Evaluating Geosynthetic Encased Columns under Dynamic Lateral Loads

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A novel laboratory apparatus has been developed in order to probe into the lateral cyclic loading response of Geosynthetic Encased Stone Columns (GECs) under the action of lateral repeated loading. The testing apparatus is capable of shearing a rather large scale unit cell that contains soil and a column in the center. The displacements and the forces required to attain the predetermined displacements are measured at a sampling rate of 50 Hz. The hysteretic response of the model unit cells to dynamic sinusoidal displacements are quantified. The GEC installed specimen has exhibited a markedly superior dynamic shear behavior under the studied test conditions.

Keywords: geosynthetic encased columns, ordinary stone columns, cyclic shear test,

INTRODUCTION

Granular columns provide a time and cost efficient means for soil remediation for the construction of rigid and flexible structures such as oil storage tanks, embankments, buildings over weak clay deposits (e.g., Gniel and Bouazza, 2009; Ali et. al., 2012; Shahu and Reddy, 2014). The ground reinforced with granular columns behaves as a composite with higher strength and stiffness compared to virgin soils (Alamgir et al., 1996; Mohapatra 2016). Other than enhancing the vertical load capacity of the soil composite, granular columns reduce the time taken for the consolidation settlement. The load capacity of granular columns is directly related with the radial support that is applied on them by the peripheral soil. If the granular columns are implemented in very soft soils ($c_u < 15$ kPa), bulging failure could occur due to lack of radial confinement. Bulging failure typically occurs in the top portion of the granular column and the overlying structures may suffer significant settlements.

Above stated short comings of the granular columns are greatly reduced by the use of a geosynthetic encasement confining the stone column. The lateral support which cannot be derived from the soft soil is provided by the high modulus, low creep geosynthetic around the granular material. The geosynthetic also prevents the mitigation of the weak clay between the granular material which may degrade the frictional properties of the granular material.

A vast majority of the research on the geosynthetic encased columns (GECs) is concerned with the vertical load capacity. Although the behavior of the GECs under the action of the shear stresses is relevant to many geotechnical problems, there are not many studies dealing with that aspect of the GEC behavior. The behavior of GECs under the action of shear forces is especially of practical concern when GECs are implemented in areas prone to lateral flow of foundation soil. It is known that such movement in the foundation soil may lead to shear failure of GECs (Mohapatra et. al., 2016). Figure 1 depicts a case in which shear failure of the GEC occurs.

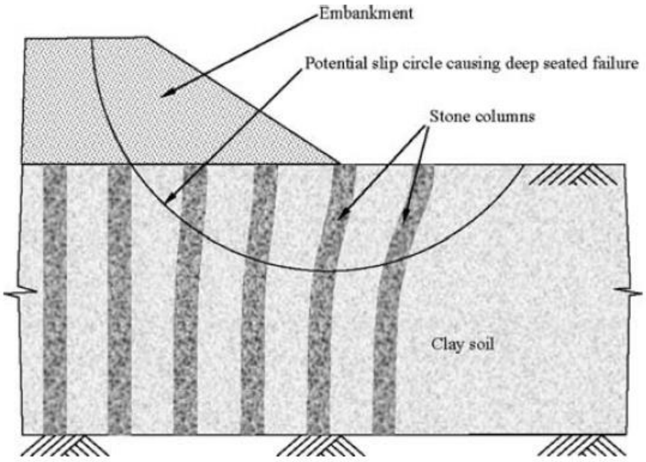

Figure 1. Schematic of stone columns subjected to shear deformations (Murugesan and Rajagopal., 2009).

Current literature on GECs offers very little on the behavior of GECs under the action of shear stresses. Notable exceptions to this are the works of Murugesan and Rajagopal, 2009; and Mohapatra et. al. 2016. In the said works GECs response to lateral shear has been investigated with rather small scale testing apparatus with the soil sample size being 300x300x200 mm (length, width, depth) in the former and 305x305x203.2 mm in the latter. The loading on the soil sample containing small scale GEC models was displacement controlled static shear loading.

