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# Experimental Investigation on Soil Susceptible to Liquefaction by using Geosynthetics and Artificial Materials

Ms. S. M. Deshmukh1[0000-1111-2222-3333], Dr. A. I. Dhatrak2[1111-2222-3333-4444] and Prof. S. W. Thakare3[2222-3333-4444-5555]

[1] M. Tech. student, Civil Engineering Department, Government College of Engineering, Amravati, India
[2] Associate professor, Civil Engineering Department, Government College of Engineering, Amravati, India
3Associate professor, Civil Engineering Department, Government College of Engineering, Amravati, India
`sanjay.thakare@1964@gmail.com, anantdhatrak@rediffmail.com`

**Abstract** - Liquefaction is known as an earthquake disaster because it has a devastating effect on infrastructure and human life. Since liquefaction is the major problems causing subsidence, spreading and displacement of liquefied soil during an earthquake, research and effort on the need for liquefaction restoration is emphasized. Thus, instead of traditional methods geosynthet- ics and artificial materials need to be considered to mitigate the effects of liquefaction. In this work, a 1 g shaking table test was performed on a liquefied sensitive sand bed under dynamic loads of varying amplitudes and frequencies. A series of three different tests were performed on liquefiable sand. Series A: Shake table tests on soil without any inclusion Series B: Shake table test on soil with provision of geotextile Series C: Shake table test on soil with provision of Light- weight Expanded Clay Aggregate (LECA). and the test results were compared for pore water pressure, settlement, acceleration and cyclic stress ratio.

**Keywords:** Liquefaction, Pore water pressure, Settlement, Acceleration, Cyclic stress ratio.

## 1 Introduction

### 1.1 General

Records of structural subsidence due to liquefaction are from the 1964 Niigata earthquake. Since then, nearly all earthquakes in regions prone to liquefaction were followed via way of means of systems that sink into liquefied soil. Liquefaction damage is crucial when there is not enough land for people to build plots on hard, reliable soil. After understanding the mechanism of liquefaction failure, engineers were able to find effective measures to prevent liquefaction. The lateral flow caused by liquefaction is one of the widespread and dangerous consequences, damaging many other important structures both underground and above the surface near or above liquefied slopes.

The mechanism for enhancing the resistance of liquefied soil to liquefaction is essentially found out with the aid of using compaction of surrounding soil, discount of extra pore pressure, and by reduction of shear pressure and strain. Several soil development strategies primarily based totally at the above mechanisms had been evolved to mitigate liquefaction, together with gravel drainage, sand consolidation, deep blending and jet injection.

### 1.2 Types of Inclusion Materials

Geotextiles and artificial material such as Light-weight Expanded Clay Aggregate (LECA) are used as inclusion materials which are considered to be non - biodegradable and are quite cost effective. These are considered hereafter.

**Geotextiles**. Geotextiles are porous geosynthetics with visible strands and fibers that resemble a thick, robust garment or blanket which are often used to reduce erosion and improve the soil upon which road embankments, pipelines, and earth retaining structures are built as shown in Fig. 1(a). These geotextiles are based on several criteria such as separation, filtration, drainage reinforcement, selling, and protection.

**Lightweight Clay Aggregate (LECA).** LECA is a lightweight, low-fabricated, and highly porous swollen grain of heated clay as shown in Fig. 1(b). LECA expands and bloats when subjected to high temperatures in a rotating kiln. It has been used as a lightweight aggregate in precast concrete products for a variety of structural and non-structural purposes. Because of its low weight and high vibrational energy absorption and drainage capacity, LECA is particularly beneficial in geotechnical and structural applications. Understanding the properties and behavior of low-cost materials is essential for long-term sustainability**.**

(a) Geotextile

(b) Lightweight Expanded Clay Aggregate (LECA)

**Fig. 1.** Types of Inclusion Material

## 2 Literature Review

The study regarding the mitigation of liquefaction by using various geosynthetics, sand compaction column, deep soil mixing, sheet piles, etc. had been carried out experimentally and analytically by various researchers. These works are reviewed keeping in view the methodology, principles and various aspects of experimental and analytical investigation for the improvement of liquefied soil.

