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Liquefaction Susceptibility and Remediation Measures of Mirpur Sand

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Abstract- Soil liquefaction can damage the building foundations resulting into irregular settlement of the buildings, structural damages, formation of cracks in foundations and overall instability of structures. Therefore, proper remediation measures are necessary to minimize the adverse effects of liquefaction phenomenon. The paper presents the undrained cyclic behavior of Mirpur sand and different remediation techniques using various additives to reduce the liquefaction potential. In this study, a series of strain controlled cyclic triaxial tests were performed at a frequency of 1 Hz. In order to simulate the field conditions of medium dense sand, the samples were prepared at 10% moisture content and at a relative density of 60%. In addition, specimens were subjected to varying confining pressures (e.g., 50, 100, 150 kPa). Ordinary Portland Cement (OPC) and Polypropylene (PP) fibers were mixed in the sample for remediation purpose. The results show that for the same level of axial strain, the deviator stress increases by 15 % when fibers were mixed in pure sand sample. In addition, when both fibers and cement were added to pure sand specimen, the value of deviator stress increased by 25%.

Keywords- Liquefaction, Remediation measures, Polypropylene, Strain Controlled Tests

I. INTRODUCTION

Soil liquefaction, the secondary effect of an earthquake; is a transformation of granular material from a solid state into a liquefied state with a significant increase of pore water pressure until the effective stress reaches zero [1]. During cyclic loading, the pore water pressure starts increasing and when the pore water pressure reaches to the confining pressure, the sand begins to transfer the stress from the soil skeleton to the pore water. Hence, the sand in the liquefied state losses the shear strength [2]. In addition, the inter-particle friction reduces, the soil structure collapses and experiences significant deformation, which leads to excessive settlement, translation of earth structures, slope failures, sand boils, and sinkholes [3].

In 2012, May 20th (ML=5.9) and 29th (ML=5.8) earthquake hit Italy's Emilia Romagna Region, 27 people died and 12000 buildings were damaged due to the earthquake [4]. Significant liquefaction effects were observed causing damage to infrastructures. On 24th September, 2019 an earthquake (ML=5.6) occurred at Mirpur in North West of Pakistan. The Mirpur Earthquake was comparatively small, it was also shallow, meaning that a significant area will have suffered high peak ground accelerations. The United States Geological Survey (USGS) has generated a map of earthquake intensity (the contours on the map), enhanced by the shading, which shows areas of liquefaction potential. More than 30 people have been reported killed and at least 450 injured, according to the report (USGS, 2019). Field analysis of Mirpur showed that the liquefaction phenomenon contributes the major part in failure of infrastructures. Figure 1 shows the liquefaction susceptibility in Mirpur. For remediation of liquefaction potential, different techniques have been used, mainly divided into two categories; by enhancing soil properties and by installing structural elements. Enhancing soil properties include densification, drainage, compressibility, hydraulic conductivity and reinforcement of sand. Fiber reinforcement has been considered as an effective approach to enhance the anti-liquefaction property of sand. The results indicated that the fiber inclusion yields to higher cumulative liquefaction energy values compared to the unreinforced (plain) ground by increasing the number of cycles and shear strength needed for the liquefaction of the soil [5]. Installation of structural elements includes piles and micro-piles, which increase the bearing capacity and reduce settlement of foundation [6].

In this study, cyclic strain controlled triaxial tests are performed on pure sand (Mirpur sand), fiber (Polypropylene) and cement (Ordinary Portland Cement) additives.

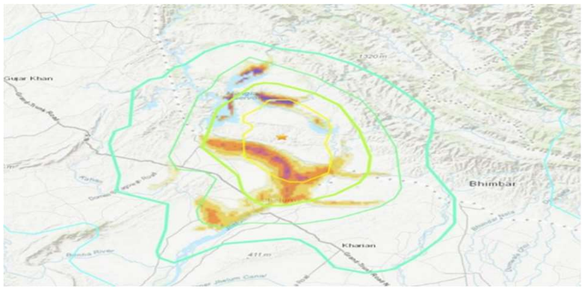

Figure 1: Map shows liquefaction susceptibility in Mirpur [7].

