



Dynamic Response of Lightweight Cellular Concrete MSE Walls

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Abstract. Due to the numerous benefits that lightweight cellular concrete offers, its use has become increasingly popular in several construction applications. One specific application is as the backfill of retaining walls or MSE walls in order to reduce earth pressure, construction cost and time. Previous studies examined the static and dynamic properties of lightweight cellular concrete with varying test and dry unit weights through laboratory testing. Furthermore, numerical modelling evaluated the deformation characteristics of geo-grid reinforced lightweight cellular concrete backfills. However, results from physical model tests to validate these results are unavailable in the literature. Given the increasing use of these geo-grid reinforced lightweight cellular concrete backfills in seismically active regions, it is critical to observe the seismic performance of these structures. As such, shake table tests were performed on a 1.2 m tall lightweight cellular concrete (material with a test unit weight of 4 kN/m³) MSE wall reinforced with a geo-grid layer at approximately 0.6 m height. The models were instrumented with a series of accelerometers and strain gauges. Additionally, in order to simulate self-weight of the MSE walls of different heights, vertical stresses of approximately 5 kPa and 8 kPa were applied to the geo-grid reinforced lightweight cellular concrete before the structure was subjected to a series of sinusoidal ground motions with varying amplitudes and frequencies. Additionally, the geo-grid reinforced lightweight cellular concrete was also subjected to the ground motions recorded from the 1994 Northridge earthquake. The entire geo-grid reinforced lightweight cellular concrete backfill was found to displace as a single monolithic unit with no significant relative displacements between the geo-grid reinforcement layer and the lightweight cellular concrete. Furthermore, no fractures were observed during the application of the ground motions.

Keywords: Lightweight cellular concrete · MSE wall · Dynamic response
Deformation · Shake table

1 Background

Lightweight cellular concrete (LCC) has become increasingly popular in several construction applications due to the numerous benefits it has to offer. Among these benefits is that LCC in addition to having low density is also highly durable, has high freeze-thaw resistance and has low permeability. Several of the applications of LCC include landslide repair works, earthquake shock absorbent near tunnels and pipelines, pavement material and engineered fills in approaches to bridges [1–4].

LCC is produced by introducing air voids into the traditional components of concrete – water, aggregates, and cement. Protein-based or synthetic-based foaming agents are used to create the air voids. The agents create the air voids by trapping the air when reacting with the other components [2, 4–7]. The percent of air voids created within the traditional mixture of concrete will be directly related to the amount of foaming agent present in the mixture with most LCC materials containing between 10% and 70% air voids [7]. The unit weight of the material will be directly dependent on the percent of air voids present in the LCC and can be as low as 3.1 kN/m^3 [1].

Results are available in the literature for several static properties of LCC including the hydraulic conductivity [1, 8, 9], the drying shrinkage [1, 10], the thermal expansion [1], and unconfined compressive strengths [2, 10, 11]. One of the most comprehensive studies on the static properties of LCC is that by Tiwari et al. [12]. They presented the shear strength parameters for undrained and drained conditions, coefficients of permeability, and at-rest earth pressures for LCC materials having four different unit weights. In addition, the results were used to develop relationships to estimate the unconfined compressive strengths as well as the total friction angle and cohesion intercept with the unit weight of the LCC material. Tiwari et al. [12] further concluded that the effective friction angle and cohesion intercept were independent of the unit weight of the LCC material over the range of stresses that they tested. The dynamic properties of LCC were examined in detail by Tiwari et al. [13], which presented the results of cyclic simple shear tests on LCC materials having four different unit weights. The cyclic simple shear tests were conducted on LCC materials subjected to a series of fifteen strain-controlled undrained sinusoidal cyclic motions with varying amplitudes at four different consolidation pressures. Tiwari et al. [13] determined that the maximum shear modulus of LCC will increase with an increase in the dry unit weight as well as with an increase in the consolidation pressure. It was further found that the damping ratio would decrease with an increase in the shear strain until a threshold shear strain was achieved, beyond which increase in the shear strain corresponded to an increase in the damping ratio.

Although results regarding the static and dynamic properties of LCC are available in the literature, the behavior of LCC in construction applications has not been studied in sufficient detail. Furthermore, with an increase in the use of LCC in several geotechnical engineering applications, it is necessary to examine how the LCC materials will behave at seismic loading. The focus of this paper will be on the behavior of LCC material as the backfill of mechanically stabilized earth (MSE) retaining walls at seismic loading. This was examined by Pradel and Tiwari [14] using numerical analyses with FLAC, but experimental testing and validation of the results they

obtained is currently not available. As such, shake table experiments were conducted in this study on two small scale LCC retaining walls reinforced with a geo-gird at the mid-height. The cyclic loading applied in the shake table experiments had varying frequencies and amplitudes in order to obtain an understanding of the performance of the LCC retaining wall under seismic loading.