Hendra Setiawan *et. al.* (2018)[1] employed a shake table device to investigate the impacts of geosynthetics and the usage of gravel to prevent liquefaction-induced vertical soil displacement. Using shaking table equipment, model tests were conducted on sand with relative densities of 90% and 50%. According to this, vertical soil displacement was reduced by 54 percent in loose sand and 32 percent in dense sand due to the application of geosynthetics and gravel. Furthermore, test results reveal that the difference in subsidence between loose and dense sand conditions is reduced by roughly 62%.

Gowtham Padmanabhan *et. al.* (2019)[2] used a Sand Compaction Pile with a diameter of 110 mm and a length of 600 mm to conduct an experiment on liquefied soil. The shake table tests were performed on soil with and without an improvement procedure at a frequency of 5Hz with consecutive accelerations of 0.1g, 0.2g, 0.3g, and 0.4g. It may be argued that as accelerations enhanced, the liquefaction potential of sand deposits increased. It was attempted to evaluate the performance of sand compaction piles subjected to repeated acceleration amplitude, and it was discovered that sand compaction piles performed exceptionally well under repeated acceleration amplitude and raised liquefaction resistance of sand deposits.

Rouzbeh Rasouli *et. al.* (2013)[3] used a shaking table test to investigate the parameters that influence the deep mixing column method, including column pattern, length ratio, and improvement ratio. The models were shaken by 200Gal (1Gal = 1cm/sec$^2$) sine waves, followed by 300 Gal at a frequency of 10 Hz and a period of 12 sec. They concluded that increasing the improvement ratio reduced lateral displacement, and increasing the length of improvement was effective on the amount of lateral flow significantly reduced liquefiable sand lateral displacement. Additionally, it lowers excessive pore water pressure within the improvement zone.

Rouzbeh Rasouli *et. al.* (2012)[4] conducted a series of shaking table tests to investigate the use of sheet piles for subsidence mitigation. It was found that fixity and rigidity of the sheet pile are important for improving the efficiency of this damping technique. All models were shaken with a 350Gal sine wave, frequency 10 Hz and shaking time 30 seconds. It can be concluded that placing sheet piles next to the structure can reduce the amount of lateral shear deformation of the soil beneath the structure. Restricting the top ends of sheet piles could minimise both the structure's subsidence and the sheet pile's maximum induced bending moment. As a result, better sheet pile performance efficiency and the use of tougher sheet piles results in reduction of subsidence.

Hemanta Hazarika *et. al.* (2019)[5] used PLAXIS two-dimensional software to conduct numerical investigations on unimproved and improved ground independently. The purpose of research was how effective jet grouting is, at preventing liquefaction. The numerical situations were analyzed and examined with and without soil improvement in order to measure the behavior and performance of the highly elastic nozzle mortar column in liquefiable soil. According to this research, the close spacing of jet grout contiguous columns with horizontal slab can effectively limit the shear deformation of the improved ground layer during an earthquake.

## 3 Experimental Investigations

1-g shaking table tests were carried out on the soil susceptible to liquefaction subjected to dynamic loading using acrylic tank of 0.6 m x 0.4 m x 0.6 m and the frequency of 3Hz, 4Hz and 5Hz for the amplitude of ±5mm, ±7.5mm and ±10mm respectively on experimental set-up at Government College of Engineering, Amravati. Total three different series of shaking table tests were conducted: Series A: Shake table tests on soil without any inclusion Series B: Shake table test on soil with provision of geotextile Series C: Shake table test on soil with provision of Light-weight Expanded Clay Aggregate (LECA). The properties of sand and inclusion materials are as shown in Table 1.

**Table 1.** Properties of Materials used for Experimental Investigation

| Sr. No. | Materials | Parameter | Corresponding Values |
|---|---|---|---|
| 1 | Sand | IS Classification | SP |
| | | Specific Gravity | 2.68 |
| | | Maximum Unit weight ($\gamma_{max}$) (kN/m$^3$) | 14.91 |
| | | Minimum unit weight ($\gamma_{min}$) (kN/m$^3$) | 13.34 |
| | | Relative Density | 30 % |
| | | Angle of Internal Friction ($\phi$) | 34° |
| | | $D_{50}$ | 0.24 |
| | | Coefficient of uniformity ($C_u$) | 2.61 |
| | | Coefficient of curvature ($C_c$) | 1.4 |
| 2 | Geotextile Inclusion | Ultimate tensile strength (kN/m) | 8.5 |
| | | Trap. Tear Strength (N) | 187.2 |
| | | Grab Tensile Strength (N) | 512 |
| | | Grab Elongation (%) | 65.9 |
| | | CBR Puncture Strength (N) | 1452 |
| | | Mass per unit area (GSM) | 156 |
| 3 | LECA Inclusion | Size (mm) | 2 – 10 |
| | | Density (gm/cc) | 0.5 |

## 4 Experimental Set-up

The experimental set-up consists of shaking table, acrylic tank, data logger, control panel, accelerometer, piezometer and motor. The 3D view of experimental set-up is shown in Fig. 2.