In this study, preliminary findings of an experimental program conducted with a novel large scale testing apparatus which is devised to test the behavior of GECs under the action of dynamic shear loads is discussed. Sinusoidal cyclic shear excitation is applied on model GECs embedded in a soil layer which resembles the weak soil strata in a unit cell. The device delivers cyclic shear displacements to the entirety of the unit cell.

TESTING APPARATUS: DYNAMIC UNIT CELL SHEAR DEVICE

The device namely, Dynamic Unit Cell Shear Device, is essentially composed of four hollow vessels which houses weak soil material with a geosynthetic encased stone column (GEC) or an ordinary stone column (OSC) at the center of the weak soil. The purpose of the device is to shear the entire unit cell placed in the hollow vessels in a dynamic manner. The shearing is archived by virtue of converting the circular output of an electric motor to pure axial movement. The CAD drawings of the apparatus are illustrated in Figure 2. The yellow part in Figure 3 is laterally pushed and pulled by the drive rod extending from the eccentric moving part which is excited by the redactor. The movement mechanism can be seen in Figure 3(right-hand-side). A 5 ton capacity load cell is fixed on the moving part with the intention of reading the push or pull force on the moving part. A laser displacement sensor is aimed at the moving part to read the displacements. There are a total of four vessels (see Figure 3) in which the soil sample is placed. The top vessel (vessel 1 in Figure 3) which has a height of 35 cm, is placed in the assembly to compensate for the consolidation settlement for the cases where clay is used to simulate the weak soil strata surrounding the model column (GEC or OSC). Once the consolidation of the clay is completed the top vessel will be removed from the assembly. The vessel 2 and 4 have a height of 60 cm and vessel 2, which is the moving part with yellow color, has a height of 30 cm. A hollow tube with a diameter of 11 cm is kept in the center of the weak soil during consolidation of weak clay/placement of weak soil sample. Upon completion consolidation or placement of the weak soil, a GEC or OSC is formed inside the hollow tube. The tube is then retracted and a unit cell with a height of 150 cm and a diameter of 46 cm is formed with a GEC or OSC in the center.

