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Shaking table tests on soil retaining walls reinforced by polymeric strips

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ABSTRACT

The seismic behavior of reinforced soil retaining walls with polymeric strips is examined. A series of 1-g shaking table tests were employed on 80 cm high reinforced-soil wall models. Also, some uniaxial tensile and pullout tests were performed in reduced-scale models to determine the best material to be used instead of polymeric strips in models. The effect of the length of reinforcement, number of steps and shape of the reinforcement arrangement (zigzag vs. parallel) on the failure mode, the wall displacement, and the acceleration amplification factor are investigated. Findings suggest that walls built with extensible reinforcement were flexible and the internal failure mechanism in the reinforced zone for these walls involved a bulging mode. The parallel implementation of reinforcements is more favorable as it decreases the displacements more than 50% before failure compared to the zig-zag arrangement. Also, wall displacement was reduced with a decrease and increase in the reinforcement length at bottom and top layers, respectively and this improved the wall behavior. Therefore, reducing the reinforcement length at the bottom of the wall without increasing the length of upper layers is not recommended as it can noticeably increase wall displacement from 1.2 to 7 times under different waves.

1. Introduction

Reinforced-soil walls are finding increasingly more applications worldwide. This is because of their seismic performance and cost effectiveness. There is a sizable body of empirical research on reinforced-soil walls and slopes in recent years. These studies have applied various methodologies including full-scale structures (Bathurst et al., 2009a; Yang et al., 2009; Kongkitkul et al., 2010; Horpibulsuk et al., 2011; Koseki, 2012; Yang et al., 2012; Demir et al., 2013; Koerner and Koerner, 2013; Lackner et al., 2013; Santos et al., 2013; Riccio et al., 2014), reduced-scale models (Nova-Roessig and Sitar, 1999; El- Emam and Bathurst, 2004, 2007; Chen et al., 2007; Latha and Krishna, 2008; Nakajima, 2008; Sabermahani et al., 2009; Viswanadham and König, 2009; Hu et al., 2010; Huang et al., 2011; Raisinghani and Viswanadham, 2011; Wang et al., 2011; Ehrlich et al., 2012; Ehrlich and Mirmoradi, 2013; Soudé et al., 2013; Hatami et al., 2014; Bao et al., 2014; Wang et al., 2015), numerical analysis (Skinner and Rowe, 2005; Huang et al., 2006; Hatami et al., 2008; Bathurst et al., 2009b; Huang et al., 2010; Ling et al., 2010; Abdelouhab et al., 2011; Rowe and Taechakumthorn, 2011; Suksiripattanapong et al., 2012; Lee and Chang, 2012; Chen et al., 2013; Clarke et al., 2013; Liu et al., 2014; Moghaddas Tafreshi and Nouri, 2014; Wang et al., 2014; Zhang et al., 2014) and laboratory tests on reinforced soil (Latha and Murthy, 2007; Moghaddas Tafreshi and Dawson, 2012; Tavakoli et al., 2012; Moghaddas Tafreshi et al., 2013, 2014). Also, the pull-out resistance on geosynthetic reinforcements has been studied by a number of researchers (Abdelouhab et al., 2010, 2012; Khoury et al., 2011; Esfandiari and Selamat, 2012; Moraci and Cardile, 2012; Hatami et al., 2013; Suksiripattanapong et al., 2013; Tran et al., 2013; Awad and Tanyu, 2014; Esmaili et al., 2014; Ezzein and Bathurst, 2014; Gao et al., 2014). Koseki et al. (2006) summarized reviews of some case histories, analytical and physical modeling research on the seismic response of reinforced-soil walls. Data obtained on the behavior of the reinforced-soil retaining walls suggest a favorable performance during large earthquakes

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(Tatsuoka et al., 1995, 1997; Ling et al., 2001; Pamuk et al., 2004). Siddharthan et al. (2004) noted that although static performance of mechanically stabilized earth walls is better understood, their seismic behavior is not.

Polymeric strips are composed of polyester tendons encased in a polyethylene sheath and are manufactured in various grades and a range of thickness. These strips are used as the geosynthetic reinforcement connected to the precast concrete facing panels using an all polymer connection. The strength of the geosynthetic reinforcement can be adjusted to suit the design loads. Moreover, the standard concrete panels possess the same number of connection points and the system is simple to construct. This optimizes the efficiency of the structure and allows the construction of very tall structures capable of withstanding high earth pressure loads. Polymeric strips are finding increasingly more applications in reinforced soil systems particularly in the regions prone to frequent earthquakes. This necessitates a careful investigation of the dynamic behavior of polymeric strips reinforced soil retaining walls.

In this study, shaking table tests were performed to investigate the dynamic behavior of the polymeric strip reinforced soil retaining walls. All physical models were constructed with a height of 0.8 m and two types of arrangement were used as reinforcement layers, namely, zigzag and parallel arrangements. Each model was subjected to several different excitations in sinusoidal shape from weak to strong, applied after the termination of the previous motion. A series of uniaxial tensile and pullout tests were also performed prior to the investigation. These tests were performed to determine the tensile parameters and interaction parameters of the reduced scale polymeric strips and also to select the suitable strips for reduced scale shaking table tests.