2 Model and Testing Details

2.1 Casting of LCC Retaining Wall

LCC is casted using two concurrent processes, the first of which will create the foaming agent while the second will produce the neat cement slurry. To create the foaming agent, 40 parts of water are combined with one part of Elastizell Foam Concentrate, which is a protein based biodegradable surfactant and a by-product of the food industry. The mixture is mechanically agitated through small nozzle while subjected to high-pressure compressed air action. The production of the neat cement slurry is achieved by mixing cement and water, per the design specifications, together in a progressive cavity pump coupled with a customized concrete mixer. The air-filled cellular concrete is then produced by adding the pre-formed foam to the neat cement slurry in a Proprietary Blending System. This material was, then, used to cast the LCC retaining wall.

In this study, the LCC material had a unit weight of approximately 4 kN/m^3 . Tiwari et al. [12, 13] reported the static and dynamic properties, respectively, of this material. To cast the retaining wall, the air-filled cellular concrete slurry obtained from the blending system was poured into a rectangular wooden mold having length of 1.8 m and width of 1.2 m. The height of the wooden mold was 1.2 m. A geo-grid layer was installed at mid-height to reinforce the LCC retaining wall. The LCC retaining wall was cured for a period of 25 days within the wooden mold, after which period the mold was removed and the LCC retaining wall was air-dried for at least 3 days before being subjected to any testing.

2.2 Shake Table Testing

Following the curing process of the LCC retaining wall, the model was placed on a shake table. As a safety measure, the LCC retaining wall was surrounded by a metal cage, as shown in Fig. 1. This was done to ensure that the model would not slip off the shake table during the shaking and cause safety issue. It is noted that the metal cage would not prevent the model from deforming freely and thus, the results are not impacted by this safety measure. The LCC retaining wall was then instrumented with three accelerometers located at the center of the model at different depths corresponding to (1) the top of the model, (2) mid-way between the top of the model and the location of the geo-grid, and (3) on top of the geo-grid. In addition, four strain gauges were also mounted to the metal cage to record the deformation at (1) the top of the model, (2) mid-way between the top of the model and location of the geo-grid, (3) at the geo-grid, and (4) mid-way between the geo-grid and the bottom of the model.

Unfortunately, the strain gauge mid-way between the top of the model and the geo-grid did not function properly. As such, the results from this strain gauge will not be presented in this paper. Figure 2 illustrates the locations of the instruments.



Fig. 1. Photograph of LCC retaining wall on the shake table with surrounding metal cage safety measure. LCC retaining wall pictured is subjected to vertical stress of 5 kPa.

The LCC retaining wall was then subjected to a surcharge stress of 5 kPa following which a series of sinusoidal cyclic loads were applied to the model. These cyclic loads had amplitudes of 0.1 g or 0.2 g and frequencies of 2 Hz or 3 Hz. In addition, a ground motion recorded during the 1994 Northridge Earthquake was also applied to the LCC retaining wall. Higher amplitudes and lower frequencies were not applied to avoid catastrophic failure due to safety issue. The sequence of cyclic loads were repeated three times for the model. Following the completion of the shake table testing, the LCC retaining was trimmed in order to remove approximately 15.2 cm from each side of the model. The resulting LCC retaining wall was 0.91 m wide by 1.5 m long with a height of 1.2 m. This model was instrumented in a similar way as in the larger model described previously and subjected to the same triplicates of the cyclic loads.

3 Results and Discussion

Displacement time histories were calculated for each applied ground motion using the acceleration time histories recorded at each of the three accelerometers. It is noted that the raw data from the accelerometers was first filtered and baseline corrected prior to use in any calculation. Furthermore, the calculations were preformed not only for the

