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Numerical study on maximum reinforcement tensile forces in geosynthetic reinforced soil bridge abutments

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A B S T R A C T

This paper presents a numerical study of maximum reinforcement tensile forces for geosynthetic reinforced soil (GRS) bridge abutments. The backfill soil was characterized using a nonlinear elasto-plastic constitutive model that incorporates a hyperbolic stress-strain relationship with strain softening behavior and the Mohr-Coulomb failure criterion. The geogrid reinforcement was characterized using a hyperbolic load-strain-time constitutive model. The GRS bridge abutments were numerically constructed in stages, including soil compaction effects, and then loaded in stages to the service load condition (i.e., applied vertical stress = 200 kPa) and finally to the failure condition (i.e., vertical strain = 5%). A parametric study was conducted to investigate the effects of geogrid reinforcement, backfill soil, and abutment geometry on reinforcement tensile forces at the service load condition and failure condition. Results indicate that reinforcement vertical spacing and backfill soil friction angle have the most significant effects on magnitudes of maximum tensile forces at the service load condition. The locus of maximum tensile forces at the failure condition was found to be Y-shaped. Geogrid reinforcement parameters have little effect on the Y-shaped locus of the maximum tensile forces when no secondary reinforcement layers are included, backfill soil shear strength parameters have moderate effects, and abutment geometry parameters have significant effects.

1. Introduction

Geosynthetic reinforced soil (GRS) bridge abutments have been widely used for transportation infrastructure and several case histories are reported in the literature (Abu-Hejleh et al., 2002; Adams et al., 2011a; Saghebfar et al., 2017). Although these structures show good field performance in terms of acceptable deformations under service load conditions, design methodologies continue to evolve. The design process includes assessment of internal and external stability to size the geometry of the structure and select appropriate backfill soil and reinforcement materials.

With regard to internal stability, reinforcement is selected based on an assumed distribution (i.e., locus) of maximum tensile forces. For the Simplified design method (Berg et al., 2009; AASHTO, 2012), this locus coincides with the assumed failure surface, which initially follows the Rankine active failure surface from the toe of the abutment and then moves vertically upward to the heel of the bridge seat. The maximum tensile force in each reinforcement layer is calculated along the locus using a 2:1 distribution for bridge surcharge load, the Rankine active earth pressure coefficient (K_a), and the total lateral stress over the appropriate tributary area. For the geosynthetic reinforced soil-integrated bridge system (GRS-IBS) design method (Adams et al., 2011b), the locus is assumed to lie on the vertical centerline of the bridge seat. The maximum tensile force in each reinforcement layer is calculated based on the ultimate bearing capacity of GRS composite structures (Wu and Pham, 2013; Wu et al., 2013) with total lateral stresses for the service load condition. The locus of maximum tensile forces is a key assumption for each method and the dependency of this locus on reinforcement parameters, backfill soil properties, and abutment geometry is largely unknown.

Numerical studies have been conducted to investigate the response of GRS bridge abutments under service load conditions (Helwany et al., 2003, 2007; Ambauen et al., 2016; Zheng and Fox, 2016a, 2017), and generally have indicated relatively small lateral facing displacements and bridge seat settlements. Most of these studies have focused on the deformation response, and fewer have investigated the magnitudes and locations of maximum tensile forces in the reinforcement. Xie et al. (2016) calculated maximum reinforcement tensile forces in GRS walls under a surcharge load using limit analysis and assuming a log-spiral failure surface, and reported important effects from backfill soil friction

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angle, wall batter, and bridge seat setback distance. Ardah et al. (2017) conducted numerical simulations for a GRS-IBS abutment and found that the locus of maximum tensile forces differs from the Rankine active failure surface and may change with increasing bridge load. This suggests that the locus of maximum tensile forces at the service load condition may not be representative of the locus at the failure condition. Other numerical studies have found that strain softening of the backfill soil and nonlinear response of the geosynthetic reinforcement are likely to be important for characterization of the response of GRS bridge abutments under high applied stress conditions approaching failure (e.g., Walters et al., 2002; Hatami and Bathurst, 2006; Liu and Ling, 2012; Yang et al., 2012; Zheng and Fox, 2016b, Zheng et al. 2018).

This paper presents a numerical study of the magnitudes and locations of maximum tensile forces for GRS bridge abutments at both service load and failure conditions. The study consists of a baseline case, followed by a parametric study of the effects of geogrid reinforcement, backfill soil, and abutment geometry. Results provide insights with regard to the internal stability of GRS bridge abutments and the Simplified and GRS-IBS design methods for these structures.