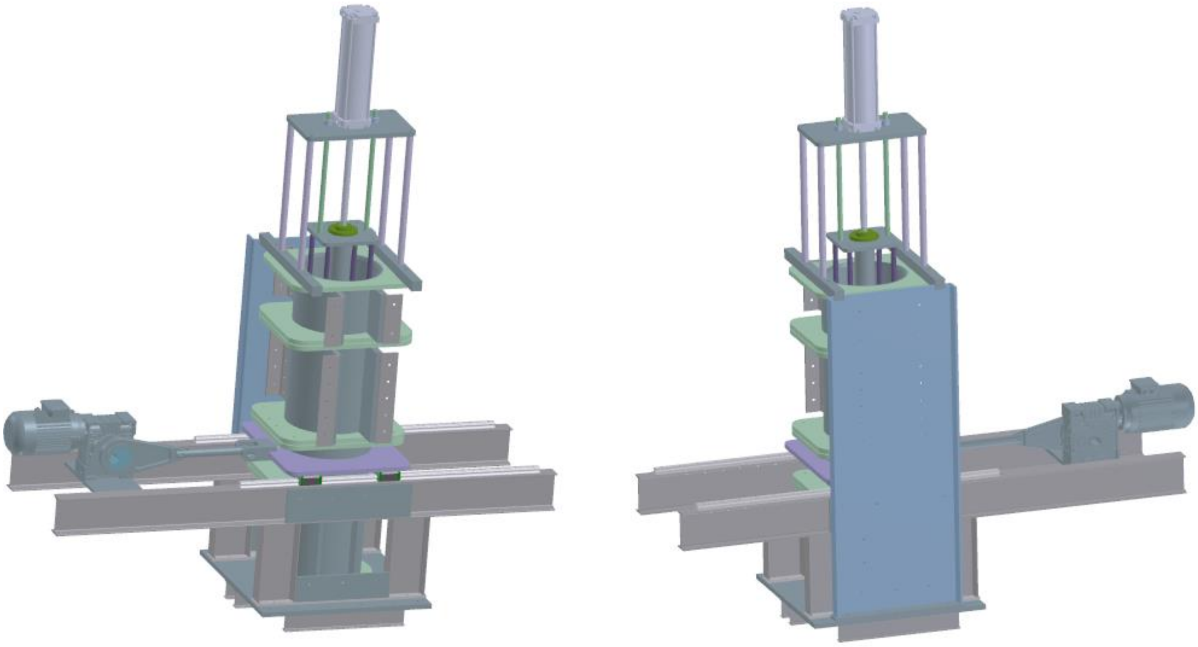

Figure 2. CAD drawings of the testing assembly

Figure 3. Pictures depicting the physical setup

MATERIALS AND METHODOLOGY

Sand was used to prepare the soil bed in place of normally consolidated clay soil due to the ease of placement, ease of achieving consistency between the tests and similarity of strength behavior (di Prisco et al., 2006). The objective of the test program was to study the improvement in lateral resistance of virgin soil due to the installation of OSC and GEC. As such, whether the lateral resistance is provided by a sandy or a clayey soil is not important as long as that lateral resistance can be estimated with reasonable accuracy. As long as the baseline shear strength of the surrounding soil can be estimated and deducted from the shear stress mobilized by the sand-OSC or sand-GEC system, it should be possible to isolate the behavior of OSCs and GECs from the test results (Mohapatra et. al. 2016).

A poorly graded sand with a specific gravity of G_s=2.62, coefficient of uniformity (C_u) of 3.0 and coefficient of gradation (C_c) of 1.08 was used to model the weak soil surrounding the column. Particle size distribution graph for the sand is given in Figure 4. The maximum and minimum void ratios of the sand (e_{min}, e_{max}) determined in accordance with ASTM D4253 and ASTM D4254 was 0.39 and 0.81, respectively. The sand was pluviated from a constant height of 3 meters into the testing assembly as depicted in Figure 5. The pluviation technique revealed samples with a void ratio of 0.54 which gives a relative density (D_r) value of approximately 65 % (medium dense sand).

The soil used for forming the model stone columns and GECs was an angular crushed rock aggregate with an internal angle of friction of 43 degrees and a specific gravity of 2.66. The crushed rock was initially wet sieved through ASTM No. 200 sieve with an opening size of

0.075 mm. The soil was then oven-dried and it was sieved through No 4 and No 10 sieves (aperture size 4.75 and 2 mm respectively). The soil retained sieve no 4 was discarded and soil retained on sieve No 10 was used as the aggregate in the stone column and GEC fillings (Cengiz et. al. 2016).

Once the model constituents were prepared, testing commenced. A sinusoidal displacement was applied with a frequency of 1 Hz and amplitude of 3.5 cm. The displacement-time plot of the sinusoidal displacement is illustrated in Figure 6. The inertia of the testing apparatus itself during the tests was considered by taking zero readings from the testing apparatus. An average of these readings was redacted from the force readings by using the principle of superposition. The hysteresis curves pertaining to zero readings of the device are given in Figure 7.

