Shaking table tests on seismic performance of geogrid reinforced slag wall

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ABSTRACT: Geosynthetic reinforced walls in seismic regions must be safe against not only static forces but also seismic forces. Flexible retaining structures are known with their high performance under earthquake loads. When potential use of waste materials or by-products is investigated for geosynthetic reinforcement, it may be a good practice to test the integrity of the composite during shaking. In this study, shaking table models were prepared for geogrid reinforced slag wall. The aim of this study is to determine the behavior of geogrid reinforced slag wall during earthquake by using shaking table tests. Several shaking table models were prepared and tested in the flexible shear stack. In the model tests, the air cooled blast furnace slag as fill material was used. The objective of performing the shaking table tests is to investigate whether will be interlocking problem with the slag and the geogrid during shaking.

1 INTRODUCTION

Largely qualitative observations of the performance of geosynthetic reinforced slopes and walls in both the USA and Japan suggest that these structures perform well during seismic events when located on competent foundation soils and above the water table. Bathurst &Alfaro (1996) stated that the depth, strength and stiffness of the foundation soil may have a greater influence on the internal and external stability of reinforced soil slopes and walls. Numerous cases have been reported where reinforced soil structure performance in major earthquakes have been documented (Collin et al. 1992; Ling et al. 2001; Tatsuoka et al. 1995).

The performance of the fill material and the interface of the fill and geogrid controls the performance of geogrid reinforced walls. It is well known that using of available industrial wastes prevents depletion of the natural resources, avoids the disposal costs of these wastes. Aim of this study is to analyze the behavior of the geogrid reinforced slag wall under earthquake loads by shake table tests. The objective of performing the shaking table tests is to investigate whether will be interlocking problem with the slag and the geogrid during shaking.

2 BACKGROUND

The modelling of the performance of geotechnical structures subjected to earthquake loadings can be achieved with either physical models or with numerical models. Physical models involve the use of a earthquake simulator, or shaking table, and require the creation of a soil bed whose response should match closely that of a semi-infinite free field. The soil is usually contained in a special box, named a laminar box, or shear stack, consisting of rigid horizontal metal rings, ideally with no friction between them. The finite stiffness of the container interacts with that of the soil and can lead to a change of the behaviour of the model with respect to that of the prototype free field (Gajo &Wood 1998). The shaking tables which were primarily designed for modeling of structures, are adopted to perform geotechnical modeling (Fukutake et al. 1990). The advantage of shaking table tests is that they are relatively easy to perform. The principal disadvantages are related to problems of similitude between reduced-scale models and equivalent prototype scale systems (Bathurst & Alfaro 1996).

A common problem to both centrifuge and shaking table testing is the design of the specimen container. A simple, rigid walled box will not allow the specimen to deform uniformly. To overcome this problem, several researchers have used variations of the “shear stack” concept. The boxes that contain the specimens are categorized in two groups; rigid sided shear boxes and flexible, layered shear stacks. The flexible shear stack is composed of alternating rubber layers and metal frames stacked over each other. Taylor et al (1994) have developed a flexible shear stack of 1.2 m long, 0.6 m wide and 0.9 m in high. They have conducted several experiments using dry sand under seismic loading. They have measured consistent acceleration values in the horizontal lane. The vertical profile of the measured accelerations was sinusoidal as desired. With the experience gained Taylor et al (1994), the results of this study revealed that the shear stack tests provided representative values for field conditions.

Sakaguchi (1996) performed shaking table tests on a 1.5 m high model test of a geogrid wall. The tests were constructed with lightweight blocks and five layers of geogrid reinforcement. It is found that the reinforced zone was observed to cut as a monolithic body with no evidence of a yield surface propagating across the reinforcement layers even after large wall displacement developed.

Matsuo et al (1998) carried out shaking table tests on six geosynthetic-reinforced soil retaining wall models. In their models, the geogrid reinforcement length, wall height, wall facing type, wall slope, and input acceleration waveform were varied in order to behavior and reinforcement mechanisms.

Latha & Krishna (2007) tested three types of walls: wrap- and rigid-faced reinforced soil walls and unreinforced rigid –faced walls constructed to different frequencies and relative densities. It is observed that the walls constructed with higher backfill relative density showed lesser face deformations and more acceleration amplifications compared to the walls constructed with lower densities when tested at higher base excitation.

