

## **DYNAMIC BEHAVIOR OF GEOGRID REINFORCED SEGMENTAL BLOCK WALLS UNDER EARTHQUAKE LOADS**

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### **ABSTRACT**

The results of an experimental study conducted on two 1/2 reduced-scale geogrid-reinforced soil retaining block walls are presented and discussed. The heights of the models were 1.9 m and El Centro, Izmit and Sakarya earthquakes were applied. The prototype design was taken from a design made for a real project. Therefore the geogrid reinforcement and facing blocks were scaled versions of the real wall. The geogrids are connected to the facing blocks only by friction. Again to simulate the real design, the walls were constructed with 6° inclined facings. Two different backfill materials were used. In the first model coarse grained gravel and in the second model well graded sand was used and their effects on the measured parameters are investigated. The aim was also to see whether the wall designed according to current specifications would behave as it was designed under an earthquake loading condition. Accelerations, strains in the reinforcement layers and facing wall deformations were registered for a later complete evaluation. The test results showed that in both experiments the walls in fact behave almost elastically and the residual displacements observed on the front of the wall were very small under the design earthquake accelerations. The first most important conclusion drawn from the experimental work is that the designed Geosynthetic Reinforced Retaining Structures behaved very successfully under earthquake loading conditions. However it was determined that the backfill type has an effect on the behavior of the wall.

Keywords: Geogrid-reinforced soil, Reinforced block wall, Shaking table test

### **INTRODUCTION**

When compared with the conventional gravity walls, Geosynthetic-Reinforced Soil Retaining Walls (GRS-RWs) offer cost-efficiency, higher performance, aesthetic appearance and much more durability. Because of these advantages, they are widely constructed in place of the conventional gravity walls (Koseki et. al. (2006). In practice, such walls are routinely designed using limit-equilibrium analysis and earthquake loads are considered using pseudo-static methods (AASHTO 1996; FHWA 1996). Shaking table tests were conducted by Ling et al (2005) and Leshchinsky et al. (2008). Leshchinsky demonstrates that although Limit Equilibrium analysis shows a FS $\approx$ 1 for an acceleration of 0.39g, for a 2.8 m high geogrid reinforced slope having geocell facing and sand backfill, no failure was observed even for an acceleration of 0.8g.

The seismic design methodologies for GRS-RWs are largely based on the results of numerical modeling of reinforced structures constructed with inextensible reinforcement although the related empirical rules

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developed from these types of structures may not be applicable to nominal identical walls constructed with geosynthetic reinforcement. To help improve these kinds of inadequacies of the current seismic design methods and to gain a better insight into dynamic behavior of a Geosynthetic-Reinforced Soil Retaining wall (GRS-RW) under earthquake loads, a large number of numerical and experimental tests must be available.

This study presents first results from two ½ reduced-scale Geogrid-Reinforced Soil Retaining Block Wall models that were tested on a shaking table. The model walls were constructed based on an original design made for a real project and loaded using the scaled El Centro earthquake (1940) and Izmit and Sakarya earthquake (1999) motions.

The constraints of the shaking table limit the weight of the model to be tested to 100 kN. Therefore in order to simulate a higher wall, scaled models are used. To evaluate the results obtained from model tests and link the results to its full size prototype, scaling laws are used. Scaling laws provided by the dimensional analysis is a compacting technique for reducing the number and complexity of experimental variables. Based on the scaling laws, similarity is achieved between the model and prototype.

In Table 1, the most common scale factors used in this study can be seen. These scale factors are in agreement with the ones proposed by Iai and Sugano (1999) and Jakrapiyanun and Ashford (2003).

**Table 1. Scaling factors used in this study**

Quantity	Theoretical Ratio (Prototype/Model)	Study
Length	n	2
Density	1	1
Stress	n	2
Strain	1	1
Acceleration	1	1
Frequency	$n^{-0.5}$	$1/\sqrt{2}$
Time	$n^{0.5}$	$\sqrt{2}$

## TEST SETUP, INSTRUMENTATION AND REINFORCEMENT LAYOUT

The shake table tests were conducted in Kandilli Earthquake Research Center laboratories of Bogazici University, Istanbul, Turkey. A steel container with dimensions of 2m x 0,5 m x 2,8 m (height, width, length) is placed on the shaking table. Details of the testing device are given in Guler and Enunlu (2009).

