Strains Measured on Geosynthetic Encased Stone Column under Earthquake Excitations

C. Cengiz*
Bogazici University, Turkey (c.cihancengiz@gmail.com)

D. Alexiew
HUESKER GmbH, Germany (dalexiew@huesker.de)

E. Guler
Bogazici University, Turkey (eguler@boun.edu.tr)

ABSTRACT: Physical models consisting of model Geosynthetic Encased Columns (GECs) placed in a remolded kaolinite bed and an embankment fill atop the GECs are tested by making use of a shaking table. The kaolinite bed is consolidated prior to installation of the GECs and placement of the embankment fill. The entire model constituents are housed in a rigid box container and the walls of the container perpendicular to the direction of shaking table movement are fitted with EPS blocks in order to prevent the reflection of the induced shaking repeatedly to the model. In this paper the strains in the geosynthetic encasement during the earthquake shaking is reported. .

Keywords: Shaking table tests, geosynthetic encased columns, strain of reinforcement

1 INTRODUCTION

Stone columns have been widely used as a cost and energy efficient, and environmental friendly method for soft soil treatment. For situations when the undrained shear strength of soil is too weak, stone columns may lose their effectiveness as the surrounding weak soils may not provide enough confinement to the columns, which may result in bulging or crushing failure of the columns at the upper section of the columns (Hughes et al., 1975). Encasing granular columns with tensile resistant materials is considered an effective technique for improving granular column performance (Kempfert et al., 1997; Raithel and Kempfert, 2000; Alexiew et al., 2005; Raithel et al., 2005; de Mello et al., 2008; Araujo et al., 2009). The use of both stone columns and GECs have proven to be a viable ground modification technique owing to their simplicity in application which reduces the construction period and costs. While the primary function of the stone columns (and GECs) is to take vertical loads from the foundation and to transmit the load to the firm strata, there is also a secondary function, namely, to accelerate the drainage and thus the consolidation. The literature about stone columns and GECs cover analytical models, finite elements models, and physical models. While there is an abundance of literature on the performance of stone columns and GECs under the action of static loads, there are not many studies addressing the engineering behavior of stone columns and GECs subjected to dynamic loads such as earthquake excitations. Guler et. al. (2014) have studied the behavior of GECs by running a series of time history analysis utilizing DIANA numerical code and have shown that significant settlement reduction can be achieved via utilizing GECs as opposed to ordinary stone columns. GECs were also found to undergo less lateral bulging when compared to ordinary stone columns.

The strains occurring on the reinforcement confining the geosynthetic encased column are rarely investigated in the literature. While it is possible to find works which dealt with hoop or horizontal strains under static loading conditions, it is virtually impossible to find any work in the literature which addresses the dynamic vertical strains occurring in the GEC under the action of seismic excitations. In this paper, it is intended to quantify and compare the dynamic vertical strain amplitudes occurring on a GEC reinforcement. For this purpose, a well-instrumented GEC was installed in a weak clay bed and the experimental setup was subjected to seismic input motions by making use of a shaking table.

2 SAMPLE PREPARATION AND TEST PROCEDURE

The aim of this study was to simulate the effects of seismic excitations on earthen embankments underlain by weak soils that are remediated by geosynthetic encased stone columns (GECs) and ordinary stone columns (OSCs). In order to model a "slice" of such an embankment, a rigid steel box with inner plan dimensions of 0.52 meters (width) by 2.5 meters (length) was used. The height of the box was 2.16 meters and the seismic excitations were applied to the box in the length-wise direction. A sketch of the test setup is illustrated in Figure 1.