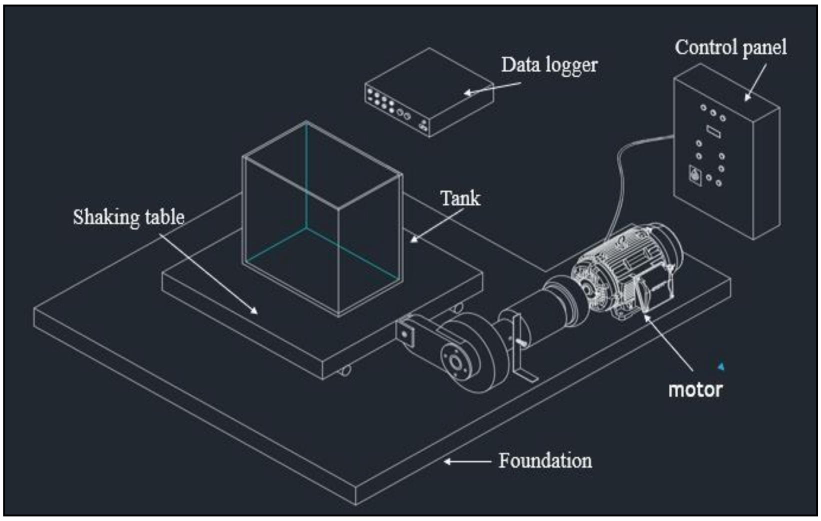


**Fig. 2.** 3D view of Shaking Table

## 5 Experimental Test Procedure

The sand was filled in the tank upto the height of 0.2 m from bottom with a relative density (Dr) of 30%, using gravity raining technique by maintaining a height of fall of 15 cm. Half of the corresponding amount of water was added to the sand bed. The Piezometer (P2) and the Accelerometer (A1) were placed on the sand bed as shown in Fig. 3(a). In case of the test without any inclusion, the remaining amount of the sand was prepared up to a height of 0.4 m from bottom and half of the remaining amount of water was added. The surface was levelled properly and the Piezometer (P1) was placed at the top of the sand bed and the Accelerometer (A2) was mounted on the shake table.

Whereas, when the soil was provided with inclusion material like geotextile/ LECA, the tank was filled up to the height of 0.35m from bottom. At the height of 0.35 m, the geotextile was provided in a single layer and the layer LECA provided (10% of the overlaying sand). The tank was then filled using sand upto the height of 0.4 m when provided with geotextile inclusion and using gravel when provided with LECA inclusion respectively. Further, half of the remaining amount of water was added and the Piezometer (P1) was placed at the top of the sand bed and the Accelerometer (A2) was mounted on the shake table as shown in Fig. 3(b) and Fig. 3(c).