Large scale shaking table tests were reported by Ling et al. (2005). Three large scale 2.8 m high modular-block geosynthetic-reinforced soil walls were subjected to Kobe earthquake motions. Each wall was excited with one-dimensional horizontal maximum acceleration of 0.4g followed by 0.86g. The reinforced soil retaining walls showed negligible deformation under simulated earthquake (peak acceleration of 0.4g). Under very strong shaking of 0.86g the walls performed well.

3 EQUIPMENT AND MATERIALS USED IN THE SHAKING TABLE

3.1 *Shaking Table*

In this study, the large uniaxial shaking table facility at the Shake Table Laboratory of Kandilli Observatory and Earthquake Research Institute (KOERI) at Boğaziçi University was used. The uniaxial shaking table (3mx3m) is driven by a servo-hydraulic actuator. Test objects up to 10 tons force can be accumulated over a frequency range of 0-50 Hz. The shake table is ideally suited to seismic applications, because the hydraulic actuator can produce a stroke of +/- 12 cm.

3.2 *Shear Stack*

In this study, a shear stack was designed and constructed by using the knowledge and experience from the studies performed at the Bristol University by Taylor et al (1994) (Figure 1). The length of the stack is 1.45 m, the width is 0.75 m and the height is 0.78 m. Eight rubber layers were specially molded to target specifications. Eight aluminum frames were manufactured using tubular aluminum profiles. The rubber frames allow the soil specimen to deform freely while the aluminum frames provide the horizontal boundaries for the specimen. The size of the frames and material properties were determined after performing finite element analysis to achieve the criteria set by Gazetas (1982). This essential criteria that the shear stack had to meet were: (i) lateral motions should be uniform on any horizontal plane through the soil and the shear stack itself, and (ii) lateral motions over the depth of the stack should follow a near sinusoidal profile.

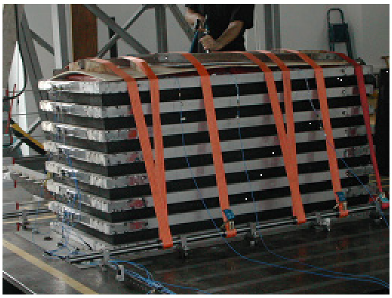


Figure 1. Experimental setup

3.3 *Backfill material*

The blast furnace slag was supplied from Kardemir Iron and Steel Ltd., Co. located in the Black Sea region of Turkey (Figure 2). The backfill material has the same physical properties with the geogrid slag wall designed in the Karabuk city of Black Sea region of Turkey (Baykal et al. 2008). Geogrids of tensile strengths (45, 60, 90 kN/m) were used at 0.4 m spacing. The construction site is located at first degree earthquake zone. The internal friction angle of slag is 49 degrees. The optimum water content and maximum dry density of blast furnace slag are 10 % and 23.09 kN/m^3, respectively.

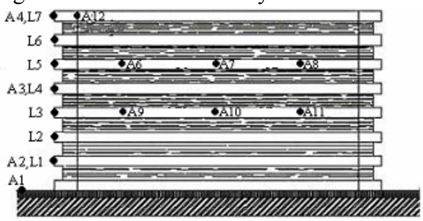
Figure 2. Blast furnace slag

3.4 *Set up System*

Compaction of the soil and slag in the shear stack was achieved by applying an energy comparable to standard compaction proctor energy. The lower geogrid layer is placed 0.3 m above the base. The upper layer is placed above the base. A 0.10 m thick layer of slag is placed above the upper geogrid layer. The vertical pressure of 40 kPa is applied by airbags. The instrumentation consisted of A11 accelerometers and 8 displacement transducers (Figure 3). At the level of lower geogrid layer three accelerometers are installed 0.24m, 0.72 and 1.20 m from the front face. The same accelerometer configuration is applied at the upper geogrid elevation (Figure 3).

The air bags are tied down with a rope on a circular rollers sliding on a steel rods. The sliding steel rod is fixed on the shaking table platform with steel screws. The rollers provided minima friction during the shaking table motion (Figure 1). The loading mechanism has been used for previous tests and performed successfully (Edincliler et al. 2007). The displacement of eight aluminum frames forming the shear stack were measured using eight displacement transducer fixed on the reaction frame.