II. MATERIAL CHARACTERISTICS

Sand:

Sand samples were obtained from Mirpur located in Azad Kashmir, Pakistan. The region lies at an earthquake active zone. The historic earthquake (i.e., 24th September 2019) showed the liquefaction susceptibility and significant damages. Researcher found that keeping the density index same, liquefaction potential decreases for fine particles sand [8]. In addition, cement and fibers additives showed that the liquefaction potential can be suppressed by adding minimal percentages of the mentioned additives [2]. Of particular interest for liquefaction mitigation, cementitious stabilizers addition to saturated sands and soft soils is one of the widely used techniques. This technique reduces the generation of excess pore water pressure, and liquefaction susceptibility of sands and silts. Fibre and cement additives also increase soil density and unconfined compressive strength, and adds cohesion to poor quality granular materials when a cementitious material is used [2].

Table 1 Properties of Mirpur sand.

Minimum void ratio (ASTM D 4253)	**Maximum void ratio (ASTM D 4254)**	**Specific gravity (ASTM D854-14)**	**Dry density (g/cm3) (ASTM D7263 – 21)**
0.63	0.8	2.68	1.4

The grain size distribution of Mirpur Sand is shown in Figure 2. Table 1 shows the physical properties of Mirpur Sand used in the research study. The results are obtained from mechanical sieve shaker. The diameter of sand particles range between 0.1 mm and 10 mm. Samples were prepared to a target dry density value of ρd = 1.40 g/cm3. This density was selected to replicate field condition (i.e., recently liquefied sand at Mirpur).

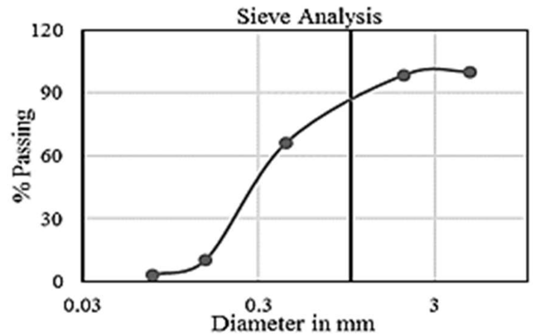

Figure 2: Grain size distribution curve for Mirpur sand

Fibers:

Polypropylene (PP) fibers were used due to lightweight nature, high strength, good elasticity and dispersity, and economical cost (about $1.10/kg). In addition, polypropylene fiber is the most widely used inclusion in laboratory testing of soil reinforcement [9]. Other advantages include, its high stiffness and resistance to heat [10,11]. Use of fibers mainly increase the tensile strength of sand. The test results revealed that the addition of fibers increased the number of cycles required to liquefaction, resulting in higher cumulative dissipated energy [12]. The strength of the fibers varies with the length and diameter of the fibers. The density of PP fibers is 0.91 gm/cc, elastic modulus of 3500 MPa and melting point 170ºc.

Cement:

Ordinary Portland Cement (OPC) were mixed in the sample, cement decreases the permeability and improve the shear strength of soil [2]. It is economical than other chemicals stabilization method and also easily available in the market. Figure 3 show sand and fibers in a tray.

Figure 3: Sample before mixing of fibers

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III. Test Apparatus and Testing Procedure

The apparatus used for experimental work was automated pneumatic control having 100 kN capacity load frame (see Fig. 4). A pneumatic dynamic actuator was fitted to load frame having double amplitude of 30mm and operational frequency range of 0.01-10Hz.

Sand sample was collected from Mirpur Site. First of all, sand was oven dried, then sieve analysis was performed (e.g., ASTM C-136). On the basis of relative density specific amount of sand and water was calculated following ASTM C-128. The sand was poured into the mold and the compaction effort was performed. Proper straight surface of the sand was ensured within the sampler locking. The top head cap was placed on the sample which has a tube for the back pressure to connect it with one of the holes of pedestal. Secondly, the top head cap was enclosed in membrane and above it rolled down the two O-rings provided before the sampler locking. Slowly and gradually the sampler locking was removed to ensure that the sample remain intake with the cap in straight position. In order to ensure uniform and random distribution of fibers in tested specimens, water is mixed with sand first and then fibers are thoroughly mixed with moist sand.

