GeoAmericas 2016
3RD PAN-AMERICAN CONFERENCE ON GEOSYNTHETICS
10-13 APRIL 2016 · MIAMI BEACH · USA

CENTRIFUGAL MODELING OF GABION FACING GEOSYNTHETIC REINFORCED SOIL RETAINING WALLS

L. Xu, Columbia University, New York, NY, USA
H. I. Ling, Columbia University, New York, NY, USA
J. G. Collin, The Collin Group Inc., Bethesda, MD, USA
J. Han, University of Kansas, Lawrence, KS, USA
D. Leshchinsky, ADAMA Engineering Inc., Portland, OR, USA
B. Tanyu, George Mason University, Fairfax, VA, USA
L. Li, Columbia University, New York , NY, USA
T. Kawabata, Kobe University, Kobe, Japan

ABSTRACT

Centrifuge modeling provides a less expensive mean of studying the behavior of reinforced soil retaining walls under well controlled testing conditions. In this study, two reinforced soil retaining walls of height 15.3 m were tested in the centrifuge under 50g acceleration. The wall model was backfilled with a fine sand, compacted up to a backfill of height 32 cm that rested on a foundation soil of 5 cm. The wall facing was constructed using gabions replicating an existing system. A fiber glass mesh of length 35 cm was used in modeling a reinforcement having prototype length of 17.5 m. The first and second walls were of vertical reinforcement spacings of 2 cm and 4 cm (prototype spacings of 1 m and 2 m), respectively. The walls were instrumented with a number of strain gages in the reinforcement layers and earth pressure transducers behind the gabion facing as the centrifugal field is increased in steps to 50g. Photos were taken during spinning from which the deformation of the facing and settlements were obtained. Measured deformations, earth pressures and reinforcement strains of the two walls are compared.

1. INTRODUCTION

Geotechnical centrifuge modeling has been an important research technique that uses a reduced scale model of a full scale structures. It involves spinning the model in a centrifuge to create a gravitational field that simulates the same stresses and strains conditions of the full scale (prototype) structure. If a centrifugal acceleration of N-times earth's gravity g is applied, then the model dimensions can be scaled down to 1/N in creating the same stress and strain conditions.

Many geotechnical structures involved staged construction. While construction procedures of simple structure may be simulated under high gravity, the simulation of complicated structure, such as reinforced soil retaining wall, is not yet possible. Thus, the model has to be built at 1-g and then tested under desired g-level. Despite such a limitation, the centrifuge modeling technique enables the stability and behavior of full-scale structure to be evaluated.

A reinforced soil retaining wall with gabion facing is designed for actual construction in the field [1]. The wall height was 15.3 m with a wire mesh facing system. The reinforcement was a geogrid with an ultimate strength of 412 kN/m. This study used the centrifuge modeling technique to simulate this wall at an acceleration of 50g. Two tests were conducted with different reinforcement layouts. The material properties, modeling technique, and test results are reported.

2. MATERIALS

The material properties for the models are given in this section. Note that the sand and reinforcement have been used in previous studies of slopes and reinforced soil retaining walls at Columbia University (e.g., [4, 5]).

Wall Facing: The gabions used for the scaled centrifuge model were made of a galvanized steel mesh and river stones as inner fill. The steel mesh (Figure 1a) has an opening size of 2.743 mm and the diameter of the wire was 0.43 mm.

The stones used in the prototype gabions had a diameter of 100-200 mm [3]. Thus, using a scale factor of 50, it was determined that the diameter of the river stones to be used for the model had to be about 2-4 mm. To separate and filter out the correctly sized river stones, #4 and #8 sieves were used, which have 4.75 and 2.4 mm size openings, respectively. A photo of the river stones with grain size distribution is shown in Figure 2(a). The mean diameter D50 was 3.3 mm.

The gabions had an average density of 2 g/cm3 with the steel mesh included and 1.7 g/cm3 with only the stones. The sides and the back of the gabions were covered with a smooth tape to decrease friction along the sides of the model box and to prevent sand from flowing into the gabions during construction. A gabion unit, with the stone infill, is shown in Figure 1b.