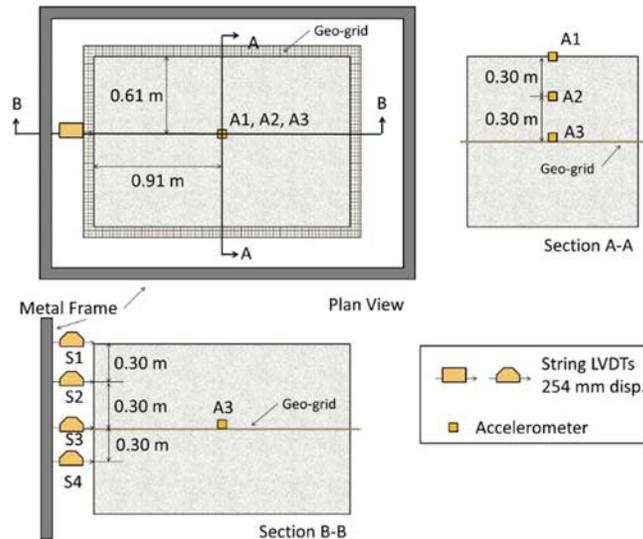


Fig. 2. Instrumentation diagram showing the locations of the accelerometers, denoted with A, and strain gauges, denoted with S.

direction of shaking, but also for the remaining two directions. However, it was determined that the results in the horizontal direction perpendicular to the shaking direction as well as the results in the vertical direction were. As such, only the results from the direction of shaking are presented in this paper.

A typical displacement time history obtained from the model subjected to a surcharge stress of 5 kPa is presented in Fig. 3. The displacement time histories presented in Fig. 3 correspond to the sinusoidal cyclic load with an amplitude of 0.1 g at a frequency of 3 Hz. Results for other loading frequencies and surcharge stress also demonstrated similar result, although is not included in this paper. The results in Fig. 3 indicate the total displacement experienced by the accelerometer at the specified location. In-depth examination of the figure indicates that the relative displacement between the geo-grid (location A3) and the top of the LCC retaining wall (location A1) is insignificant. This suggests that the entire LCC retaining wall moved monolithically.

Figure 4 presents the typical displacement time histories recorded in the strain gauges. The results were obtained from the model subjected to surcharge stress of 5 kPa and sinusoidal cyclic loads with an amplitude of 0.2 g with a frequency of 3 Hz. Results for other loading frequencies and surcharge stress also demonstrated similar result, although is not included in this paper. Unlike the accelerometers, the strain gauges measure the relative displacement of the LCC retaining wall and the shake table. The results in Fig. 4 indicate that the top of the model experiences greater displacements than those experienced by geo-grid. However, the magnitude of the differences is quite small and can be considered negligible in relation to the height of the model. This is in agreement with results obtained from the displacement time histories determined from the accelerometer data.

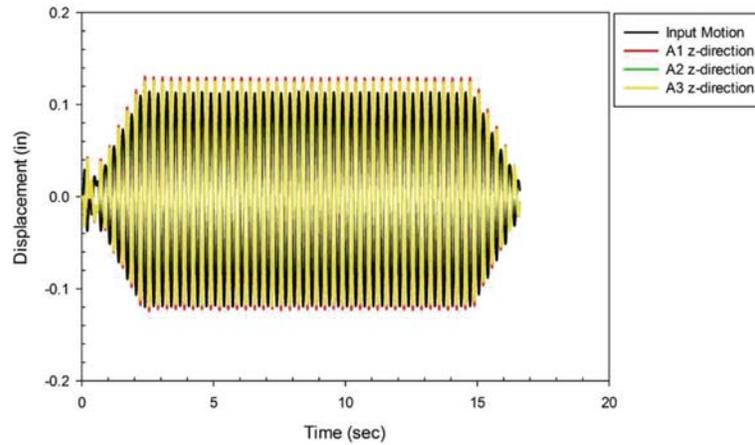


Fig. 3. Displacement time histories obtained from the double integration of accelerometer data collected during the application of sinusoidal cyclic load with amplitude of 0.1 g and frequency of 3 Hz in LCC retaining wall model with a surcharge stress of 5 kPa.

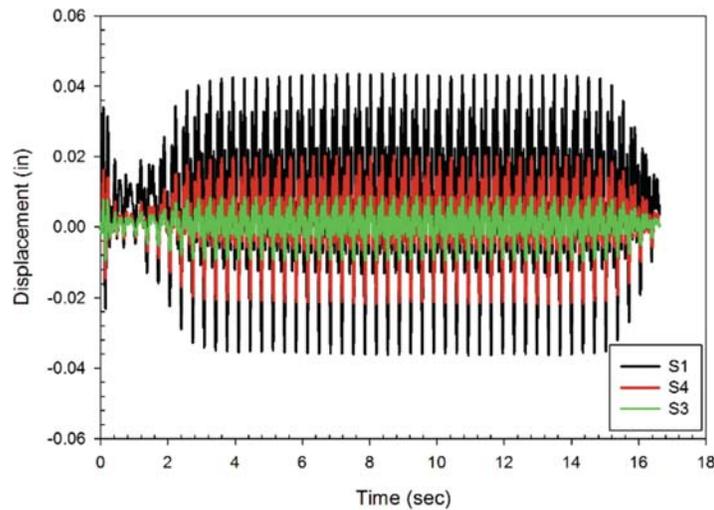


Fig. 4. Displacement time histories recorded in strain gauges during the application of sinusoidal cyclic load with amplitude of 0.1 g and frequency of 3 Hz in LCC retaining wall model with a surcharge stress of 5 kPa.