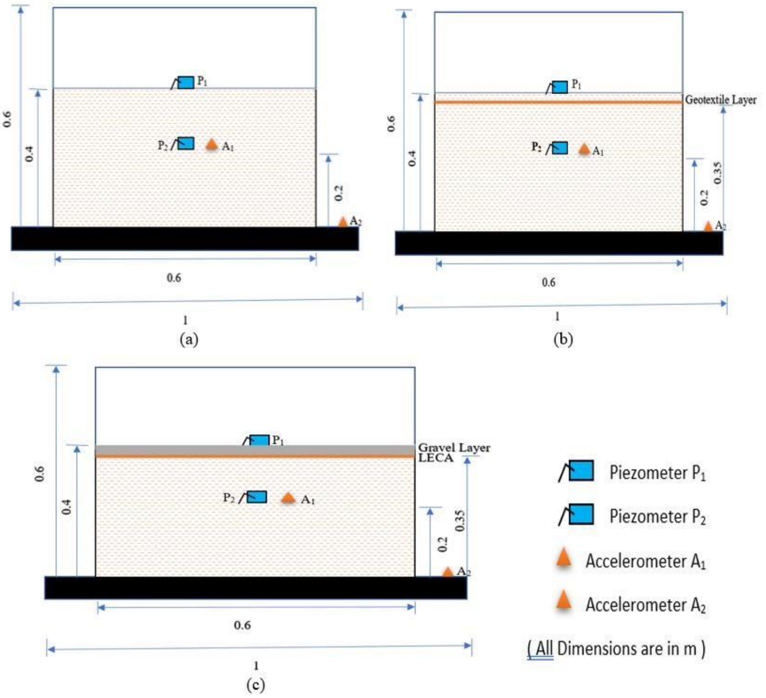


**Fig. 3.** (a) Schematic view of test without any inclusion (b) Schematic view of test with geotextile inclusion (c) Schematic view of test with LECA inclusion

## 6 Results and Discussion

The results of tests on soil without and with inclusions were compared in terms of the value of pore pressure, settlement, acceleration and cyclic stress ratio. The typical pore pressure verses time and acceleration verses time graph as obtained from data logger are shown in Fig. 4 and 5 respectively.

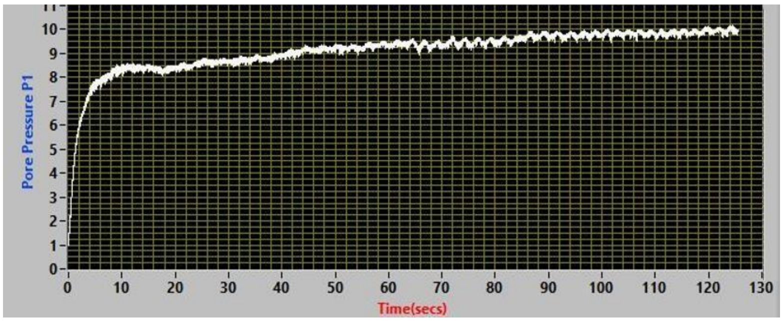


**Fig. 4.** Graph of Pore Pressure verses Time

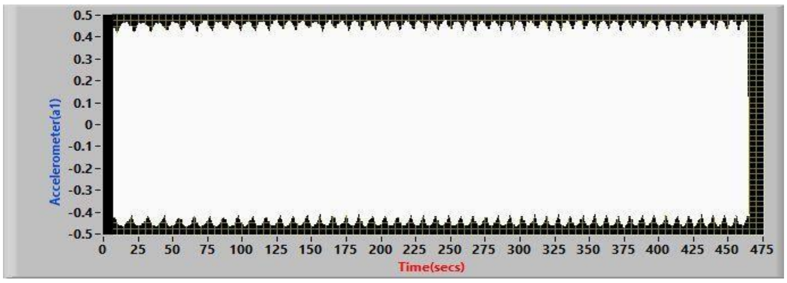


**Fig. 5.** Graph of Acceleration verses Time

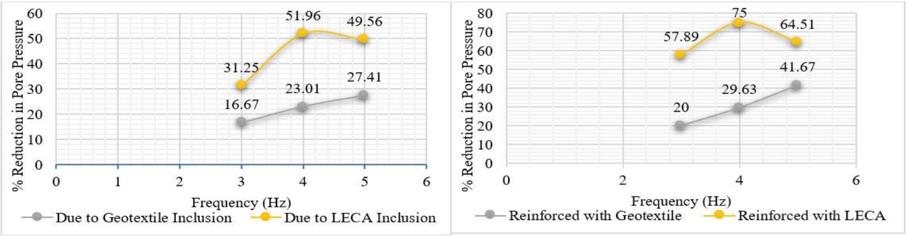
The values of pore pressure, settlement, acceleration and cyclic stress ratio for various frequencies and amplitude are shown in Table 2.