Backfill: Nevada sand was used as the backfill of the model retaining wall. It is a light colored fine sand from California. The grain size distribution of Nevada sand is shown in Figure 2(b). The mean diameter D50 was 0.15 mm. A series of tests, including sieve analysis, standard proctor tests, and direct shear tests, were conducted to determine the basic properties of the sand. Some of the properties have been reported in [2].

From the compaction curve (Figure 3a), the maximum dry unit weight γd, max, was found to be 16.6 kN/m3. The backfill soil used in the model had a small water content of 5%. The resulting total unit weight γt was 16.04 kN/m3. A series of direct shear tests were conducted on Nevada sand. From the direct shear test results, the angle of internal friction ϕ for Nevada Sand at the compacted density was determined as 35.4o (Figure 3b).

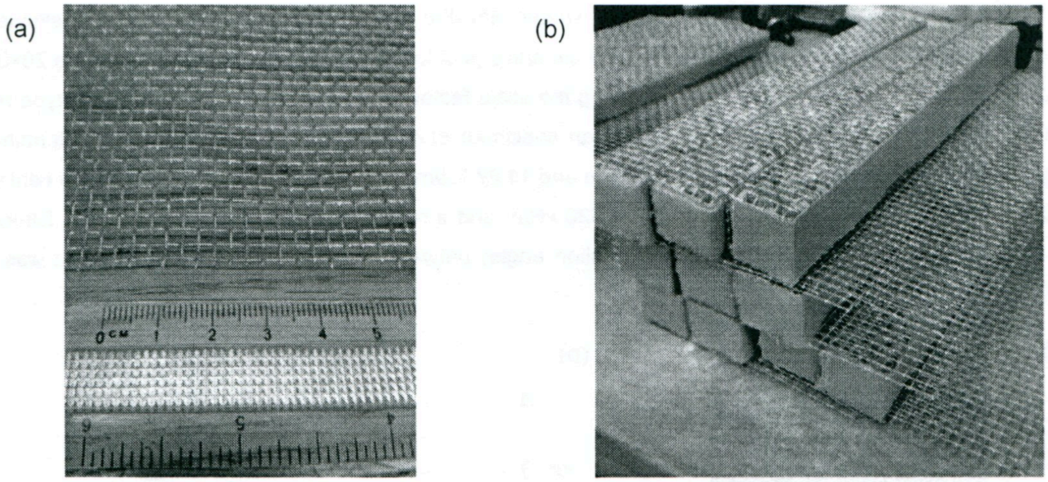


Figure 1. Gabion: (a) Galvanized Steel Mesh, (b) Models of Gabion.

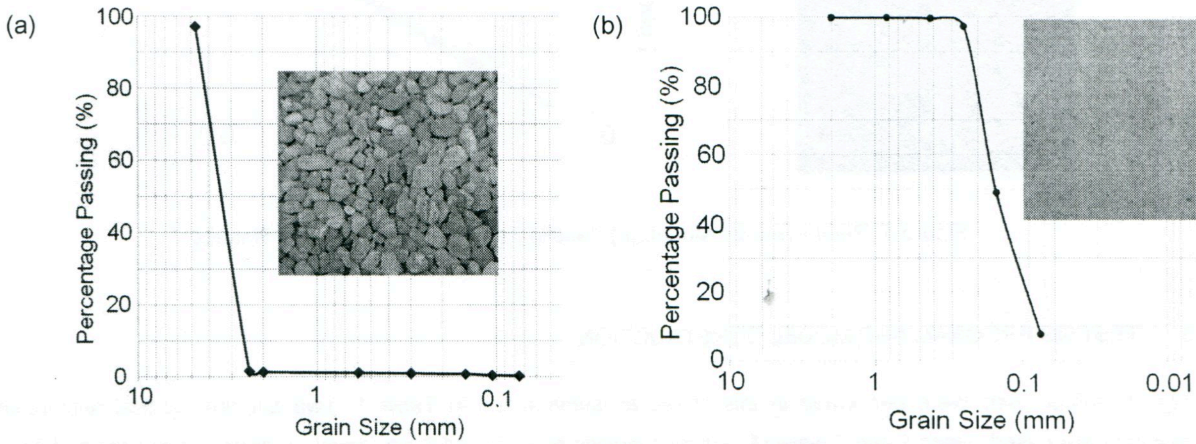


Figure 2. Grain Size Distributions: (a) River Stones, (b) Nevada Sand [2].

