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Lateral bearing capacity and failure mode of geosynthetic-reinforced soil barriers subject to lateral loadings

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ABSTRACT

In addition to self-weight and vertical surcharge, geosynthetic-reinforced soil (GRS) structures have recently been used as barriers to resist lateral forces from natural disasters, such as floods, tsunamis, rockfalls, debris flows, and avalanches. The stability of such structures subject to lateral loading is often evaluated using conventional external stability analyses with the assumption that the reinforced soil mass is a rigid body. However, this assumption contradicts the flexible nature of reinforced soil. In this study, finite element (FE) models of back-to-back GRS walls were developed to investigate the performance of GRS barriers subject to lateral loading. The FE analysis results indicated that the failure mode and lateral bearing capacity of GRS barriers depend largely on the aspect ratio (L/H: ratio of wall width to wall height). When $0.5 < L/H < 1.0$, the GRS barriers would fail internally because of internal sliding along the soil–reinforcement interface at the loading side and the active soil failure at the opposite side. When $1.0 < L/H < 3.0$, bottom sliding failure would occur along the foundation–reinforcement interface. When $L/H > 3.0$, passive soil failure would occur within the GRS barriers at the side subject to the lateral force. The ultimate lateral bearing capacity of GRS barriers increased with an increase in L/H: the ultimate lateral capacity factor N_L was 1.4–20.1 times K_a for $L/H = 0.5$–3.0. In addition to the effect of L/H, the numerical results indicated that the backfill friction angle ϕ, unit weight γ, and reinforcement vertical spacing S_v considerably affected the lateral bearing capacity of GRS barriers. A hypothetical case study of a GRS barrier against a tsunami force is provided, and a viable method using vertical preloaded soil anchors for improving wall lateral capacity is analyzed and discussed.

1. Introduction

Geosynthetic-reinforced soil (GRS) retaining structures have been widely used in various projects, including buildings, highways, and bridge abutments, to provide improved load bearing behavior. Many past studies focused on the performance and stability of GRS structures subject to vertical loadings (Anubhav and Basudhar, 2011; Ehrlich and Mirmoradi, 2012; Ehrlich et al., 2013; Santos et al., 2013, 2014; Damians et al., 2014; Mirmoradi and Ehrlich, 2014; Cristelo et al., 2016; Nicks et al., 2016). In addition to general applications to carry self-weight and vertical surcharge, GRS structures have recently been used as barriers to resist lateral forces from natural disasters, such as floods, tsunamis, rock falls, debris flows, and avalanches (Brandl, 2011; Fowze et al., 2012; Kuwano et al., 2012; Lambert and Bourrier, 2013; Koseki and Shibuya, 2014), and to protect shorelines (Recio-Molina and Yasuhara, 2005; Yasuhara and Recio-Molina, 2007).

Kuwano et al. (2012) summarized seismic performance of approximately 1600 walls subject to direct impact of the 2011 Tohoku earthquake and tsunami. They observed that more than 90% of the walls did not show any damage. Only less than 1% of the walls were critically damaged because of soil erosion caused by the tsunami. Therefore, multiple tsunami defense facilities using GRS structures (Fig. 1) were proposed by the Japanese Geotechnical Society (JGS, 2011) after the 2011 Tohoku earthquake. Yasuhara and Recio-Molina (2007) conducted a series of model tests on geotextile wrap-around revetments (GWRs) against wave action. The GWRs were stable against the wave action, and their stability can be further increased with a few simple modifications (i.e., GWRs with

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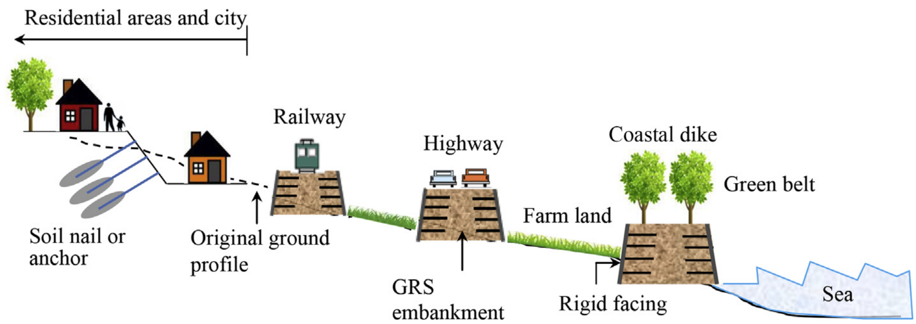

Fig. 1. Multiple tsunami defense facilities using GRS structures proposed by the Japanese Geotechnical Society after the 311 Great East Japan Earthquake in 2011 (replotted from JGS, 2011).

a seaward face are injected with mortar, and the reinforcement layers are sewn together). Moreover, their tests demonstrated that GWRs performed favorably against differential settlement and scour erosion.