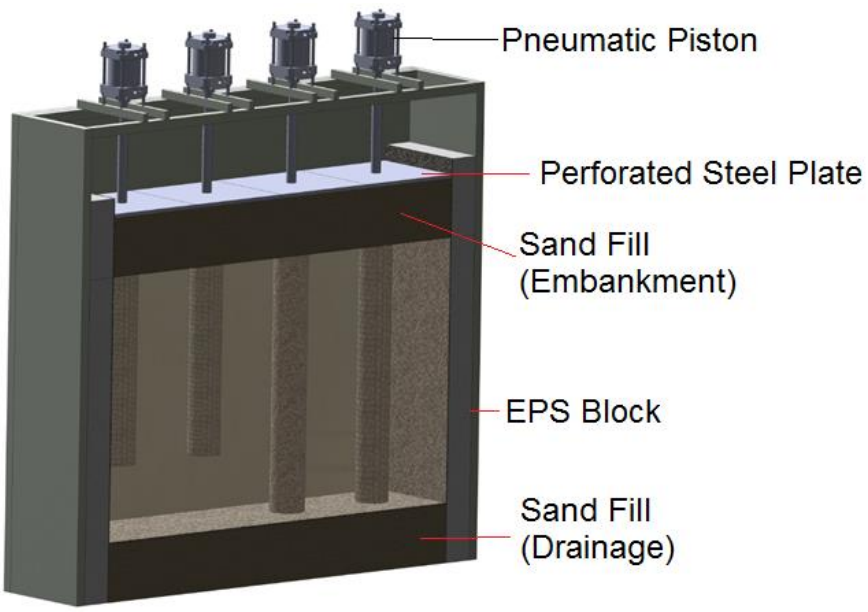

Figure 1: A sketch of the test setup

At the base of the rigid box, a sand layer is installed which is intended to provide drainage of the overlying clay. The clay is placed in a non-woven geotextile (500g/m^2) sack and the top portion of the geotextile is wrapped onto itself and glued in order to prevent clay slurry from leaking out in the early stages of consolidation. The overburden pressure is generated by four pneumatic pistons and applied to the GEC system via steel bars and perforated steel plates covering the full area and being in direct contact with the geotextile sack's top portion which was used to contain the clay slurry.

In general the behavior of OSCs in really soft soils with typically undrained unconsolidated shear strength c_u < 15 kPa is problematic due to bulging, while due to the confining encasement there is practically no lower c_u –limit for GECs. However, because of the comparative character of this study a clay bed (soft soil) with c_u < 15 kPa was chosen. For this purpose a kaolinite clay was mixed with tap water at a water content of 75 %. This water content value was adopted after a series of trials where the most suitable water content for forming clay slurries was investigated. Ideally, selected water content should be high enough so that it minimizes the risk of lumps occurring inside the slurry which would jeopardize the homogeneity of the clay bed, and it should be low enough not to introduce excessive settlements upon application of the desired overburden pressure for consolidation. The clay slurry was prepared in large drums and mechanically mixed and agitated until no visible lumps are present. Once the slurries homogeneity was confirmed, the slurry was allowed to flow into the testing box via gravity where it was then consolidated under an overburden pressure. Figure 2 (a) illustrates the test setup as it is being filled with clay slurry and (b) depicts the test setup during consolidation.

Figure 2: Rigid box assembly, a) during the infill of kaolinite slurry; b) during consolidation of the slurry by pneumatic pistons

The inner part of the rigid box was fitted with EPS blocks on either side (in the front and the back of it) which were perpendicular to the direction of shaking. The reason for placing the EPS blocks was to prevent the seismic waves from traveling in a recurrent manner throughout the model. In other words, the sole purpose of the EPS blocks was to dampen the seismic waves travelling through the model so that they did not get reflected back to the model in an amplified manner. Cengiz et. al. (2015) has shown that having no damping at the model boundary could cause the model to experience loads which are way beyond the magnitude of realistic load amplitudes. Such severe loading gives erratic results and may lead to conservative design approaches. The clay bed was consolidated to an overburden pressure of 25 kPa. Similarly shaking table tests were also conducted at an overburden pressure of 25 kPa. The settlements and strains occurring under the surcharge load are beyond the scope of this study. Upon completion of consolidation, a closed-end casing pipe whose diameter was 168 mm was driven into the clay bed and model column constituents (gravel only for the case of OSCs and geotextile encasement and gravel for GECs) were placed in the hollow space. The pipe was retracted once the placement of the column constituents was completed. The model encasing geotextile used in this study was a non-woven Polyfelt TS 10 which has a machine and cross machine tensile strength of 8 kN/m. The granular infill material for both types of columns (OSCs and GECs) was a clean fine gravel (GP, D_{10} = 5mm, D_{30} = 6mm, D_{60} = 8 mm) according to USCS.