**Table 2.** Values of Pore Pressure, Settlement, Acceleration and Cyclic Stress Ratio

| Inclusions | Amplitude (mm) | Frequency (Hz) | Pore Pressure (kPa) | Settlement (cm) | Acceleration (g) | Cyclic Stress Ratio |
|---|---|---|---|---|---|---|
| Soil without any inclusions | ± 5 | 3 | 10 | 1.5 | 0.26 | 0.34 |
| | | 4 | 15.5 | 3.2 | 0.54 | 0.71 |
| | | 5 | 17.2 | 4.6 | 0.75 | 0.98 |
| | ± 7.5 | 3 | 12 | 1.6 | 0.5 | 0.65 |
| | | 4 | 17.5 | 3.5 | 0.68 | 0.89 |
| | | 5 | 25.5 | 4.7 | 0.83 | 1.09 |
| | ± 10 | 3 | 16 | 1.7 | 0.68 | 0.89 |
| | | 4 | 20 | 3.9 | 0.83 | 1.09 |
| | | 5 | 45 | 5.1 | 0.83 | 1.09 |
| Soil with Geotextile inclusion | ± 5 | 3 | 9 | 1.2 | 0.37 | 0.48 |
| | | 4 | 12.6 | 2.5 | 0.48 | 0.63 |
| | | 5 | 13.5 | 3.5 | 0.60 | 0.78 |
| | ± 7.5 | 3 | 10 | 1.3 | 0.45 | 0.59 |
| | | 4 | 13.5 | 2.8 | 0.6 | 0.78 |
| | | 5 | 18 | 4.2 | 0.75 | 0.98 |
| | ± 10 | 3 | 10.5 | 1.6 | 0.6 | 0.78 |
| | | 4 | 15.5 | 3.5 | 0.75 | 0.98 |
| | | 5 | 35.5 | 4.8 | 0.83 | 1.09 |
| Soil with LECA inclusion | ± 5 | 3 | 8 | 1 | 0.30 | 0.39 |
| | | 4 | 9 | 2.2 | 0.45 | 0.59 |
| | | 5 | 10.2 | 3.1 | 0.60 | 0.78 |
| | ± 7.5 | 3 | 7.6 | 1.2 | 0.45 | 0.59 |
| | | 4 | 10 | 2.6 | 0.54 | 0.71 |
| | | 5 | 15.5 | 3.8 | 0.68 | 0.89 |
| | ± 10 | 3 | 8 | 1.4 | 0.54 | 0.71 |
| | | 4 | 10.5 | 3.2 | 0.68 | 0.89 |
| | | 5 | 22.5 | 4.5 | 0.83 | 1.09 |

**Discussion of Results**. The results obtained from the experiments carried out on the soil susceptible to liquefaction are discussed in this section. The effect of amplitude and frequencies of dynamic loading on pore pressure, settlement, acceleration and cyclic stress ratio with geotextile and Lightweight Expanded Clay Aggregate are summarized in following sections.

**Effect of Geotextile and LECA inclusions on Pore Pressures developed in soil**. The percentage reduction in pore pressure developed in soil due to provision of Geotextile and LECA for various amplitudes and frequencies of dynamic loading are shown in Fig. 6(a), 6(b) and 6(c) for the amplitude of ± 5mm, ± 7.5mm and ± 10mm respectively.



(a) Amplitude of ± 5mm (b) Amplitude of ± 7.5mm

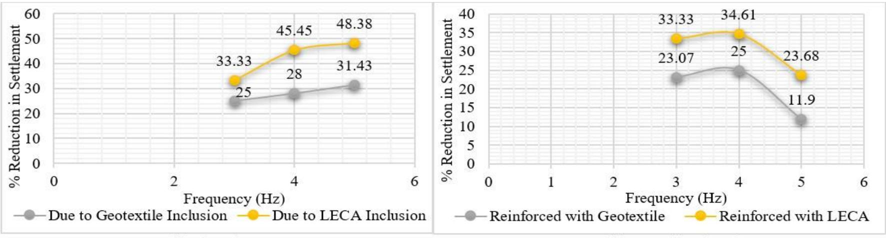
(c) Amplitude of ± 10mm

**Fig. 6.** Percentage Reduction in Pore Pressure

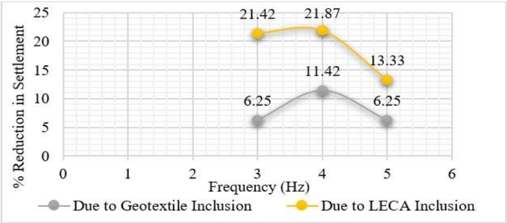
The percentage reduction in the values of pore pressure developed in soil when provided with Lightweight Expanded Clay Aggregate was found to be much higher, almost twice, as compared to that of Geotextile. By providing the geotextile inclusion, the value of pore pressure decreases upto 27%, 41% and 52% for the amplitude of ± 5mm, ± 7.5mm, and ± 10mm respectively. In case of LECA, inclusion the value of pore pressure decreases by 51%, 75% and 100% for the amplitude of ± 5mm, ± 7.5mm and ± 10mm respectively.