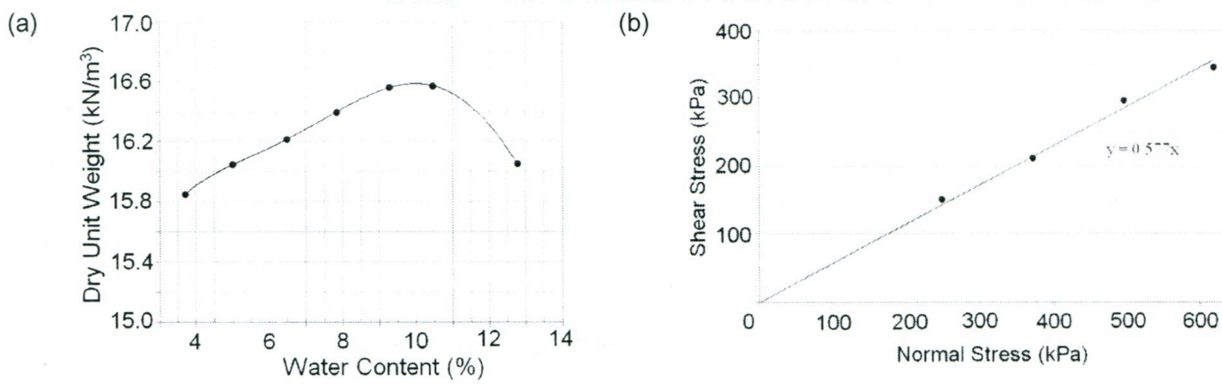


Figure 3. Nevada Sand: (a) Compaction Curve, (b) Direct Shear Test Results.

Reinforcement: A fiberglass mesh coated with polymeric film (Figure 4a) was used in the model to simulate an actual reinforcement having a strength of 520 kN/m. The dimensions of the reinforcement for the model were 20×35 cm (WxL). This length of 35 cm was determined from applying the scale factor of 1/N (where N= 50) to the prototype reinforcement length of 17.5 m. Tensile tests were conducted on specimen of dimensions 20×6 cm (L×W) to determine the tensile strength and initial modulus, which were 10.4 kN/m and 11.67 kN/m, respectively (Figure 4b). Under a centrifugal field of 50g, this model reinforcement has a strength of 520 kN/m and a modulus of 583 kN/m, respectively. Direct shear tests were conducted to determine the interaction (friction angle) between the reinforcement and sand. It was found to be 28.2o.

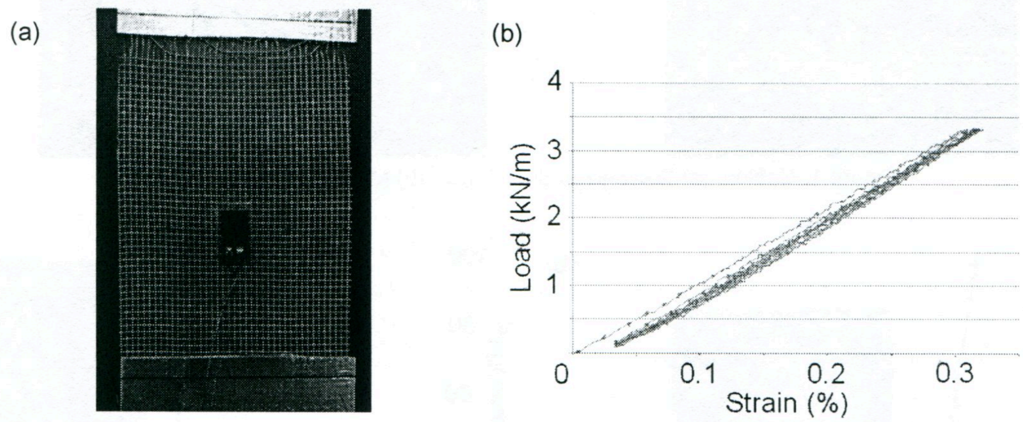


Figure 4. Reinforcement Model: (a) Tensile Test Specimen, (b) Test Results.