In order to quantify the strains occurring on the geosynthetic encasements, strain rosettes were applied on them. They were used instead of conventional strain gauges. The reason behind this was to be able to track the planar strain in the entire geosynthetic surface. An illustration of the strain rosettes used in this study is given in Figure 3. The centers' of the strain gauges (depicted in the drawing on the right-hand-side of Figure 6) in the first line and the third line from the top of the GEC is as follows: 140, 280, 420, 560, 750, 940, and 1130 mm. The centers of the strain gauges in the first vertically running line and the third line are coincident. The strain rosette locations were determined as such in order to have redundant gauges in the event that the gauges were damaged or data could not be taken from them for any reason. In the event that both lines survived, the data acquired from the gauges could be cross-checked. The gauges located on the second line (depicted in Figure 3) enabled the acquisition of the strain data at intermediate elevations of the GEC where first and third line strain gauges were not able to scan. Thusly, a heavily instrumented model GEC was formed.

Upon completion of the tests, a series of vane tests were conducted to quantify the undrained shear strength of the clay bed. A total of four vertical arrays on the clay bed were tested and from each array vane readings were taken at various elevations (35, 65, 90, and 120 cm below the top of the clay bed) and results pertaining to those tests are given in Figure 4. The increase of the undrained shear strength can be explained by clay consolidating under its self-weight. Upon completion of the entire testing scheme, the setup was disassembled and the clay bed was vertically cut in order to visually inspect the GECs and OSCs. A view of the instrumented GEC can be seen in Figure 5.

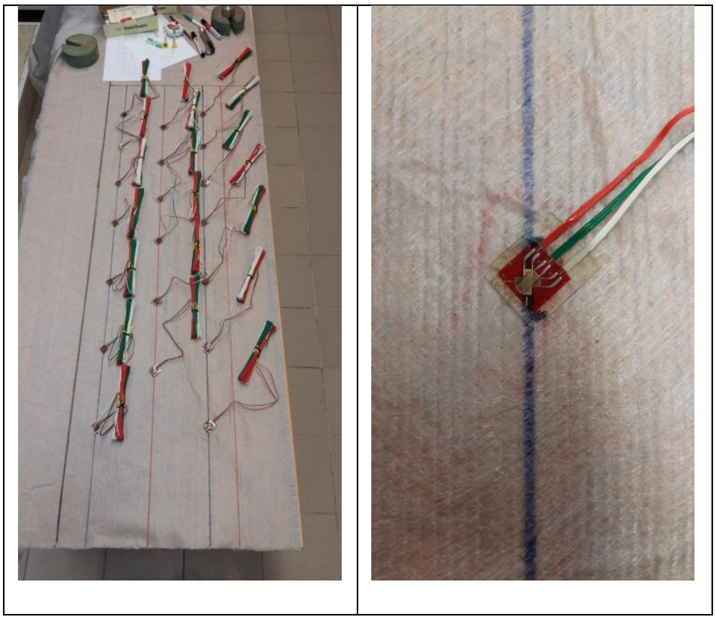

Figure 3: The positions of the strain gauges on the geotextile encasement before it was sewn (on the left), and a singular strain gauge (on the right)