In the first model, the container is filled with gravel and two different types of geogrid reinforcements were horizontally placed. The Huesker Fortrac 45/15-20 geogrid reinforcements were placed on the lower portion till mid height of the wall. They have an L/H ratio of 0,8 (Length of the geogrid=1,5 m). They are placed with a vertical spacing of 0,2 m, in other words a reinforcement was placed for every two rows of model blocks. Huesker Fortrac 20/15-20 geogrid reinforcements were placed on from the midheight till the upper portion of the wall and they have an L/H ratio of 0,7 (Length of the geogrid=1,3 m. The vertical spacing of reinforcement is again 0,2 m. A schematic of the wall is given in Fig. 1 and a photograph of the facing is given in Fig. 2. No intermediate reinforcement layers were placed during the experiments. The interconnection between the facing blocks and geogrid reinforcement was purely frictional as can be

seen in Fig. 3. In the second model, all the parameters regarding the reinforced wall were the same as the first model except the backfill material, which was selected as well-graded sand. When placing the backfill, both gravel and sand were compacted at each 100 mm.

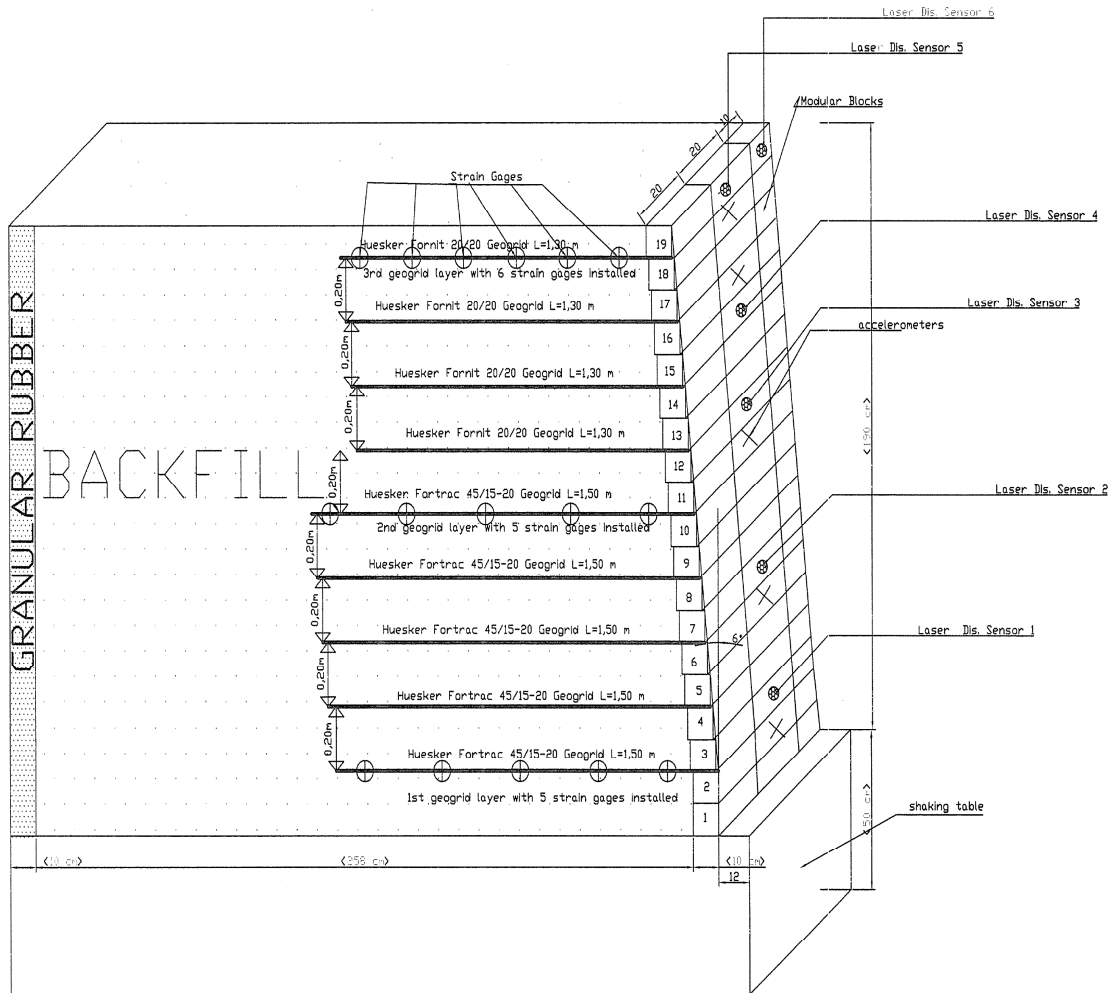
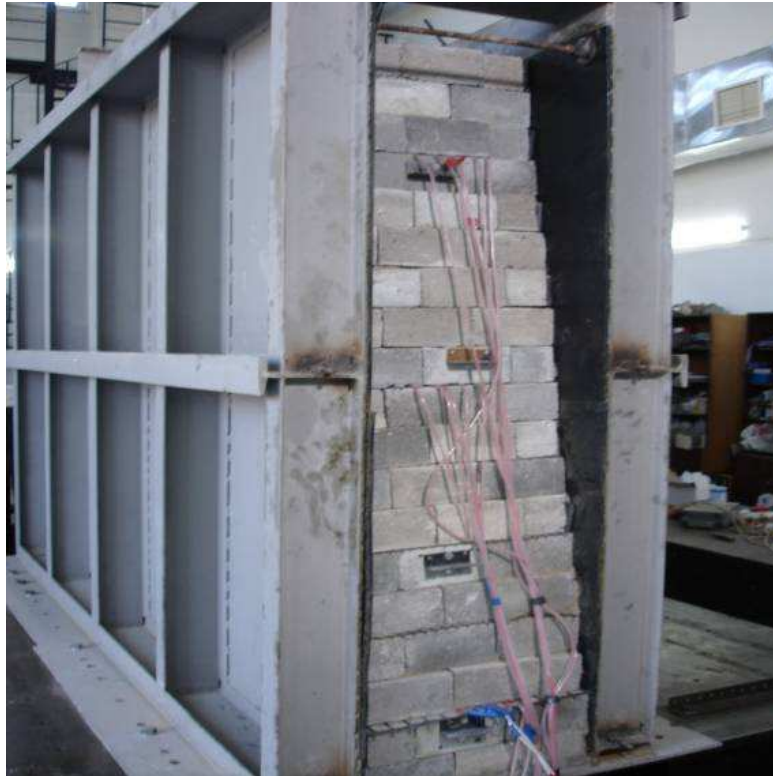