3. TESTING PROGRAM AND MODEL CONSTRUCTION

Two centrifuge tests were performed in this study, as summarized in Table 1. Two different vertical reinforcement spacings were used. Tests 1 and 2 were of vertical spacings of 4 cm and 2 cm (equal to prototype spacings of 2 m and 1 m), respectively. The configurations of the two models are shown in Figure 5.

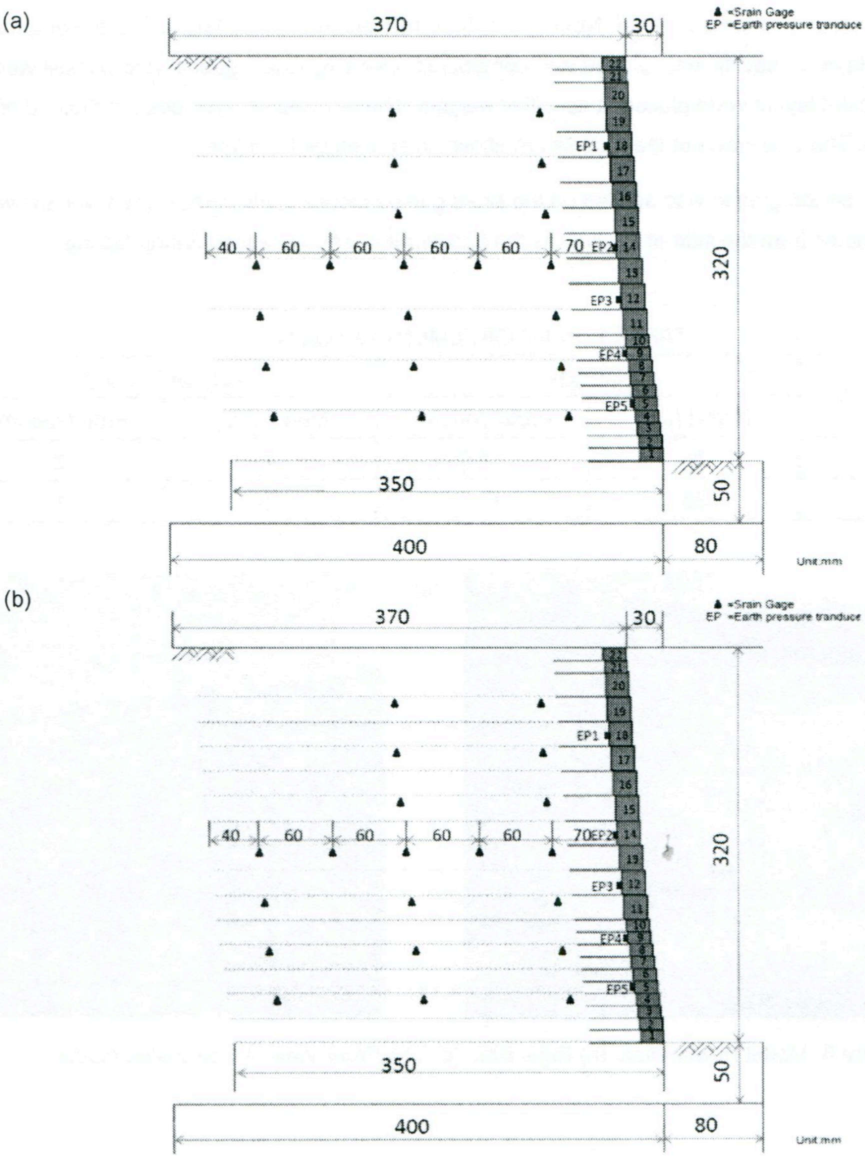


Figure 5. Configuration of Centrifuge Models: (a) Test 1, (b) Test 2. (unit: mm)

Instrumentations included measurements of reinforcement strains and lateral earth pressures behind the gabions. A total of 20 strain gages were attached to the reinforcement layers, as well as 5 earth pressure transducers were installed at different heights behind the gabions.