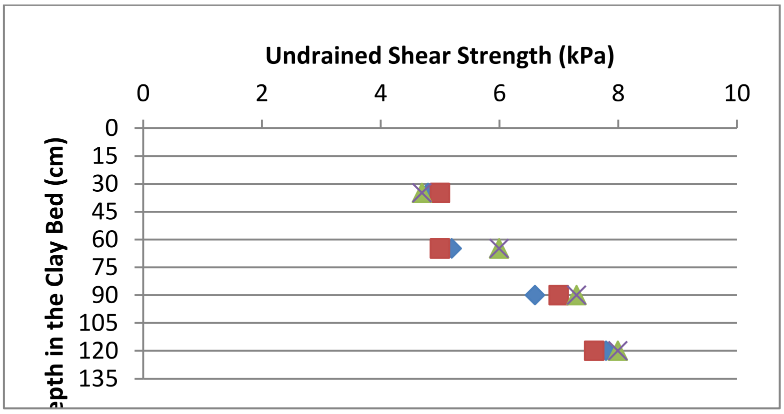

Figure 4: Undrained shear strength readings taken from the clay bed in the rigid box (different data markers indicate various vertical alignments that the vane probe was inserted to the clay bed)

3 SHAKING TABLE TESTING SCHEME

The experimental setup was subjected to strong ground motions by making use of a shaking table. El-Centro earthquake's motion was applied to the setup at various amplitudes. The setup was shaken first with 50% and then with 100% amplitude. To observe the behavior after being exposed to a severe earthquake, the model was shaken one more time with 25% of the same earthquake record. Each earthquake loading was recorded at 200 Hz sampling rate for 90 seconds. In each test ambient vibration was recorded for about 10 seconds before the application of the dynamic excitations which lasted roughly 30 seconds. The remainder of each record pertains to post-dynamic excitation ambient vibrations of the experimental setup which is about 50 seconds.

Figure 5: A view of instrumented model GEC after the tests

The strain data that is elaborated in this study is a subset of measured strains pertaining to a larger experimental program. The anticipated movement of the GEC under the action of the seismic forces is that of a sideways oscillation. With this in mind, in order to capture the GEC behavior during the seismic input, strain rosettes are placed where maximum bending, and therefore strains will occur. The maximum anticipated bending of the GEC is expected at alignments 1 and 3, as illustrated in Figure 6 (plan view). Alignment 2, is thought to be the neutral axis for the movement of the GEC in horizontal direction. This is why the vertical strains coming from this alignment is thought to reveal the vertical response of the GEC reinforcement. The schematic illustrating the positions of the strain rosettes is given in Figure7 where the distances shown are for alignment 1.

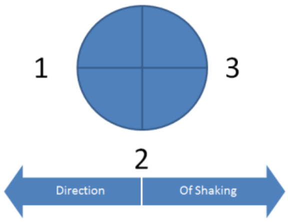

Figure 6. Plan view of the alignments in which strain rosettes are instrumented

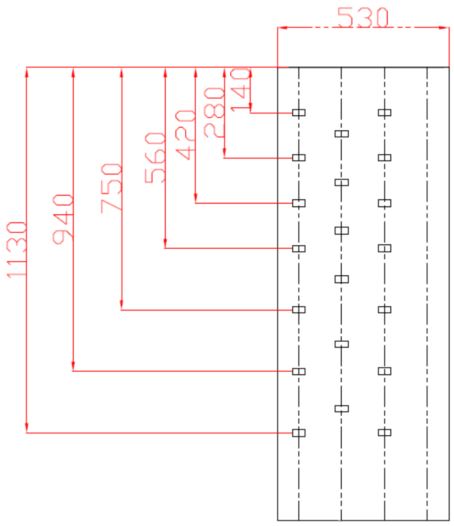

Figure 7. Schematic showing the vertical alignment of the strain rosettes

Within the scope of this work, vertical components of the strains coming from alignment 2 will be used. The distances of the six strain gauges placed on alignment 2 from the column head plane downwards is 205, 345, 485, 625, 815, and 1005 mm.

