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Numerical analysis of instrumented mechanically stabilized gabion walls with large vertical reinforcement spacing

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ABSTRACT

The paper describes numerical models that were developed to simulate the performance of two instrumented mechanically stabilized earth walls constructed in Izmir, Turkey. These walls were constructed with gabion facing, hybrid reinforcement layers, and fill on a rigid foundation. The hybrid reinforcement layers comprised primary reinforcement (geogrid) and secondary reinforcement (wire mesh). The vertical spacing between the primary reinforcement changed from 1 m to 2 m in two walls while other properties were kept the same. The responses of the field walls at the end of construction were simulated and compared with the numerical results. The results calculated from the numerical models showed generally good agreement with the measured wall facing displacements, horizontal fill displacements, and tensile forces in the geogrid and in the wire mesh. The maximum calculated facing displacements for the walls with 1 m and 2 m reinforcement spacing were 30.7 and 36.4 mm, respectively. The maximum tensile forces in the geogrid layers were increased by 1.5 times in the 2 m spacing wall as compared with the 1 m spacing wall due to the increase of primary reinforcement spacing. However, the spacing change did not have an obvious effect on the increase of tensile forces in the secondary reinforcement (the wire mesh). The calculated results were also compared with theoretical results relating to the earth pressure distributions and the location of the maximum tensile strains in the primary reinforcement. The horizontal earth pressures against the wall facing were close to the active earth pressures for both walls. The maximum tensile strain line of the reinforcement was close to the Rankine's failure line.

1. Introduction

Mechanically stabilized earth (MSE) walls constructed with geosynthetic reinforcement have been widely used as retaining wall structures since their introduction in the 1970s (Koerner and Soong, 2001; Allen and Bathurst, 2001; Leshchinsky et al., 2004; Yoo and Kim, 2008; Abdelouhab et al., 2011; Koerner and Koerner, 2013; Han, 2015). The commonly used geosynthetic reinforcement is geogrid or woven geotextile. The typical vertical spacing between the reinforcement layers is not more than 0.8 m according to the requirement of the Federal Highway Administration (FHWA, 2009) and the American Association of State Highway and Transportation (AASHTO, 2014). However, MSE walls with large reinforcement spacing were constructed recently in the field by

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taking the advantage of secondary reinforcement. The secondary reinforcement was short in length and connected with facing elements to provide facing stability (Jiang et al., 2016). Moreover, the presence of the secondary reinforcement could reduce the loads carried by the primary reinforcement (long in length), thereby also contributing to the overall internal wall stability (Leshchinsky and Vulova, 2001; Leshchinsky et al., 2014; Jiang et al., 2016).

Rimoldi and Scotto (2012) reported two tall MSE walls with the reinforcement spacing larger than 0.8 m were built recently. One wall with the maximum height of 40 m was constructed in Albania for a highway project in 2011, where the vertical spacing of the primary reinforcement reached up to 2.0 m. Another MSE wall with the maximum height of 74 m was constructed near a new airport in India in 2012, where the vertical spacing of the primary reinforcement also reached up to 2.0 m. However, there was no detailed instrumentation program involved in these two projects in order to assess quantitatively the performance features of the wall with large reinforcement spacing. Tanyu et al. (2016) presented an instrumented field case study of the Izmir wall, where the wall was constructed with gabion basket facings having the double twisted wire mesh and the vertical reinforcement spacing of 1.0 and 2.0 m, respectively, in two sections. The physical performance of these monitored walls (two sections) was recorded and summarized.

The measurements from the instrumented wall case studies have been widely used to assess the accuracy of limit equilibrium-based design methods found in the current design guidelines (AASHTO 2012; Canadian Geotechnical Society, 2006; British Standards Institution (BSI), 2010) and to calibrate the resistance factors for the reliability-based LRFD methods (Huang et al., 2012; Kim and Salgado, 2012; Bathurst et al., 2013). Allen et al. (2002) pointed out that the number of instrumented field walls with geosynthetic reinforcement was sparse. For instrumented walls with large reinforcement spacing, the measured database is even more limited. A strategy to make up the lack of physical measurements of MSE walls with large reinforcement spacing and improve the understanding of their behavior is to develop numerical models which are verified against physical measurements. The calculated results from the verified numerical models can be used to extend the limited database of instrumented case studies to a wider range of reinforced soil and reinforcement properties, reinforcement spacing, loading conditions, and configurations.