The wall model was constructed under 1-g field inside a rigid box. The dimensions of the rigid box (Figure 6a) were 48Lx20Wx50H cm (length×width×height). For constructing the model, first the soil was placed in the box and compacted to create a foundation layer of thickness 5 cm. Next, the bottom reinforcement was laid with the first gabion placed on top, and then the first layer of backfill was placed and compacted. Layer by layer, gabion and backfill were placed and compacted. Reinforcement layers were placed at specified heights. The top view of the model, at the end of construction, is shown in Figure 6(b). The side views of the models are shown in subsequent Section.

In preparing the model, silicon grease was applied on the sides gabion blocks to minimize friction with the wall. A camera was installed to take photos from the side of the wall as the acceleration was increased during testing.

TABLE 1. REINFORCEMENT LAYOUTS

Test #	Length		Vertical Spacing	
	Model (cm)	Prototype (m)	Model (cm)	Prototype (m)
1	35	17.5	4	2
2	35	17.5	2	1

(a) (b)

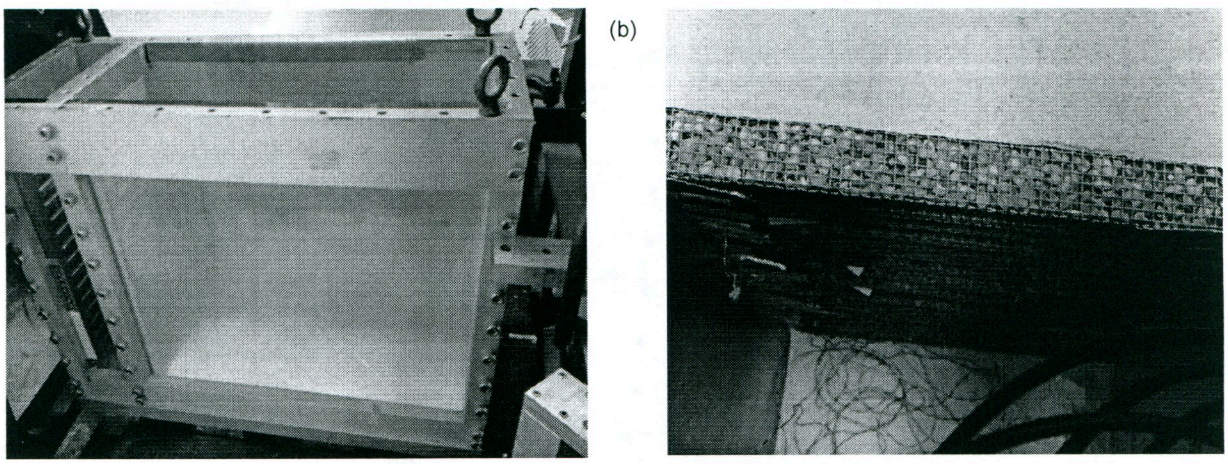


Figure 6. Model Preparation: (a) Rigid Box, (b) Top Front View of Completed Model.

4. TEST RESULTS

4.1 Deformations

Models 1 and 2 were spun up to 50g without failure. A photo of model 2 after reaching 50g is shown in Figure 7(b), which can be compared to configuration before testing (Figure 7a). Local cracks were observed on the wall surface as seen in Figure 7(c). The cracks were surficial and shallow, resembling tension cracks, indicating that they were caused by the apparent cohesion in the soil when deformation occurred.