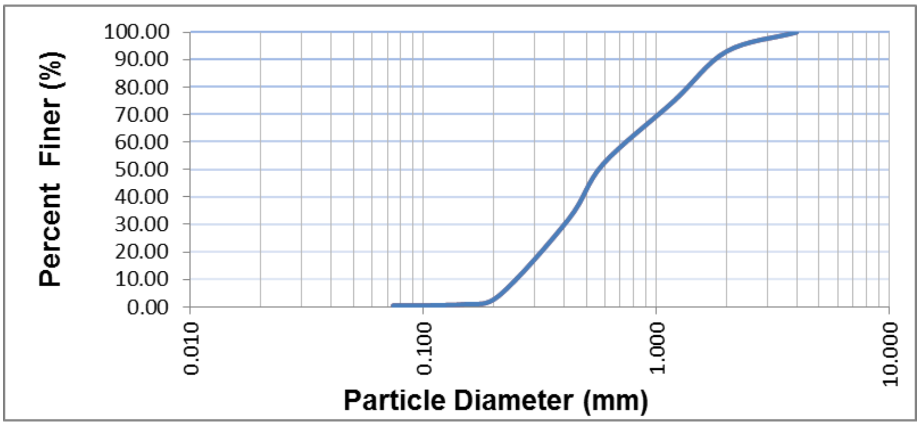

Figure 4. Grain size distribution of the sand

Figure 5. Pluviation of sand into the testing assembly

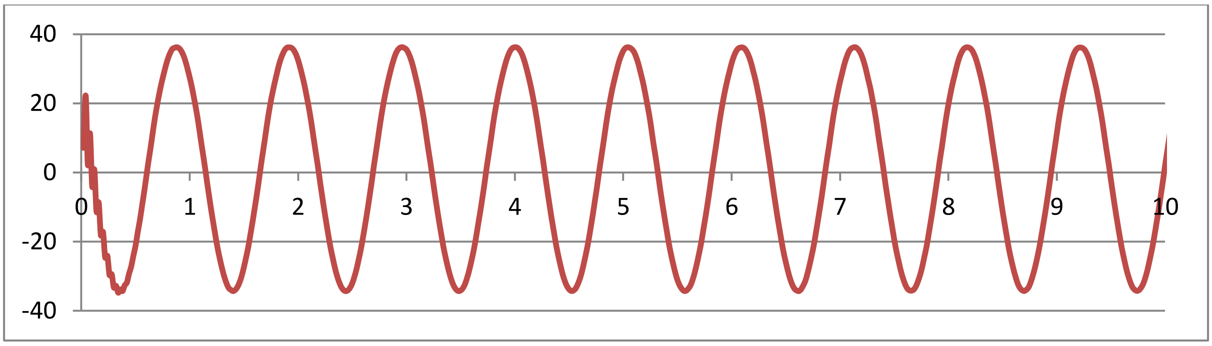

Figure 6. Sinusoidal input motion

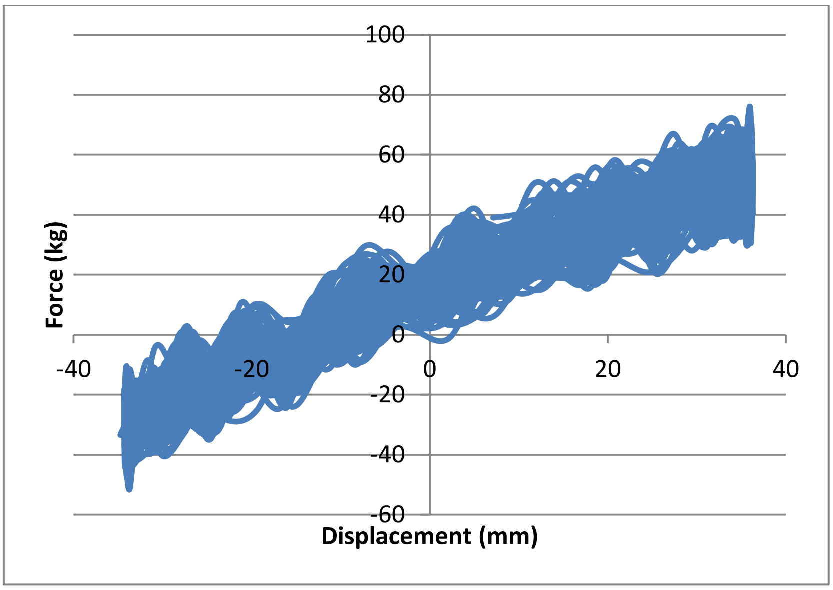

Figure 7. Zero reading that is taken from the device (force required to move the yellow part in a dynamic-sinusoidal fashion)

The reinforcement material used in the GEC sample was Tencate Polyfelt TS 10 which had a machine and cross-machine tensile strength of 8 kN/m. The stiffness (J) of the material was 35 kN/m up until 2 % strain. The testing program consisted of three experiments. The first experiment was conducted to reveal the dynamic shear response of the medium dense sand. An OSC and a GEC was implemented in the second and the third tests.