4 RESULTS

Figures 8 through 13 illustrate the dynamic straining behavior of the GEC reinforcement at

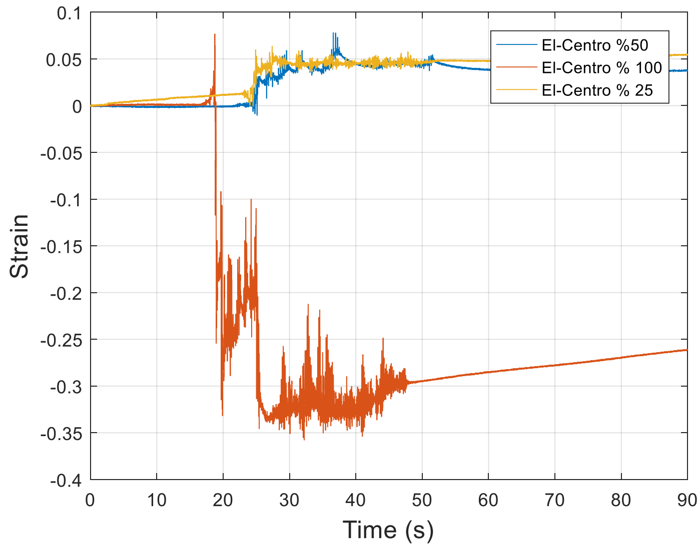

Figure 8. Plots of vertical strain for 50, 100, and 25 % El-Centro excitations at 205 mm

various depths from the top of the column head plane. It is seen that the largest strains are reached as the magnitude of the input motion is increased to 100 % El- Centro. The nature of the strain (tension or compression) occurring on a specific point on the GEC is not constant and it changes as the input motion's magnitude is altered. This shows that the response of the GEC reinforcement to seismic excitations is affected by the magnitude of the input. The exact same location of the GEC responds differently when the magnitude of the shaking is changed. In classical design approaches seismic loads are not thoroughly accounted for and the design is made for the static case. Even under these circumstances, hoop or horizontal strains are considered and vertical strains are often overlooked.

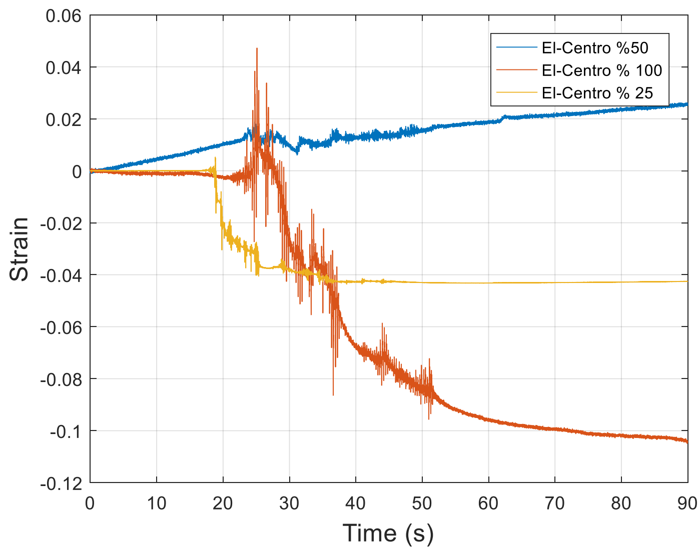

Figure 9. Plots of vertical strain for 50, 100, and 25 % El-Centro excitations at 345 mm