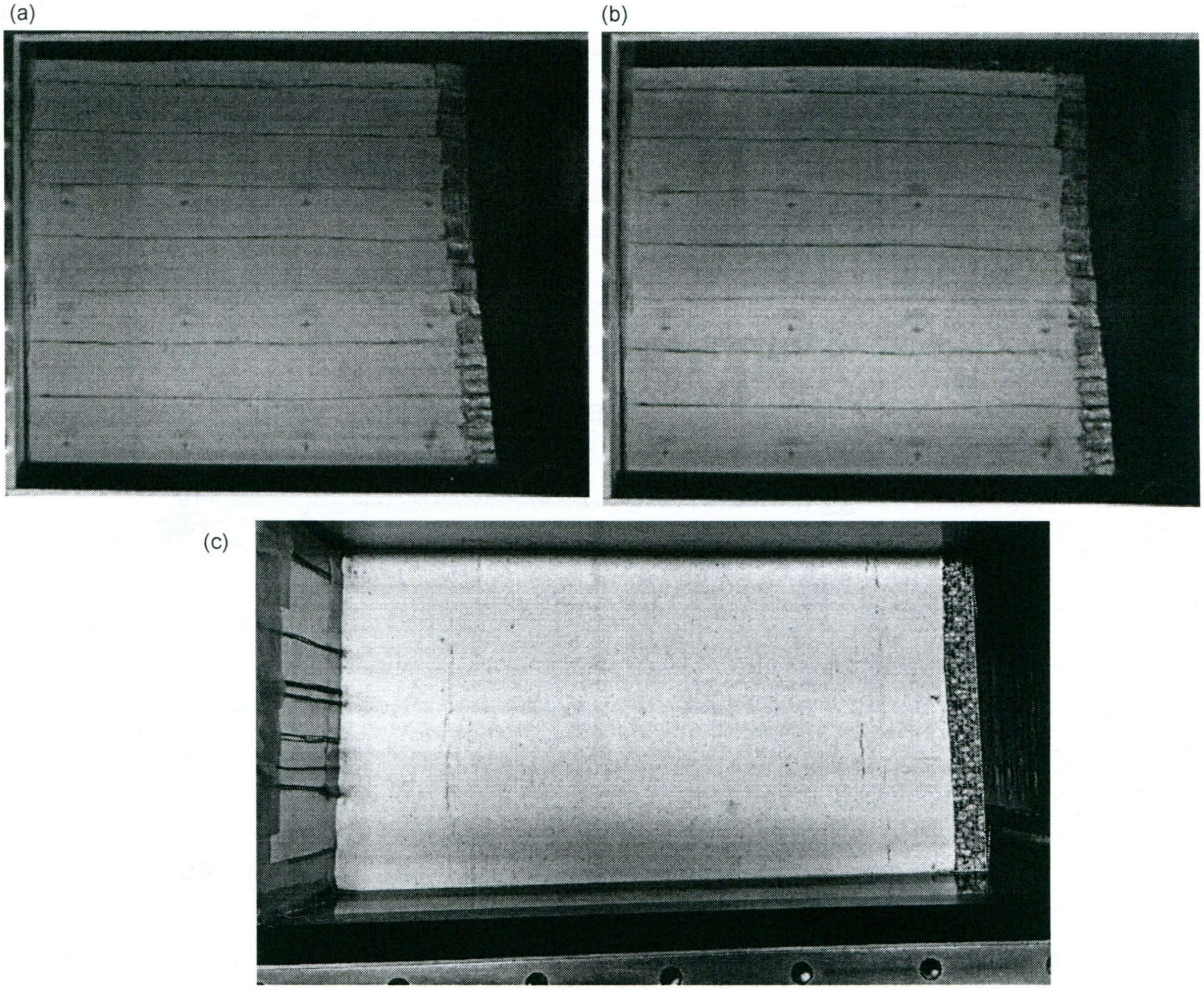
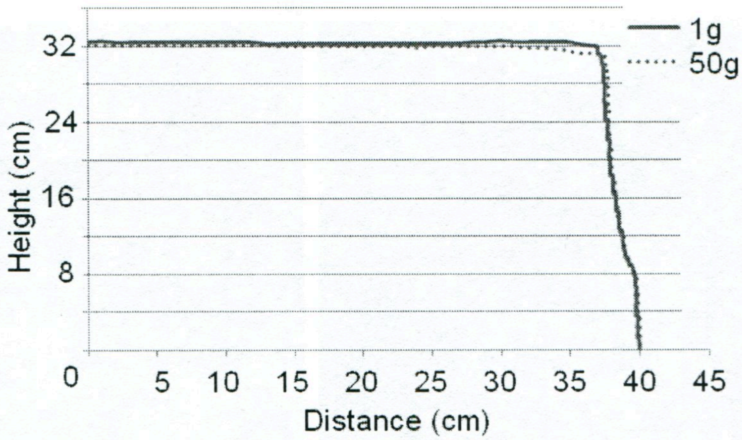