RESULTS AND CONCLUSIONS

The hysteresis loops given by the sample consisting solely of medium dense sand for 50 cycles is given in Figure 8. The hysteresis loops for medium dense sand with OSC and GEC are given in Figure 9 and 10, respectively. Force readings of medium dense sand remediated with GEC in time domain are illustrated in Figure 11.

The hysteresis loops given in Figures 8, 10, and 12 suggest that the presence of OSC or GEC increases the load necessary to move the soil by a predetermined amount in a cyclic manner. The peak force achieved by the GEC installed sand is slightly less than 800 kg whereas the peak force exerted to the OSC installed sand is about 720 kg. The curves for the cyclic testing depicting the force readings in time domain are given in Figures 9, 11, and 13. The peak strength achieved by the sample consisted of medium dense sand remained at a value of 600 kg. It could be deducted that presence of GEC has enhanced the cyclic lateral capacity of the unit cell under the studied conditions. It should also be mentioned that the amplitude of deformation was not sufficiently large to force the soil samples into plastic deformations which may induce modulus reduction. The trend of the hysteresis curves is that of an elastic response in all cases. Larger displacements should be employed in order to observe the degradation of unit cell stiffness under the action of cyclic shear displacements.

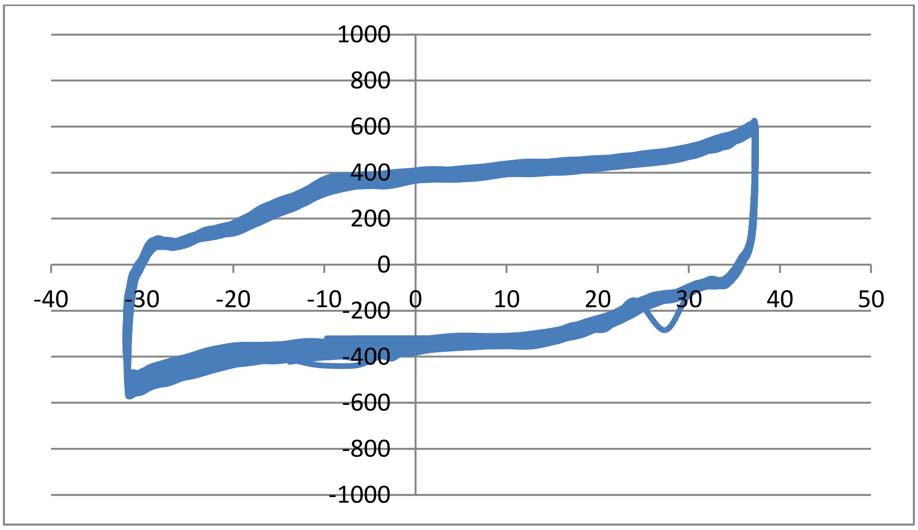

Figure 8. Hysteresis loops for the specimen that is made solely of medium dense sand