Displacement control experiments were conducted using an automated control cyclic triaxial apparatus following ASTM D 3999 (displacement control modulus and damping test). A sample was prepared having 50mm diameter and 100 mm height (see Fig. 5). Tests were performed in three stages, the first stage was saturation of sample, finishing by observing B value greater than 0.95 followed by consolidation and finished with cyclic stage. Each test specimen was subjected to 40 cycles of sinusoidal strain-controlled loading at f=1 Hz. DYNATRIAX software recorded the data with the help of a data logger. For interpretation of test results, the data was plotted in excel spread sheets. Table 2 shows specimens used in the current study, relative density of medium dense specimens to replicate field conditions. In addition, 1 Hz frequency and differing percentages of cyclic strain amplitudes were used to simulate the earthquake loading conditions in the laboratory tests.

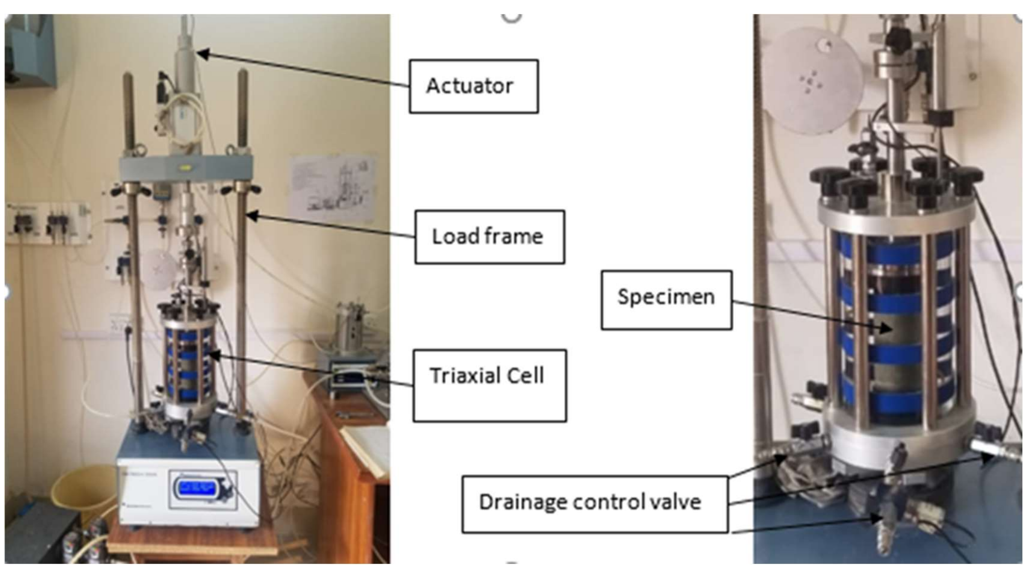


Figure 4: Triaxial apparatus used

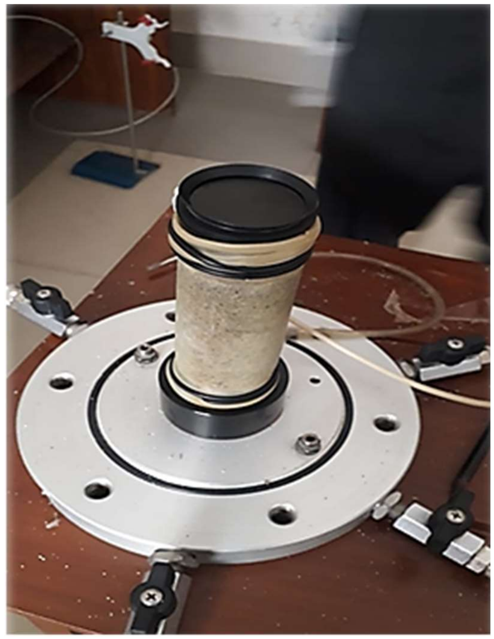


Figure 5: Prepared sample

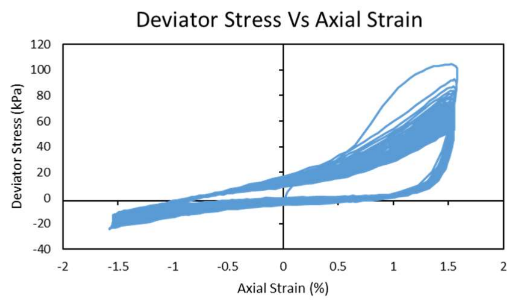
Table 2: Experimental parameters

Sand Specimen type	Relative density (%)	Confining pressure (kPa)	Frequency (Hz)	Shear strain (%) single amplitude
Pure Sand	60	50	1	0.02, 0.1, 0.15, 0.3, 0.45, 0.65, 1, 1.5, 3
		100		0.02, 0.1, 0.15, 0.45, 0.6, 0.75, 1, 1.5
		150		0.02, 0.065, 0.115, 0.3, 0.45, 0.6, 1, 1.5, 3
Fiber reinforced sand		50		0.02, 0.1, 0.15, 0.3, 0.45, 0.65, 1, 1.5, 3
		100		0.045, 0.08, 0.15, 0.35, 0.45, 0.6, 0.75, 1.5, 3
		150		0.045, 0.08, 0.15, 0.3, 0.45, 0.6, 0.75, 1.5, 3
Sand reinforced with fibers and cement		50		0.02, 0.1, 0.15, 0.3, 0.45, 0.65, 1, 1.5, 3
		100		0.045, 0.08, 0.15, 0.35, 0.45, 0.6, 0.75, 1.5, 3
		150		0.045, 0.08, 0.15, 0.3, 0.45, 0.6, 0.75, 1.5, 3

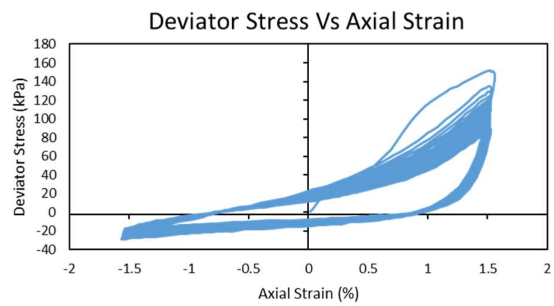
IV. Results and Discussion

Strain controlled cyclic triaxial tests were conducted on consolidated samples. Each Specimen was subjected to 40 cycles of sinusoidal strain controlled loading. The response obtained is shown in the following figures. Asymmetric loops were obtained due to high strain value. The soil sample were prepared at 60 % relative density with the application of 