2. Numerical model and baseline case

The two-dimensional finite difference program *FLAC Version 7.0* (Itasca Consulting Group, 2011) was used for the current investigation. Zheng and Fox (2016a) developed a *FLAC* model to simulate the response of GRS bridge abutments under service load conditions and validated the model using field measurements for the Founders/Meadows Parkway Bridge in Castle Rock, Colorado (Abu-Hejleh et al., 2000, 2001). Zheng et al. (2018) enhanced this model by incorporating strain softening for the backfill soil and nonlinear stiffness for the geogrid reinforcement and concluded that these effects are relatively small for GRS bridge abutments under service load conditions but significant for high applied stress conditions approaching failure. The current investigation is based on the *FLAC* model and numerical simulations described in Zheng et al. (2018).

2.1. Model geometry

The finite difference grid and boundary conditions for a baseline case GRS bridge abutment model are shown in Fig. 1. The model represents a single-span bridge system with a span of $L_b = 30$ m and symmetrical support structures on both ends. Each end support structure consists of a lower GRS fill and wall, bridge seat, upper GRS fill, and approach roadway. Only the right-hand side of the bridge system was simulated due to symmetry. The GRS bridge abutment has a lower wall height of $h = 5.0$ m and a total height of $H = 6.9$ m. An L-shaped bridge seat with a thickness of 0.4 m rests on top of the lower GRS fill and has a setback distance of $a_b = 0.2$ m from the back of the wall facing. The clear distance between the top of the facing and the bottom of the bridge beam d_e is equal to the bridge seat thickness (0.4 m). The clearance height for the bridge beam above the foundation soil is 5.4 m, which satisfies the FHWA minimum requirement of 4.9 m for interstate highways (Stein and Neuman, 2007). The bridge seat has a contact length of $L_c = 1.0$ m with the bridge beam on the upper surface and a contact length of $L_s = 1.5$ m with the backfill soil on the lower surface. There is a 100 mm-wide vertical expansion joint between the bridge beam and bridge seat. Assuming a span-to-depth ratio of $R_{sd} = L_b/D = 20$, the depth of the bridge beam is $D = 1.5$ m. A upper GRS fill lies behind the bridge seat, has a thickness of 1.8 m, and is covered by a 0.1 m-thick concrete roadway. The geosynthetic reinforcement has uniform length $L_r = 3.5$ m (0.7h) and vertical spacing $S_v = 0.2$ m for both the lower GRS fill and upper GRS fill. No secondary (i.e., bearing bed) reinforcement is included under the bridge seat for the baseline case. To minimize the influence of boundary conditions on system response, the foundation soil has a depth of 10 m (2h) and the right-hand side lateral boundary is located at a distance of 20 m (4h) from the wall facing. Model lateral boundaries are fixed in the horizontal direction and free to move in the vertical direction, whereas the bottom boundary is fixed in both the horizontal and vertical directions. Horizontal coordinate x is measured toward the right-hand side from the back of the wall facing and vertical coordinate z is measured upward from the top surface of the foundation soil.

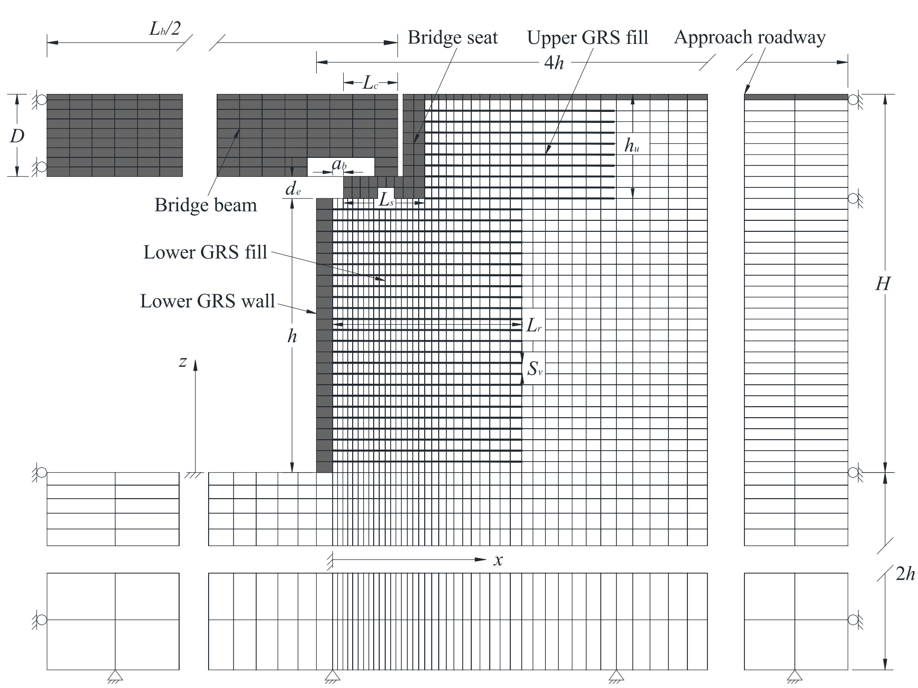

Fig. 1. Finite difference grid and boundary conditions for the baseline case GRS bridge abutment model.