The negligible relative displacements between the top of the LCC retaining wall model and the geo-grid appears to suggest that the function of the geo-grid in the model is simply to reduce crack propagation. While the geo-grid may also assist to secure the facing material, it does not appear to contribute to reinforcing the LCC material.

The results obtained from Pradel and Tiwari [14] agree with those presented in this study. However, their results were based on FLAC analyses of a hypothetical LCC retaining wall structures founded on soft clays.

4 Conclusions

Shake table tests were conducted on two LCC retaining wall models. These models were constructed using the LCC materials having a unit weight of approximately 4 kN/m^3 with a geo-grid reinforcement placed at mid-height. The models were subjected to surcharge stresses corresponding to 5 kPa and 8 kPa respectively. They were subjected to a series of sinusoidal cyclic loads as well as a motion recorded during the 1994 Northridge earthquake. The displacement response was determined by double integrating the acceleration time histories. In addition, the displacements were also recorded using strain gauges. Results from both methods suggested that displacement of the top of the LCC model was nearly the same as the displacement of the geo-grid at mid-height. Therefore, it was determined that the geo-grid was not providing reinforcement in the LCC, but instead was only aiding to reduce crack propagation and to secure the facing material.

References

1. Aberdeen Group: Cellular Concrete. Publication No. C630005. Aberdeen Group, Boston (1963)
2. LaVallee, S.: Cellular Concrete to the Rescue. Aberdeen Group, Boston (1999). Publication No. C99A039
3. Tikalsky, P.J., Popisil, J., MacDonald, W.: A method for assessment of the freeze-thaw resistance of preformed foam cellular concrete. *Cem. Concr. Res.* **34**(5), 889–893 (2004)
4. Maruyama, R.C., Camarini, G.: Properties of cellular concrete for filters. *Int. J. Eng. Technol.* **7**(3), 223–228 (2015)
5. Tian, Y.: Experimental study on aerated concrete produced by iron tailings. *Adv. Mater. Res.* **250**, 853–856 (2011)
6. Albayrak, M., Yorukoglu, A., Karahan, S., Atlihan, S., Aruntas, H.Y., Girgin, T.: Influence of zeolite additive on properties of autoclaved aerated concrete. *Build. Env.* **42**, 3161–3165 (2007)
7. Panesar, D.K.: Cellular concrete properties and the effect of synthetic and protein foaming agents. *Constr. Build. Mater.* **44**, 575–584 (2013)
8. Loudon, A.G.: The thermal properties of lightweight cellular concretes. *Int. J. Lightweight Concr.* **11**(2), 71–85 (1979)
9. Neville, A.M.: *Properties of Concrete*, 4th edn. Pearson Educational Limited, Essex (2002)
10. Narayanan, N., Ramamurthy, K.: Structure and properties of aerated concrete: a review. *Cem. Concr. Compos.* **22**, 3210329 (2000)
11. Zaidi, A.A.M., Rahman, A.I., Zaidi, N.H.A.: Behavior of fiber reinforced foamed concrete: indentation test analysis. In: *Proceedings of the Seminar on Geotechnical Engineering*, pp. 92–101 (2008)

12. Tiwari, B., Ajmera, B., Maw, R., Cole, R., Villegas, D., Palmerson, P.: Mechanical properties of lightweight cellular concrete for geotechnical applications. *J. Mater. Civil Eng.* **29**(7), 06017007 (2017)
13. Tiwari, B., Ajmera, B., Villegas, D.: Dynamic properties of lightweight cellular concrete for geotechnical applications. *J. Mater. Civil Eng.* **30**(2), 04017271 (2017)
14. Pradel, D., Tiwari, B.: The use of MSE walls backfilled with lightweight cellular concrete in soft ground seismic areas. In: *Proceedings of the Third International Conference of Deep Foundations*, vol. 1, pp. 107–114 (2015)