Ronco et al. (2009) and Peila et al. (2007) performed several full-scale tests and finite element (FE) dynamic modeling of reinforced embankments for rockfall protection. Embankments made of various geogrid types, soils, and construction layouts were tested at various impact energy levels to evaluate the resistance impact of these structures. They concluded that among various protection methods, reinforced embankments can be considered an effective technique. Walz (1982) conducted 20 dynamic 1 g model tests on protective barriers against rockfalls (reported by Brandl, 2011). The GRS barriers effectively absorbed the impact energy from rockfalls. Lambert and Bourrier (2013) provided a comprehensive review of rockfall protection by using GRS embankments. In Taiwan, many GRS embankments have been constructed as debris and rockfall barriers (Fig. 2). In addition to lateral loadings induced by nature, impact of lateral loadings from blasts on reinforced soil (Tuan, 2013) and impact of traffic on reinforced structures (Soude et al., 2013; Kim et al., 2010) have been investigated.

Earthquake-induced seismic loading is another type of lateral loading on GRS structures. The performance of GRS structures under seismic loadings has been extensively investigated, and these studies have reported satisfactory performance of GRS structures against seismic loadings (e.g., Tatsuoka et al., 1995; Bathrust and Hatami, 1998; Matsuo et al., 1998; El-Emam and Bathurst, 2004, 2005, 2007; Ling et al., 2005; Nova-Roessig and Sitar, 2006; Krishna and Latha, 2007; Latha and Krishna, 2008; Liu et al., 2010; Huang et al., 2010, 2011; Murali and Madhavi, 2012; Vahedifard et al., 2013; Ren et al., 2016). The seismic design methods in design guidelines (Berg et al., 2009; Elias et al., 2001) typically assume seismic loading to be an inertial force that acts laterally on the centroid of the failure mass of reinforced soil to assess seismic internal stability, and use the pseudostatic Mononobe–Okabe method to calculate the dynamic earth pressure to evaluate seismic external stability. Notably, GRS structures directly subject to lateral impacts from natural disasters may respond differently to those

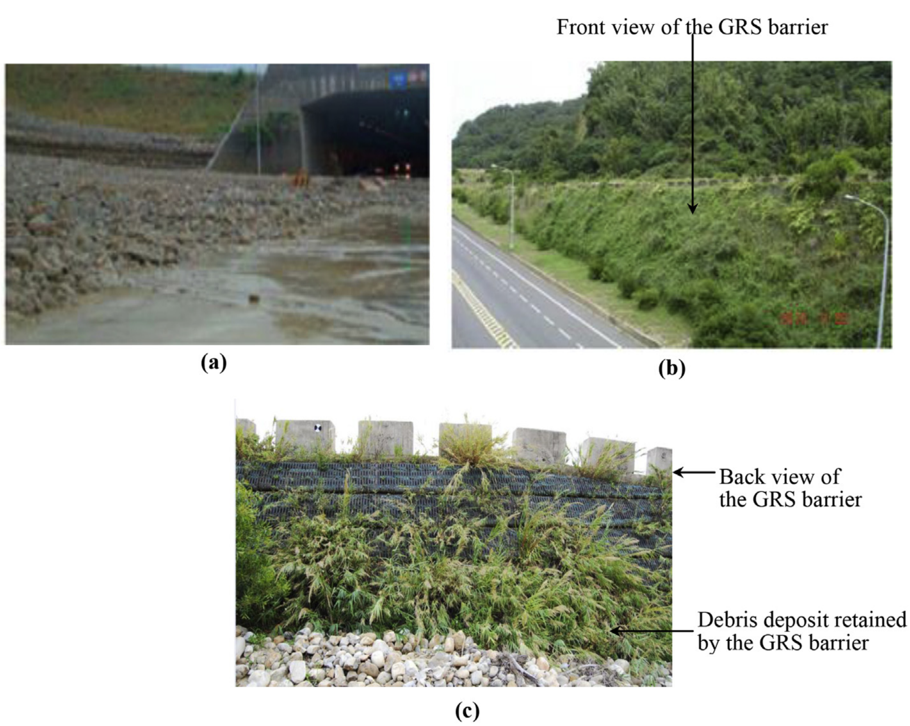

Fig. 2. Application of GRS structures against debris flow in mountain area in Taiwan: (a) debris deposited on the local road (Tai 140 Line) before construction of a GRS barrier; (b) front view; and (C) back view of a GRS embankment (wrapped around facings) as a debris barrier.