100 kPa confining pressure. The hysteresis loops in Fig. 6 shows that to reach 1.5% axial strain level, the maximum deviator stress of 93.28 kPa is required for pure sand. The value of maximum deviator stress increases to 150.8 kPa, when 1 % fibers were added to the soil sample. With addition of 1% fibers and 2% cement to the pure sand specimen, the maximum deviator stress reaches to 267.9 kPa. The hysteresis loops show the stress degradation behavior of pure sand, fiber reinforced sand, and fiber reinforced cemented sand samples. The stress degradation decreases with the addition of various additives in pure sand sample. It can be seen that (see Fig. 6) the value of stress degradation decreased from 45% to 40% and 25% for pure sand, fiber reinforced sand, and fiber reinforced cemented sand specimens respectively. The stress degradation is calculated from the deviator stress value in the 1st loading cycle compared to the ith loading cycle (i.e., 40 cycles). Also, the effect of different strain amplitude and confining pressures are presented in Fig.7 and Fig. 8 respectively. The results are typical plots of specimen subjected to 1.5% axial strain of single amplitude applied at 1 Hz frequency (see Fig. 9).

The results of the triaxial tests show that the generation of pore water pressure decreases with the addition of fibers and cement additives. The value of pore water pressure for pure sand is higher at the start among the three samples with a greater slope. The maximum value of pore water pressure reached almost to 80 kPa in case of pure sand specimen. For fiber reinforced specimen, the pore water pressure reached to 68 kPa. The results show that with addition of 1% fibers, the pore water pressure is reduced by 15%, compared to pure sand specimen. With addition of both fiber and cement additives, the pore water pressure increased slowly, having the least value of 62 kPa. The results show that with addition of 1% fibers + 2% cement, the pore water pressure is reduced by an approximate 22%, compared to pure sand specimen. The decrease in pore water pressure generation due to fiber and cement additives can be attributed to increase in apparent cohesion (e.g., cementation), interlocking mechanism between sand and fiber (see Fig. 10)



(a)