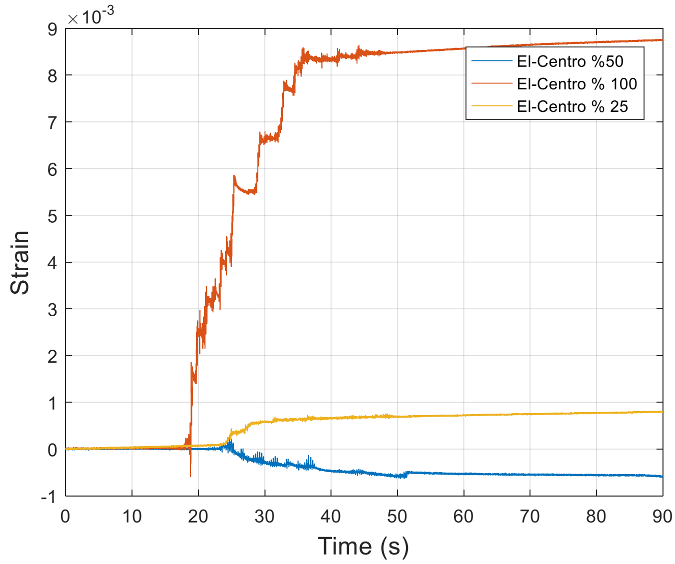

Figure 10. Plots of vertical strain for 50, 100, and 25 % El-Centro excitations at 485 mm

Although the seismic input provided by the shaking table is purely horizontal and the alignment of the strain gauges is on the neutral axis (where bending of the column should not introduce any vertical strains) of the column, vertical strains develop. It is also possible that the placement of the GEC reinforcement may not have been exactly orthogonal to the neutral axis. Slight deviation from the neutral axis may have resulted in vertical strains. This finding should urge the designers to consider the vertical strains on the geosynthetic reinforcement.

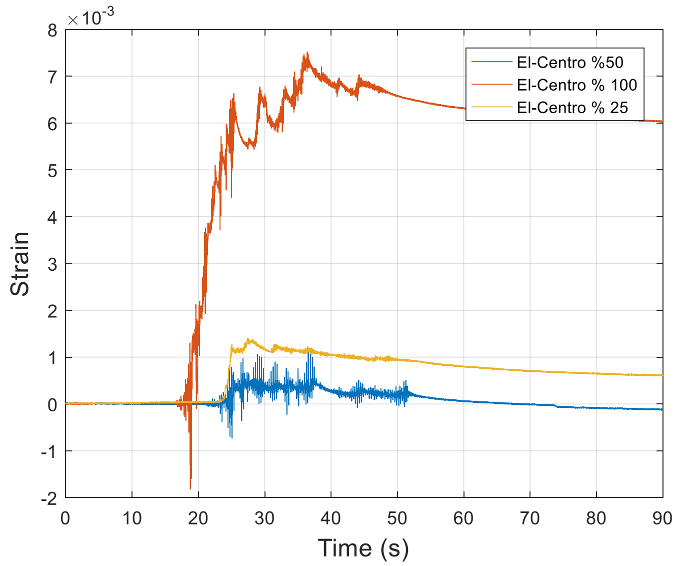

Figure 11. Plots of vertical strain for 50, 100, and 25 % El-Centro excitations at 625 mm

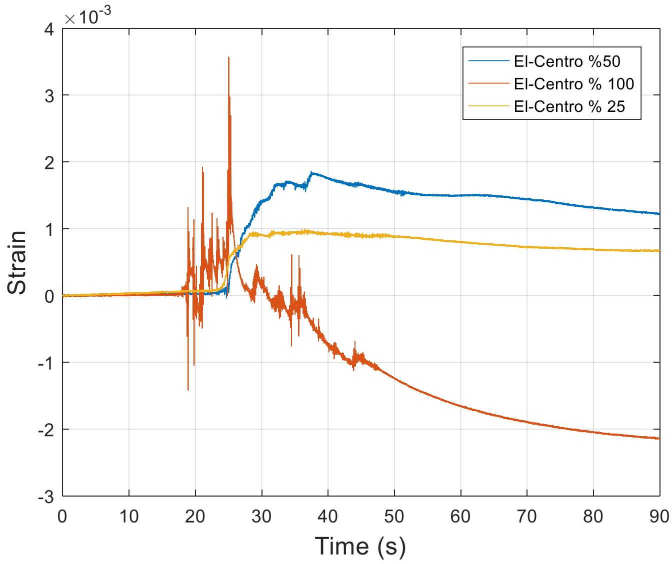

Figure 12. Plots of vertical strain for 50, 100, and 25 % El-Centro excitations at 815 mm