Figure 3. Instrumentation layout



4 EXPERIMENTAL STUDY

In order to gain better insight into dynamic behavior of a geogrid reinforced slag wall, shaking table tests carried out using the shaking table facility at the KOERI. El Centro Earthquake motions were used to excite the model at a maximum acceleration of 0.3g followed by 0.6g.

A total of nine models were tested. One test with sand (Model 1), only slag (Model 2), 2 layers of geogrid fold up at the back wall of the stack (Model 3a), The same configuration with Model 3a with no vertical pressure (Model 3b), two layers of geogrid with geogrid trimmed near the back wall instead of folding up (Model 4). For the Models 1 through 4, ElCentro earthquake record with 0.3g were applied as input motion. For models 5a, 5b, 6a, 6b, and 6c, Model 5 refers to folded geogrid, Model 6 refers to trimmed geogrid. The letters refers to number of repetitions. The maximum accelerations and time (t) values are tabulated in Tables 1 through 6.

Table 1. Maximum acceleration on the shear stack (0.3g)

	Base Acc.		Accelerations on Shear Stack								
	A1		A2 (Bottom)			A3 (Middle)			A4 (Top)		
No	Time (Sec)	Acc. (g)	Time (Sec)	Acc (g)	Amp	Time (Sec)	Acc (g)	Amp	Time (Sec)	Acc (g)	Amp
1	1.39	0.3	1.29	0.35	1.1	1.12	0.39	1.2	2.95	0.35	1.1
2	2.31	0.3	2.31	0.31	1.1	1.61	0.34	1.1	1.64	0.42	1.4
3a	1.64	0.3	1.64	0.31	1	1.64	0.34	1.1	1.64	0.38	1.3
3b	2.32	0.3	1.46	0.26	1	2.32	0.29	1.1	2.32	0.33	1.3
4	2.31	0.3	2.32	0.28	1	2.32	0.31	1.2	2.33	0.35	1.3

Table 2. Maximum acceleration at upper geogrids (0.3g)

	Base Acc.		Accelerations on Shear Stack								
	A1		A2 (Bottom)			A3 (Middle)			A4 (Top)		
No	Time (Sec)	Acc. (g)	Time (Sec)	Acc (g)	Amp	Time (Sec)	Acc (g)	Amp	Time (Sec)	Acc (g)	Amp
1	1.39	0.3	1.29	0.35	1.1	1.12	0.39	1.2	2.95	0.35	1.1
2	2.31	0.3	2.31	0.31	1.1	1.61	0.34	1.1	1.64	0.42	1.4
3a	1.64	0.3	1.64	0.31	1	1.64	0.34	1.1	1.64	0.38	1.3
3b	2.32	0.3	1.46	0.26	1	2.32	0.29	1.1	2.32	0.33	1.3
4	2.31	0.3	2.32	0.28	1	2.32	0.31	1.2	2.33	0.35	1.3

Table 3. Maximum Accelerations at Lower Geogrids (0.3g)

	Base Acc.		Accelerations. on Upper Level								
	A1		A6			A7			A8		
No	Time (Sec)	Acc. (g)	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp
1	139	0.3	2.94	0.34	1.1	2.94	0.35	1.1	2.94	0.33	1
2	2.31	0.3	1.64	0.33	1.1	1.64	0.34	1.1	1.64	0.33	1.06
3a	1.64	0.3	1.64	0.34	1.1	1.64	0.34	1.1	1.64	0.34	1.13
3b	2.32	0.3	2.32	0.29	1.1	2.32	0.3	1.2	2.32	0.28	1.08
4	2.31	0.3	2.32	0.31	1.2	2.32	0.32	1.2	2.32	0.3	1.11

Table 4. Maximum accelerations on the shear stack (0.6g)