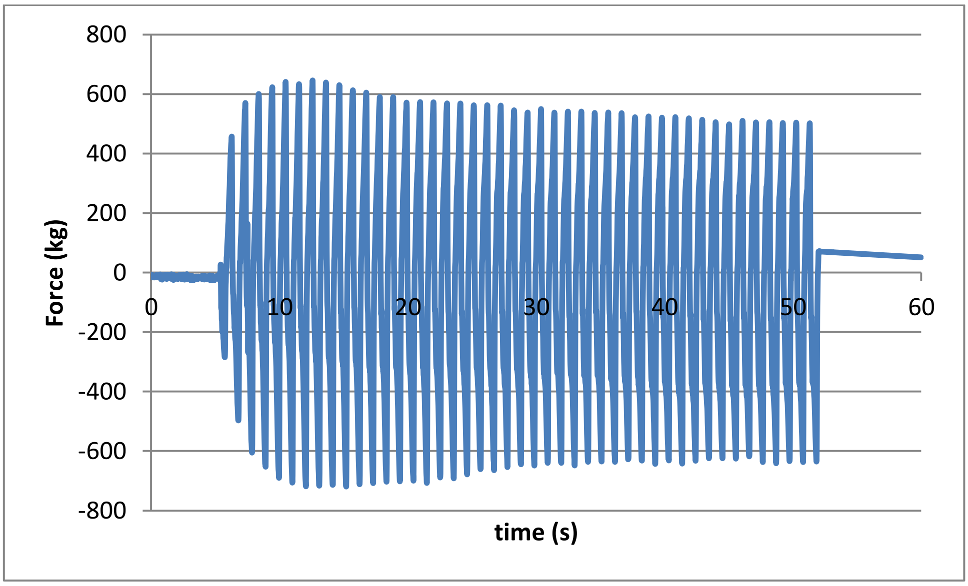

Figure 9. Force readings of medium dense sand in time domain.

The positive component of the cyclic peaks extracted from Figures 9, 11, and 13 are given as single curves for unit cells containing only dense sand, OSC, and GEC are illustrated in Figure 14.

