall allowed the observation and photogrammetry of the failure modes and deformations of the GRS walls during construction and loading. To minimize the side effect due to the friction of the wooden side wall of the box, a 1.5 mm thick transparent plastic sheet was fixed on the inside of the wooden side wall. Tognon et al. (1999) showed that polyethylene plastic sheets were placed on the walls of the box to minimize the angle of friction between the walls and soil to less than 5°. At the same time, a pair of jacks were placed on the outer faces of the box to ensure the rigidity of the box. The loading system