Thus, LECA is more effective as an inclusion in soils susceptible to liquefaction as compared to Geotextile.

**Effect of Geotextile and LECA inclusions on Settlement.** The percentage reduction in settlement due to provision of Geotextile and LECA for various amplitudes and frequencies of dynamic loading are shown in Fig. 7(a), 7(b) and 7(c) for the amplitude of ± 5mm, ± 7.5mm and ± 10mm respectively.



**(a)** Amplitude of ± 5mm (b) Amplitude of ± **7**.5mm



**(c)** Amplitude of ± 10mm

**Fig. 7**. Percentage Reduction in Settlement

The percentage reduction in the values of settlements in soil when provided with Lightweight Expanded Clay Aggregate was found to be much higher as compared to that of Geotextile. By providing the geotextile inclusion, the value of settlement decreases upto 31%, 25% and 11% for the amplitude of ± 5mm, ± 7.5mm, and ± 10mm respectively. In case of LECA, inclusion the value of settlement decreases by 48%, 34% and 21% for the amplitude of ± 5mm, ± 7.5mm and ± 10mm respectively.
Thus, LECA is more effective as an inclusion in soils susceptible to liquefaction as compared to Geotextile.

**Effect of Geotextile and LECA inclusions on cyclic stress ratio.** The percentage reduction in cyclic stress ratio due to provision of Geotextile and LECA for various amplitudes and frequencies of dynamic loading are shown in Fig. 8(a), 8(b) and 8(c) for the amplitude of ± 5mm, ± 7.5mm and ± 10mm respectively.

**Fig. 8.** Percentage Reduction in Cyclic Stress Ratio

The percentage reduction in the values of cyclic stress ratios when provided with Lightweight Expanded Clay Aggregate was found to be higher, as compared to that of Geotextile. By providing the geotextile inclusion, the value of cyclic stress ratio decreases upto 25% for the amplitude of ± 5mm and 14% for the amplitude of ± 7.5mm, and ± 10mm respectively. In case of LECA, inclusion the value of cyclic stress ratio decreases by 25% for the amplitude of ± 5mm, ± 7.5mm and ± 10mm respectively.
Liquefaction potential depends on the cyclic stress ratio. Thus, as the cyclic stress ratio decreases liquefaction potential increases and factor of safety against liquefaction rises as well. Thus, LECA is more effective as an inclusion in soils susceptible to liquefaction as compared to Geotextile.
But the value of CSR increases by 43.27% and 14.28% when the geotextile and LECA inclusion is provided for the frequency of 3Hz and the amplitude of ± 5mm. Thus, providing the reinforcement for the frequency of 3 Hz and the amplitude of ± 5mm is not the effective solution to decrease the value of cyclic stress ratio.

## 7 Conclusions

Experimental investigations were carried out on the soil susceptible to liquefaction with the help of shaking table. The effect of providing the inclusions viz., geotextile and LECA towards reducing the pore pressure, settlement, acceleration and cyclic stress ratio was studied. Based on the results of the study, following broad conclusions were drawn.

1. As the frequency and the amplitude of dynamic loading increases the pore pressure, settlement, acceleration and cyclic stress ratio increases.
2. The percentage reduction in the pore pressure, settlement, acceleration and cyclic stress ratio when provided with inclusions of Lightweight Expanded Clay Aggregate is more as compared to the sand bed when provided with Geotextile.
3. Thus, Lightweight Expanded Clay Aggregate is more effective inclusion as compared to geotextile for the improvement in liquefaction susceptibility of soil.
4. The excess pore water pressure can be effectively reduced up to 52% with geotextile and 100% with LECA inclusions respectively.
5. The settlement can be effectively reduced up to 31% with geotextile and 48% with LECA inclusions respectively.
6. The acceleration can be effectively reduced up to 25% with geotextile and up to 33% with LECA inclusions in soil.
7. The cyclic stress ratio can be effectively reduced up to 25% with geotextile and LECA inclusions in soil.
8. For the frequency of 3Hz and the amplitude of ± 5mm, inclusions of Geotextile and LECA are not much effective for reducing the acceleration and cyclic stress ratio.

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