Figure 7. Test 2: (a) Before Testing, (b) After Testing (50g), (c) Surface Cracks.

The overall deformations at 50g for models 1 and 2 are shown in Figures 8(a) and (b), respectively. Test 2 showed less deformations than Test 1 because of a smaller spacing. However, the backfill settlement of Test 2 was unexpectedly greater than that of Test 1. There was little to no settlement in the foundation of both two models. There was, however; considerable flattening of the gabions near the toe of the wall due to vertical compression under high stress. Note that the deformations as measured should not be compared with the actual constructions because they were obtained from a single stage construction. In the field, staged constructions are performed to create the wall of desired geometry.

(a)



(b)

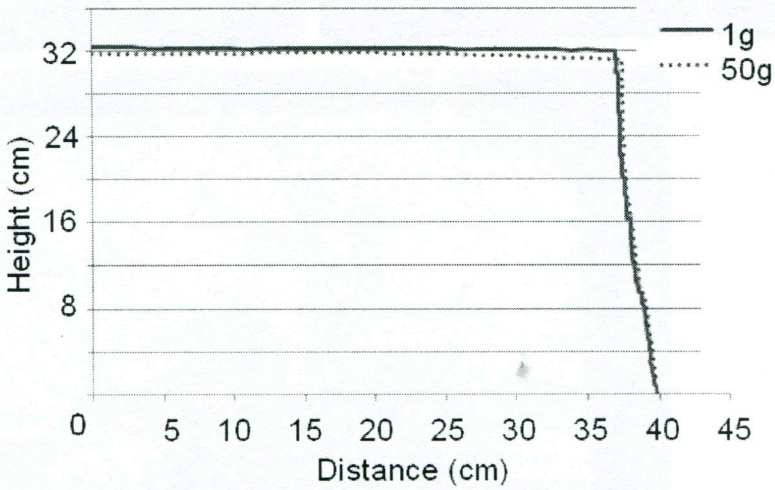


Figure 8. Wall Profiles at 50g: (a) Test 1, (b) Test 2.

4.2 Lateral Earth Pressure

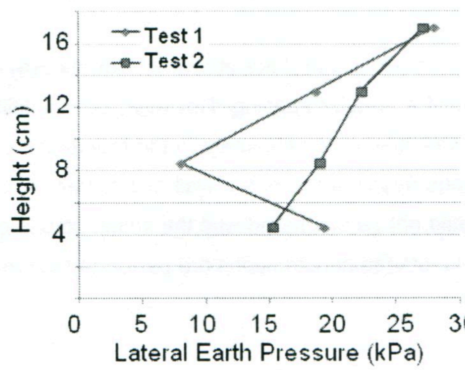


Figure 9. Lateral Earth Pressure (at 50g)

The measured lateral earth pressure at 50g for both Tests 1 and 2 are shown in Figure 9. The readings of the bottom transducer were eliminated due to lack of accuracy. The measured pressures of Test 2 were slightly greater than those of Test 1 that may be due to less movement on the facing gabions. The movement of gabions reduced the soil confinement on the transducers. Note that the orientation of the transducers might have also changed as the gabions deformed and tilted slightly.

4.3 Tensile Force in Reinforcement

The forces in the reinforcement layers at 50-g are shown in Figure 10 for Tests 1 and 2. Test 2 recorded slightly higher tensile force than Test 1. Generally, the tensile forces measured close to the facing are greater than those at the tails. It is as expected since deformation was greater in the wall facing compared to the inner backfill. The maximum force obtained from the two tests is about 250 kN/m, which is about 60% of the ultimate tensile strength of the prototype reinforcement (412 kN/m).