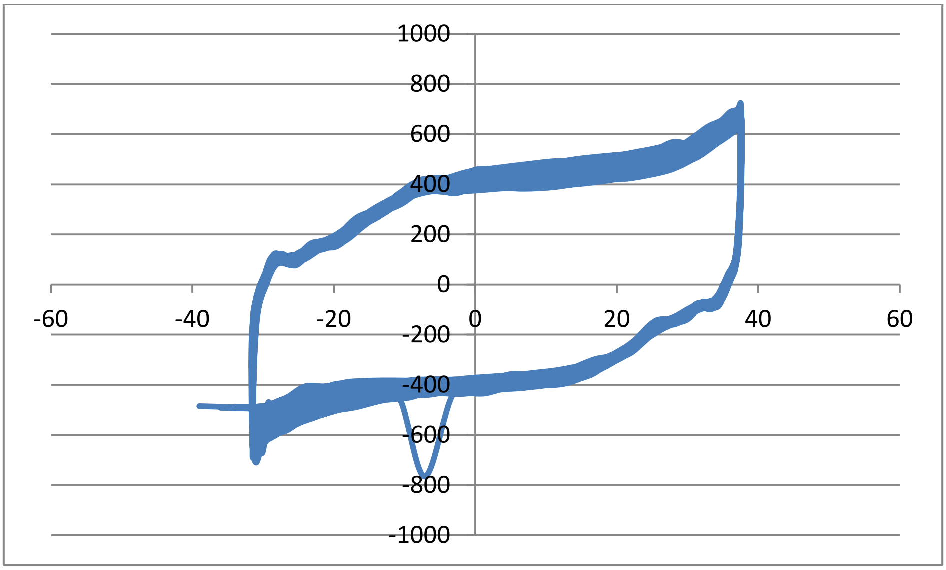

Figure 10. Hysteresis loops for medium dense sand remediated with OSC

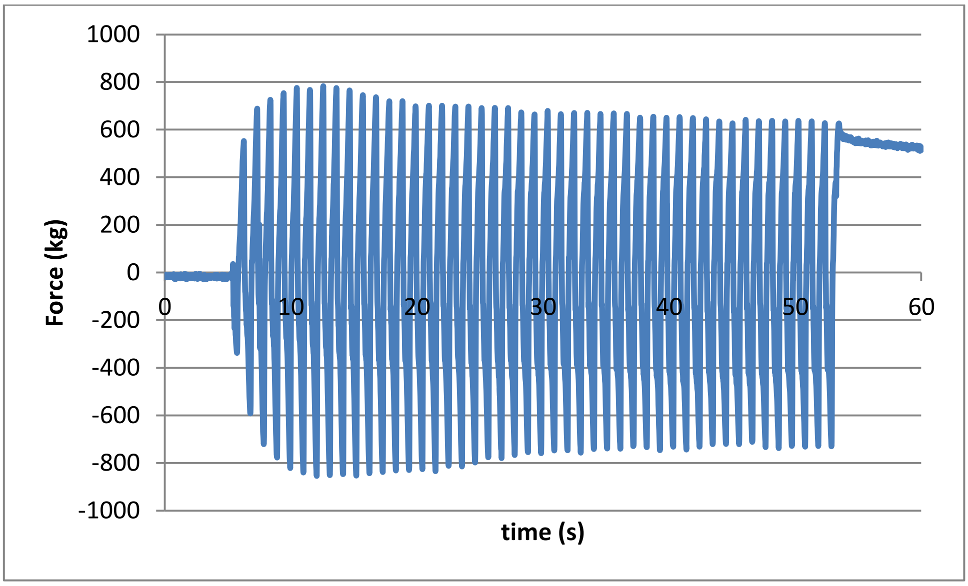

Figure 11. Force readings of medium dense sand remediated with OSC in time domain.