Fig. 1. Schematic view of the model wall and locations of instrumentations.

Since the side boundaries of the steel container and backfill materials are prone to friction, rubber sheets were utilized on the side boundaries. Those rubber sheets were not only helpful on eliminating the side effects of the friction phenomena but also the rubber sheet would follow the deformation of the backfill without significant resistance.

In order to simulate segmental retaining structures, hollow concrete facing blocks are placed vertically on the facing with an inclination of  $6^\circ$  from the vertical to simulate the original design. As facing blocks, scaled versions of hollow blocks used by Geoduvar in Turkey were used. The dimensions of these model blocks were 100 mm x 100 mm x 200 mm (height, depth, width).



**Fig. 2.** An overall view of the model wall with accelerometers and strain gages mounted



**Fig. 3.** Installation of geogrids with frictional connection to the facing blocks

10 cm. thick granular rubber fill was placed between backfill and the back of the steel container in order to prevent reflection of the earthquake waves.

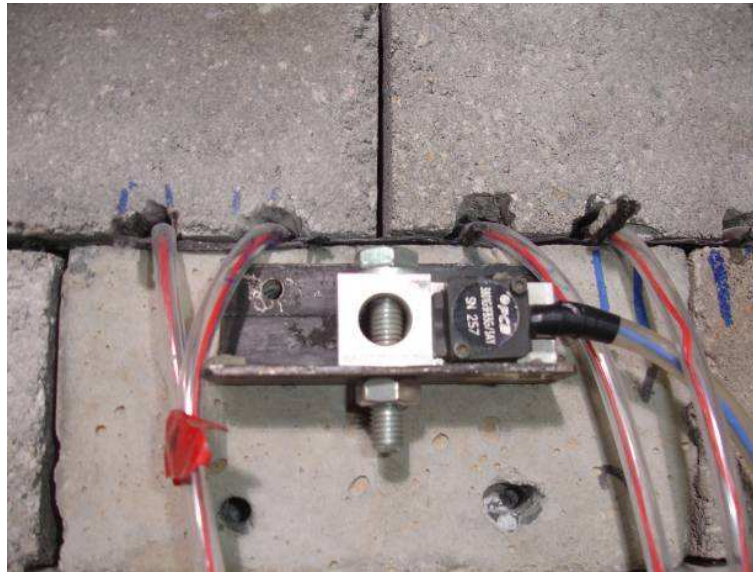
A total number of 16 strain gages are installed on three different geogrid reinforcement layers (at the bottom layer, at mid height layer and top layer) to measure the strain behavior under dynamic conditions. The strain gages are installed on the middle section of the geogrids which can be seen in Fig. 4. The strain gage cables were passed through polymer flexible pipes so as not to effect the measurements. The strain gages are installed on geogrids using special kind of adhesive and connected to an 16 channel TDG Aib8 data acquisition system.