	Base Acc.		Accelerations on Lower Level								
	A1		A6			A7			A8		
No	No. (Sec)	Acc. (g)	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp
1	1.39	0.3	1.31	0.32	1	1.31	0.33	1.03	1.31	0.34	1.06
2	2.31	0.3	2.28	0.31	1	2.28	0.33	1.06	2.28	0.33	1.06
3a	1.64	0.3	1.64	0.32	1.1	1.04	0.32	1.07	1.64	0.32	1.07
3b	2.32	0.3	2.31	0.27	1	2.32	0.27	1.04	2.32	0.29	1.12
4	2.31	0.3	2.32	0.29	1.1	2.32	0.31	1.15	2.32	0.31	1.15

Table 5. Maximum Accelerations at upper geogrids (0.6g)

Base Acc.	Accelerations on Shear Stack

	A1		A2 (Bottom)			A3 (Middle)			A4 (Top)		
No	Time (Sec)	Acc. (g)	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp
5a	2.23	0.6	2.29	0.66	1	2.29	0.76	1.19	2.29	0.84	1.39
5b	1.64	0.6	1.66	0.63	1.1	1.66	0.72	1.22	1.66	0.84	1.42
6a	1.1	0.6	1.04	0.61	1	1.1	0.63	1.03	1.11	0.75	1.23
6b	2.32	0.6	2.31	0.62	1	2.31	0.69	1.13	2.33	0.78	1.28
6c	2.32	0.6	2.32	0.65	1.1	2.46	0.73	1.2	2.46	0.9	1.48

Table 6. Maximum accelerations at lower geogrids (0.6 g)

	Base Acc.		Accelerations. on Upper Level								
	A1		A6			A7			A8		
No	Time (Sec)	Acc. (g)	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp	Time (Sec)	Acc. (g)	Amp
5a	2.23	0.6	2.29	0.75	1.2	2.29	0.78	1.22	2.29	0.77	1.2
5b	1.64	0.6	1.66	0.74	1.3	1.66	0.76	1.29	1.66	0.75	1.27
6a	1.1	0.6	1.11	0.62	1	1.11	0.63	1.03	1.11	0.61	0.98
6b	2.32	0.6	2.33	0.68	1.1	2.31	0.71	1.16	2.33	0.66	1.08
6c	2.32	0.6	2.46	0.74	1.2	2.46	0.77	1.27	2.46	0.73	1.2

5 TEST RESULTS

The variation of horizontal displacements for sand and slag recorded on the shear stack are given in Figure 4. It is seen that shaking table test for only slag reduces the horizontal displacement on the shear stack.

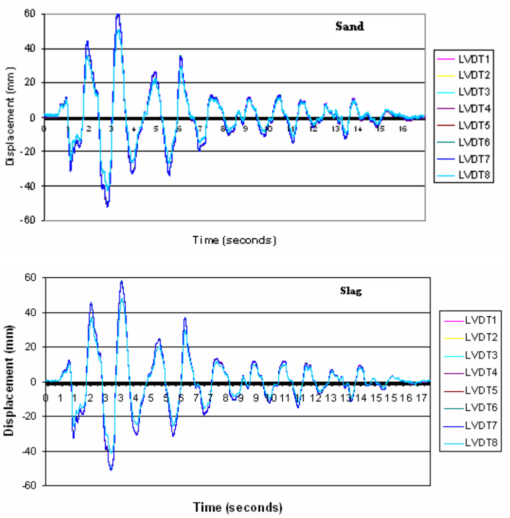


Figure 4. Displacements on Shear Stack

The maximum amplification factor was evaluated for all of the earthquake motions. The maximum accelerations were observed at the time instances of t=1.04 sec and t=2.94 for 0.3g and t=1.02sec and t=2.29 for 0.6g. The amplification ratio of the models was less than 1.35 under a peak acceleration of 0.3g and 1.48 under the peak acceleration of 0.6g. Amplification factors range between 1.00 and 1.35 for 0.3g and 0.98 and 1.48 for 0.6g. At the top of the frame higher amplification values were observed for slag when compared to that of sand. This is due to higher stiffness of slag which results higher amplification.

6 CONCLUSIONS

In this study, the potential use of waste materials for reinforced walls was investigated. The integrity of the composite during shaking was determined by shaking table tests. During the tests, the compatibility of the slag and geogrid was observed. It has been observed that the new type of fill material used did not segregate and performed well under earthquake loads.

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