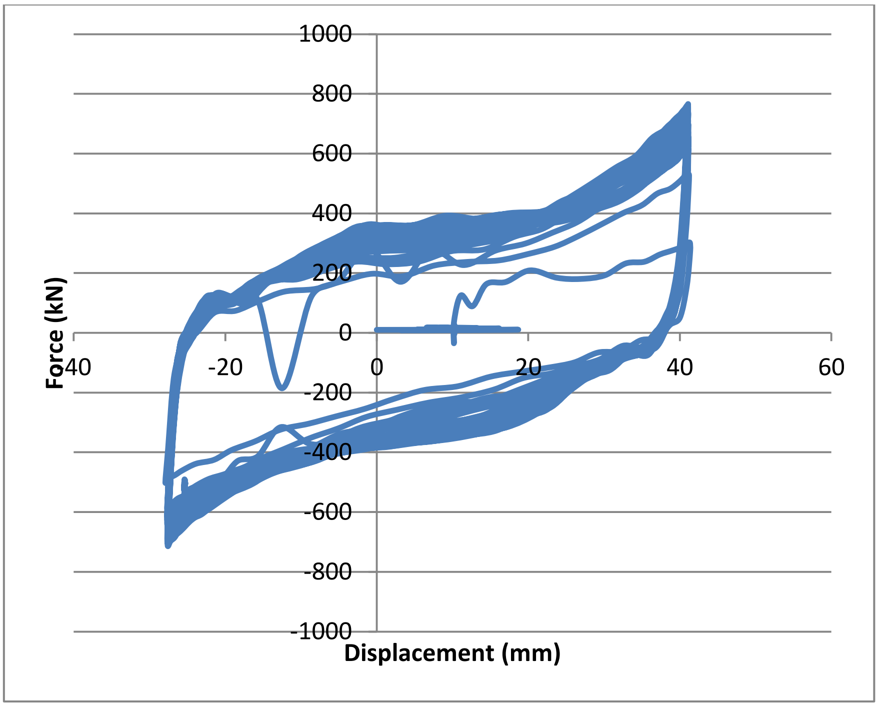

Figure 12. Hysteresis loops for medium dense sand remediated with GEC

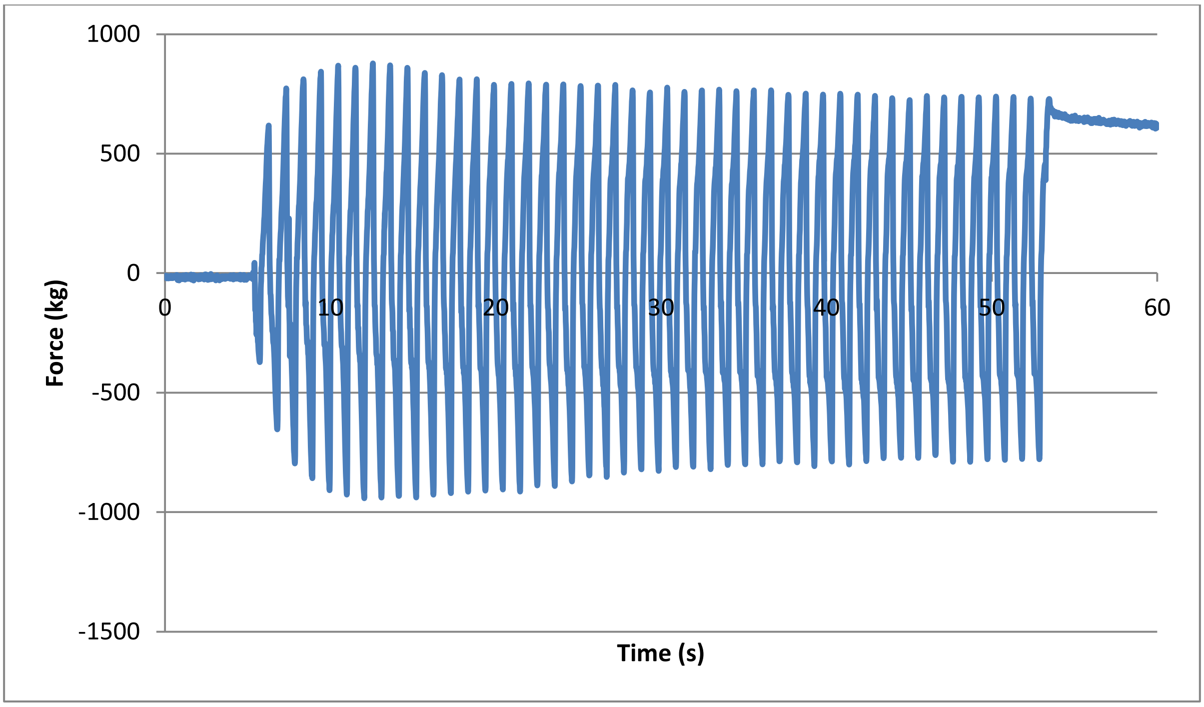

Figure 13. Force readings of medium dense sand remediated with GEC in time domain.

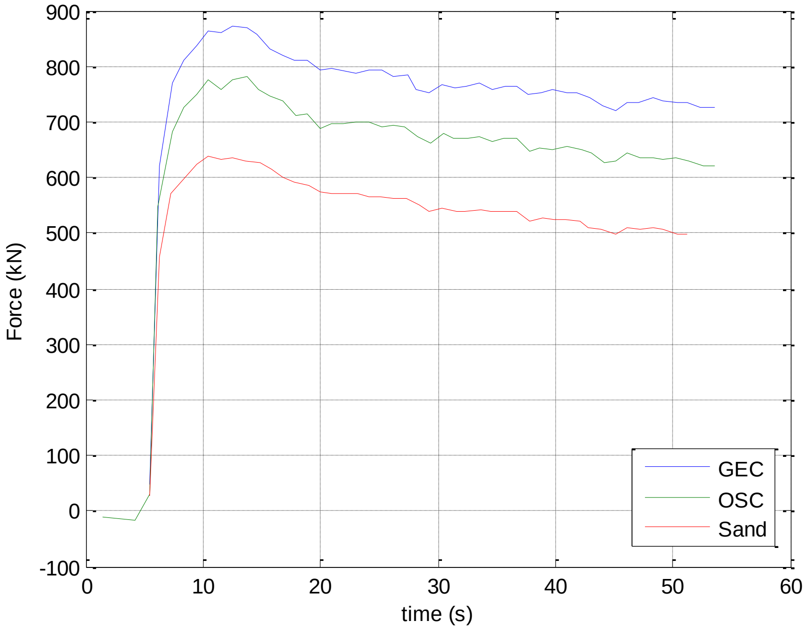

Figure 14. Positive peak achieved by the hysteresis loops illustrated in time domain

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