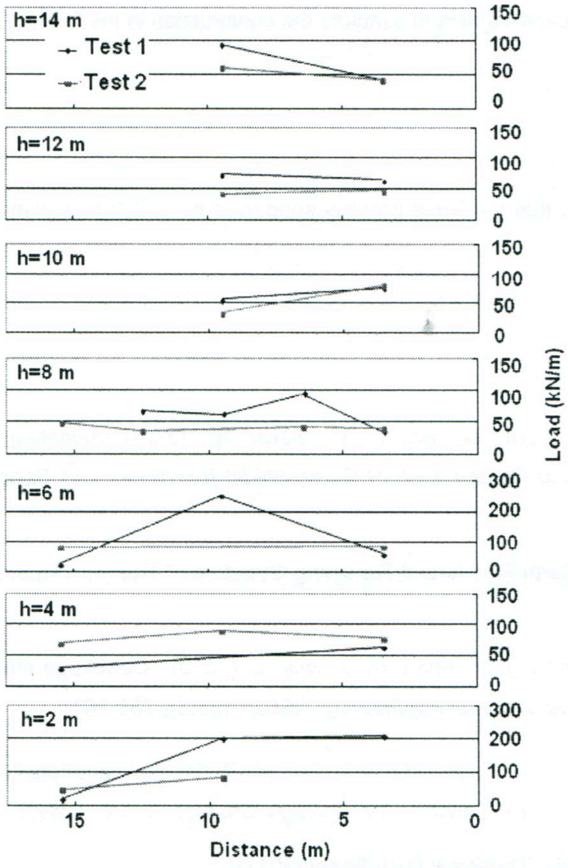


Figure 10. Tensile Force in Reinforcement Layers at 50g.

5. CONCLUSIONS

The centrifuge model tests of the gabion facing reinforced soil retaining wall provided important information on the behavior of the wall and practical insight to the construction of future models for testing or construction. The walls did not experience any failure in the tests.

For wall 1, although there was not any failure at acceleration of 50g, the vertical settlement was about 0.45 m when converted to prototype dimensions. Note that the deformations as measured in a centrifuge (single stage construction) are different from those of a real wall constructed in stages.

The settlement in the wall was less when the spacing was reduced from 2 m to 1 m. In addition to the spacing, a solution to this settlement problem for construction could be to increase the compacted density of the backfill.

Additional models should be conducted to study the influence of the reinforcement length and stiffness, as well as the failure mechanism of the wall by reducing the length or stiffness of reinforcement layers. In addition, staged construction technique could be used in future studies to simulate the construction in the field [6].

ACKNOWLEDGMENTS

It is gratefully acknowledged that Lei Xu is partially supported by a GSI Fellowship. This study was funded by Officine Maccaferri SpA.

REFERENCES

Iacorossi, M., Ling, H.I., Gottardi, G., and Li, L. (2013). "Centrifuge modeling of earth-reinforced retaining walls." *Proceedings on Design and Performance of Geosynthetic-Reinforced Soil Structures*. October 14-16, Bologna, Italy, 3-12.

Iacorossi, Matteo (2012). "Earth Reinforced Retaining Structures." Report, Department of Civil Engineering, Columbia University, New York, NY.

Ling, H.I., Wu, M-H., Leshchinsky, D., and Leshchinsky, B. (2009). "Centrifuge modeling of slope instability." *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 135(6), 758-767.

Ling, H.I., Xu, L., Leshchinsky, D., Collin, J.G., and Rimoldi, P. (2016) "Centrifugal Modeling of Reinforced Soil Retaining Walls Considering Staged Construction." *Geo-Chicago*, Chicago, IL. (accepted)

Maccaferri, "Paralink Geogrids" Technical Data Sheet (2011).

Maccaferri," Terramesh System: Galvanized and PVC Coated" Product Standard Specifications (2012).