Horizontal strains (hoop strains) force the GEC reinforcement to expand laterally while causing a shortening of the material vertically, due to poisson effects. The vertical shrinkage combined with vertically acting dynamic tensile strains may cause the GEC reinforcement to rupture.

The plots of the vertical strains depicted in Figure 14 for all strain gauges on alignment 2 for El-Centro 100 % earthquake excitation shows that there is a general trend of straining on the GEC. The trend is that of a compression wave passing from the column. The bottom and top ends of the column undergo tension while the middle portion is compressed. This may reveal key features of GEC's behavior under seismic excitations.

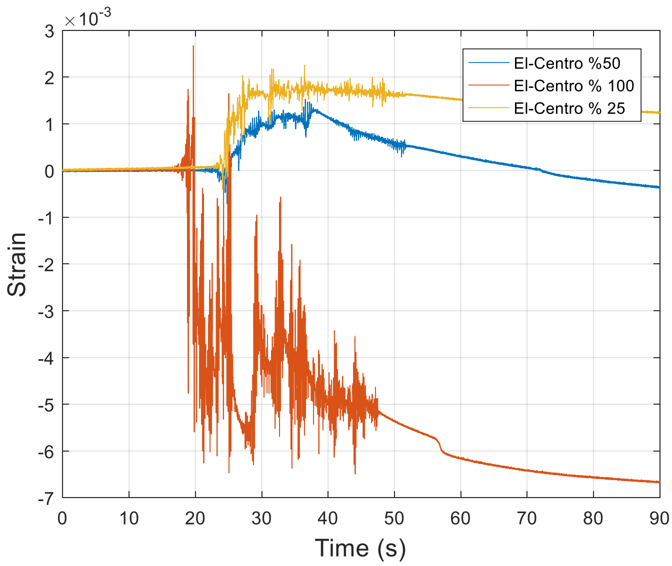

Figure 13. Plots of vertical strain for 50, 100, and 25 % El-Centro excitations at 1005 mm