2. Shaking table tests

Five 1-g shaking table tests were carried out on polymeric strip reinforced soil walls. Tests were performed on the shaking table of the Centrifuge and Physical Modeling Center at Tehran University. Based on the recommendation of FHWA (2009), the minimum embedment depth was selected for all walls from adjoining finished grade to the top of the leveling pad. The dimensions of the shaking table were 1.2 m wide and 1.8 m long with single degree of freedom. The physical models were constructed in a 0.8 m (width) × 1.82 m (length) × 1.23 m (height) container made of rigid, transparent Plexiglas sheets to make wall deformations and behavior visible. The shaking table box is shown in Fig. 1. Parameters such as the length, arrangement, and performance of reinforcements (zigzag or parallel) varied in tests to allow investigation of their effects on the seismic response of the wall with an emphasis on the modes of deformation, failure mechanisms, and dynamic behavior. The lengths of reinforcements in the first test were determined according to FHWA (2009) standard while they were changed in the subsequent tests to achieve the best design and arrangement. A brief description of the tests is provided in Table 1. Also, the final shape of reinforced wall model is presented in Fig. 2.

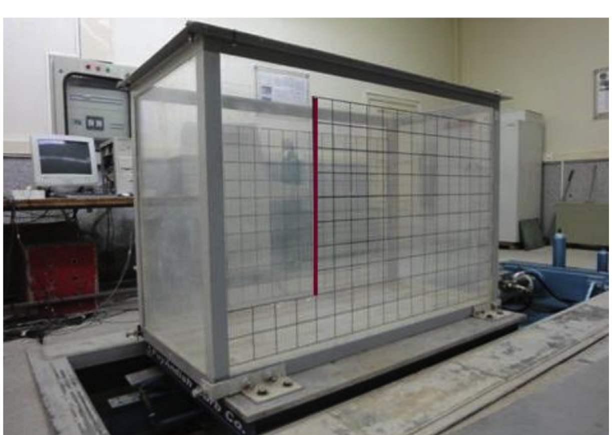

Fig. 1. The shaking table box.

2.1. Model geometry

2.1.1. Wall dimensions

The height in reinforced wall model is an important factor which controls the scale effects and the response of the model in comparison with its prototype. Ling et al. (2005) carried out the large scale physical model tests on 2.8 m high models. Also, Matsuo et al. (1998) performed a series of shaking table tests on the walls with 1.0 m and 1.4 m height and Sakaguchi (1996) used 1.5 m high walls. On the other hand, a number of researchers performed model tests with smaller walls. Wang et al. (2015) performed a series of large-scale shaking table test models of 0.7 m height constructed in a large laminar shear container. Krishna and Latha (2007) conducted shaking table test on wrap face 0.6 m high Geosynthetic Reinforced Soil (GRS) walls. Watanabe et al. (2003) and Koseki et al. (1998) constructed the walls of 0.5 m height, and finally, Richardson and Lee (1975) performed their experiments on the walls ranging from 0.28 m to 0.41 m with the average height of 0.33 m. In this study, a number of 0.8 m-high models with a scale factor of 7.5 were considered as a suitable representative physical model to reflect the reasonable seismic behavior. Fig. 3 shows the schematic geometry of the experimental models and the length, number, and location of the strips for the present study.

2.1.2. Foundation and embedment depth

The thickness of the foundation was 20 cm, reflecting the limitations in the height of the container and the total weight of the physical model. Foundation layers were compacted to make a rigid layer for all of the model walls in the study. It is important to note that foundation thickness and stiffness can influence the seismic response of superstructures. On the other hand, as recommended by FHWA (2009), a leveling pad for the erection of the facing panels was used for Mechanically Stabilized Earth Walls (MSEW) construction which is often 0.3 m (1 ft) wide and 0.15 m (6 inches) thick in full scale walls. Also, the minimum embedment depth for walls from adjoining finished grade to the top of the leveling pad should be 0.6 m (2 ft), thus in reduced-scale model with a scale factor of 7.5, the scaled embedment depth of 80 mm is attained.

2.1.3. Facing type

Precast concrete panels (1.5 m × 1.5 m) with a minimum thickness of 140 mm in cruciform, square, rectangular or T-shape geometry are often used as the standard facing panel (FHWA, 2009). The connection between the panels and the facing is achieved by galvanized toggles and reinforcement loops. Thus,

Table 1
A brief description of tests.

Name	Length			Polymeric strips arrangement
	Upper layers (2 layer)	Middle layer (3 layer)	Lower layers (3 layer)	
Test 1	0.9H	0.7H	0.7H	Zigzag
Test 2	0.9H	0.7H	0.5H	Zigzag
Test 3	0.9H	0.7H	0.5H	Parallel
Test 4	0.7H	0.7H	0.7H	Parallel
Test 5	0.7H	0.7H	0.5H	Parallel