**Fig. 4. Strain gage setup on geogrid**

The instrumentation also consisted of 9 accelerometers which were installed on the facing elements of the wall, top of the backfill and one accelerometer on the shaking table. The accelerometers mounted on the wall can be seen in Fig. 5





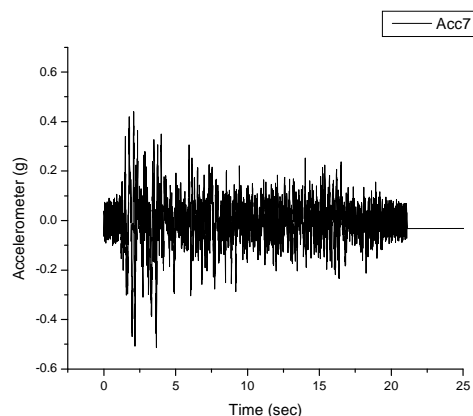
**Fig. 5. One of the accelerometers mounted on block facing and strain gage cables**

Six laser displacement sensors measuring the displacement of the wall face are installed (with a distance of 25 cm away from the facing elements) in a glass covered steel cell. This glass covered steel framed cell was mounted on the steel container and made the same displacement as steel container in earthquake motion. By this way, only the relative displacement values are measured.

### **Shaking Sequence**

Three different recorded earthquake motions (El Centro, Izmit and Sakarya Earthquakes) were applied on each model. Since the model is a 1:2 scaled model, the natural periods are decreased by  $1/\sqrt{2}$ .

The period of the motion for each earthquake lasted 18.75 seconds for El-Centro, 28 seconds for Izmit and 20 seconds for Sakarya in which the peak accelerations were 0.3 g for El Centro and lower peak accelerations for other two earthquakes. As an example, the acceleration record used for the El-Centro Earthquake is given in Fig. 6.



**Fig. 6. The 100% El-Centro Earthquake Record**

On later stages of the experiment the peak acceleration values were doubled and tripled meaning that almost 1 g peak acceleration values are applied on the models.

## RESULTS AND DISCUSSION

The results indicated that geogrid reinforced retaining structures designed according to the specifications show good resistance to earthquake loading conditions. Both gravel and sand backfilled models behaved successfully under earthquake loading with peak acceleration values of up to 1 g. One of the most interesting facts registered is that although the connections blocks to geogrids are only frictional they resisted even extreme seismic loads. Although significant facing displacement and vertical settlement at top is observed at peak acceleration values of 1 g the reinforced walls did not fail.

The facing displacement values for 100% and 250% El-Centro Earthquake are given in Table 2. The backfill type had some effect on the peak displacements of the uppermost facing block. As can be seen from the table no significant permanent displacement occurred for 100% El-Centro Earthquake. When peak deformations under the extreme loading condition of 250% El-Centro are considered, the gravel backfill showed a slightly better behavior. However, even under these extreme accelerations the residual displacements remained minimal.

Also, in sand backfilled models tensile cracks are observed as well as large settlements at peak acceleration values of 1 g. The tensile cracks observed at the top of the model can be seen in Fig. 7

The strain gage data were obtained successfully and still being analyzed.

**Table 2. Horizontal Displacements Measured on Top Modular Block (mm)**

	Gravel (Peak)	Gravel (Residual)	Sand (Peak)	Sand (Residual)
100% El Cento	1,9	0,5	2,2	0,6
250% El Cento	28,1	4,7	30,6	4,3



**Fig. 7. Tensile cracks observed in sand backfill**

## **CONCLUSION**

The geogrid reinforced segmental block walls designed according to current specifications showed a very good resistance to earthquake loading conditions. They remained stable even under extreme lateral accelerations. Both gravel and sand backfill showed very successful behavior. No stability problem occurred even under extreme lateral accelerations. The Geogrid Reinforced Segmental Block Walls showed minimal residual deformations and acceptable maximum deformations under extreme lateral earthquake accelerations.

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