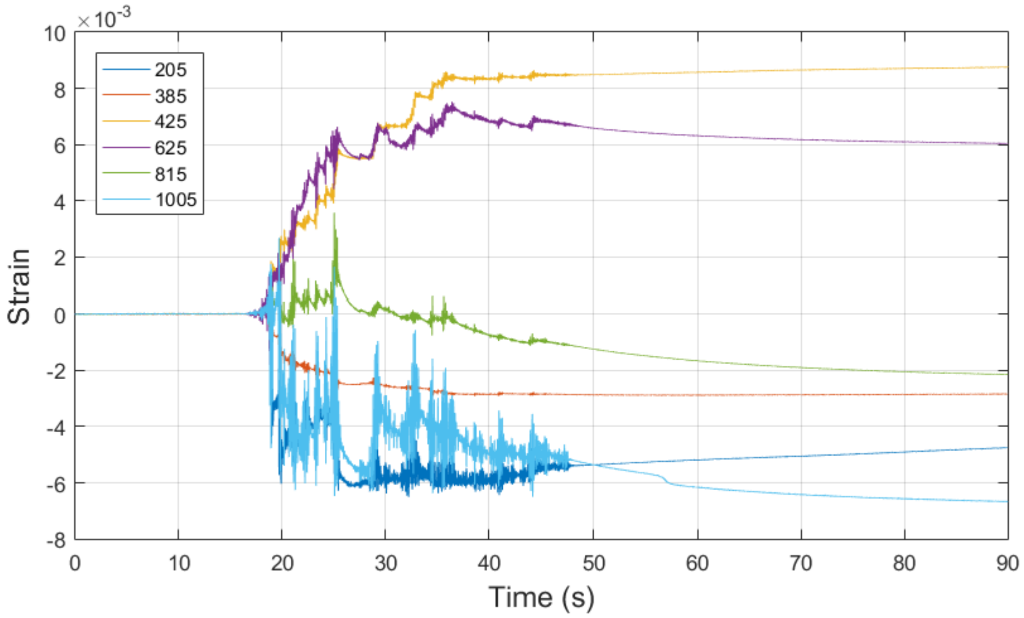

Figure 14. Plots of strain data from all strain gauges on alignment 2 for El-Centro 100 % earthquake excitation

5 CONCLUSION

The Geosynthetic Encapsulated Columns are designed in considering the lateral strains only. It was shown in this paper that significant vertical strains occur in the GEC reinforcement.

The magnitude of the strain is not proportional to the maximum acceleration applied. Even the strain may change from compression to tension depending on the magnitude of the earthquake applied.

The magnitude of the strain also changes along the depth of the Geosynthetic Encapsulated Column.

Further research is necessary to understand the strain development in the Geosynthetic Encapsulated Column in order to account for it in the earthquake resistant design of geosynthetic Encapsulated Columns.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge the financial support for this project provided by TUBITAK (Scientific and Technological Research Council of Turkey) under the project number 213M359 and HUESKER GmbH.

REFERENCES

Hughes, J.M.O., Withers, N.J., Greenwood, D.A., 1975. A field trial of the reinforcing effect of a stone column in soil. Geotechnique 25 (1), 31-44.

Kempfert, H.G., Jaup, A., Raithel, M., 1997. Interactive behaviour of a flexible reinforcedsand column foundation in soft soils. In: Proceedings of 14th InternationalConference on Soil Mechanics and Geotechnical Engineering, Hamburg,Germany, pp. 1757e1760.

Raithel, M., Kempfert, H.G., 2000. Calculation models for dam foundations withgeotextile coated sand columns. In: Proceedings of the International Conference on Geotechnical and Geological Engineering, GeoEng-2000, Melbourne, Australia, p. 347.

Alexiew, D., Brokemper, D., Lothspeich, S., 2005. Geotextile encased columns (GEC): load capacity, geotextile selection and pre-design graphs. In: Proceedings of the Geo-frontiers Conference, Austin, Texas. ASCE, pp. 497e510. GeotechnicalSpecial Publication No. 131.

Raithel, M., Kirchner, A., Schade, C., Leusink, E., 2005. Foundation of construction on very soft soils withgeotextile encased columns - state of the art. In: Proceedings of Geo-frontiers 2005, Austin, Texas, United States, pp. 1e11.

de Mello, L.G., Mondolfo, M., Montez, F., Tsukahara, C.N., Bilfinger, W., 2008. First use of geosynthetic encased sand columns in South America. In: Proceedings of1st Pan-American Geosynthetics Conference, Cancun, pp. 1332e1341.

Araujo, G.L.S., Palmeira, E.M., Cunha, R.P., 2009. Behaviour of geosynthetic- encased granular columns in porous collapsible soil. Geosynth. Int. 16 (6), 433e451.

Guler, E., Alexiew, D., Abbaspur, A., Koc, M., “Seismic performance of geosynthetic encased stone columns”, TRB 2014 Annual Meeting, Washington D.C., USA

Cengiz, C., Kılıc, I. E., Guler, E. (2015) “Geosentetik Donatılı Taş Kolonlarla Desteklenen Bir Toprak Seddenin Farklı Sönümleme Modelleri ile Analizleri” 6. Adana Geoteknik Sempozyumu, (In Turkish).