Numerical models have been used to analyze the performance of MSE walls in the literature. For example, Ling et al. (2000) conducted a finite element study of a geosynthetic-reinforced soil retaining wall with concrete-block facing. Hatami and Bathurst (2005) developed and verified a two-dimensional numerical model for the analysis of geosynthetic-reinforced soil segmental walls under working stress conditions against large-scale walls tested in the laboratory. Huang et al. (2013, 2014) developed three-dimensional finite difference models to simulate laterally loaded single and group piles in MSE walls in the field.

In the current study, the numerical models based on a finite difference method were developed to simulate the behavior of two carefully instrumented and monitored MSE walls reported by Tanyu et al. (2016). The vertical spacing between the primary reinforcement changed from 1 m to 2 m in two walls while other properties were kept the same. The results calculated from the numerical models will be compared with the measured wall facing displacements, horizontal fill displacements, and tensile forces in the geogrid and in the wire mesh. After the verification of the numerical models, the calculated results will also be compared with the theoretical results relating to the earth pressure distributions and the locations of maximum tensile strains in the primary reinforcement. Seismic analysis of mechanically stabilized gabion walls with different vertical reinforcement spacing has been conducted by the authors. The seismic analysis is beyond the scope of this paper. The numerical results obtained from the seismic analysis will be presented in another paper in the future.

2. Characteristics of the Izmir walls and instrumentation

The project walls were 16.0 m high, “hybrid” mechanically stabilized earth (MSE) walls constructed in Izmir, Turkey (Ozcelik et al., 2014; Tanyu et al., 2016). The walls were seated on a rigid foundation, where the bedrock consisted with 75% tuff, 18% volcanic rocks and breccia, and 7% limestone and shale. The wall facing was comprised of gabion units which were formed by filling the gabion baskets with stones (e.g., boulders). Nonwoven geotextile was placed at the back facing of the gabion unit to minimize mass loss. The structure is considered “hybrid” because its reinforcement materials made up of both metallic and geosynthetic elements. The metallic elements referred to as the gabion basket were formed by double twisted steel wire mesh as well as the secondary reinforcement (i.e., the tails of the steel mesh extending from the bottom of the basket) for the facing stability. The geosynthetic elements referred to as high strength geogrids were designed as the primary reinforcement for the global stability. The vertical spacing between the primary reinforcement (the geogrid) was defined as the reinforcement spacing of the wall. For the 1 m spacing wall, the vertical reinforcement spacing for all layers was 1.0 m. For the 2 m spacing wall, the vertical reinforcement spacing in the three bottom layers was 1.0 m while the spacing in the other upper layers was 2.0 m. Fig. 1 shows the schematic views of two instrumented walls with reinforcement spacing of 1.0 and 2.0 m, respectively. Other structural elements were kept the same in these two walls and are summarized in Table 1.

The instrumentation program included soil extensometers to measure horizontal displacements of the reinforced fill, load cells on the geogrids and the wire meshes to monitor tensile forces in reinforcement layers, vertical and horizontal pressure cells to measure earth pressures, and survey targets along the gabion facing to observe wall facing displacements. The location of the instrumentation can be found in Fig. 1. The performance of two walls during and after the end of construction was monitored and recorded. The field data used in this study were the measurements obtained after the construction.

3. Numerical modeling

3.1. General

Two-dimensional finite-difference program FLAC2D 5.0 (Itasca, 2005) was employed to simulate the MSE gabion walls with different reinforcement spacing. Fig. 2 shows the numerical model and mesh details for the simulation of the field wall with 1 m reinforcement spacing. For brevity, another numerical model for the 2 m spacing wall was also developed while not shown here because the only difference was the reinforcement spacing and other details were kept the same as in the model for the 1 m spacing wall. The total length and height of the numerical model were 76.2 and 24.5 m, respectively. The wall embedment depth was 0.7 m. The mechanical connection between the geogrid and the gabion unit was simulated in the numerical model, where the end point of the strip element (simulating the geogrid) was rigidly bonded to the grid point of the facing.

The boundary conditions are considered in the numerical models as follows: (1) the bottom of the foundation soil was fixed in both horizontal and vertical directions and (2) the two sides of the foundation soil and the left side of the retained soil were only fixed in the horizontal direction. The numerical model simulated

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