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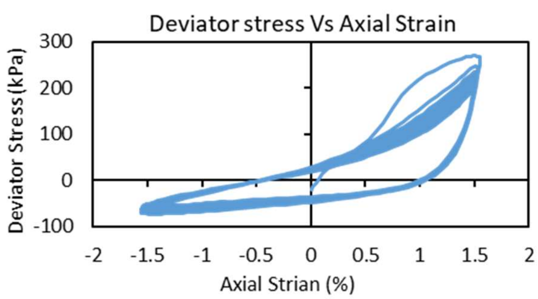

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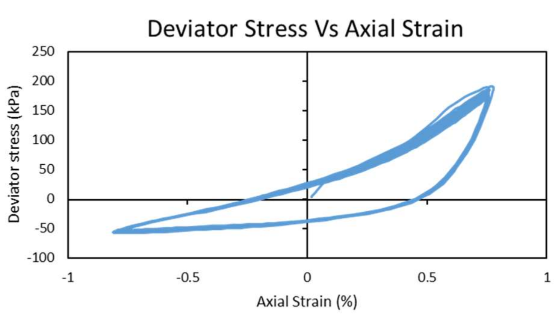
Figure 6: Hysteresis loops at 100 kPa (a) Pure sand b) Sand with 1% Fiber (c) Sand with 1% Fibers and 2% cements



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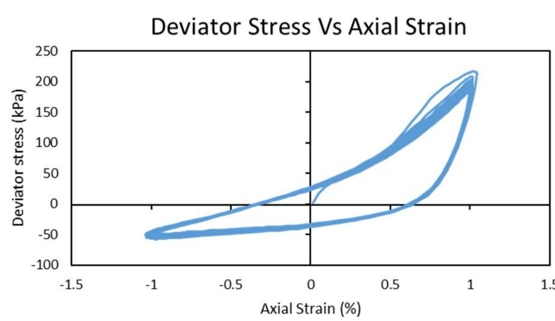

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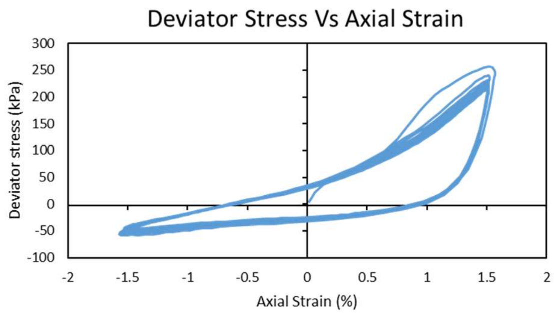

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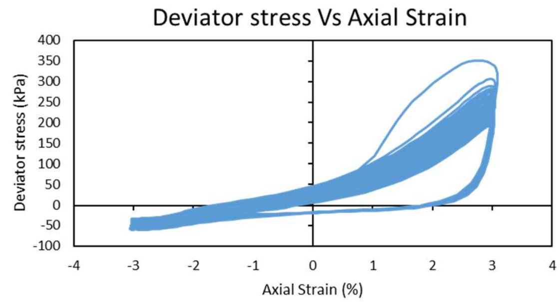
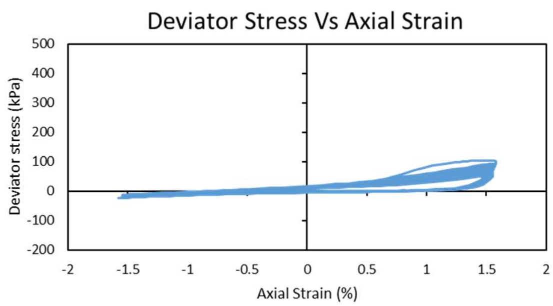
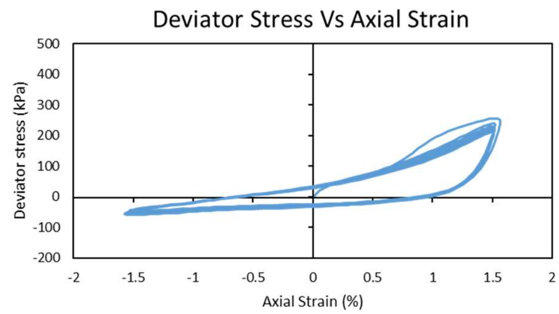


(d)

Figure 7: Strain amplitude variation for pure sand specimen at 100 kPa (a) 0.65 % (b) 1 % (c) 1.5 % (d) 3 %



(a)



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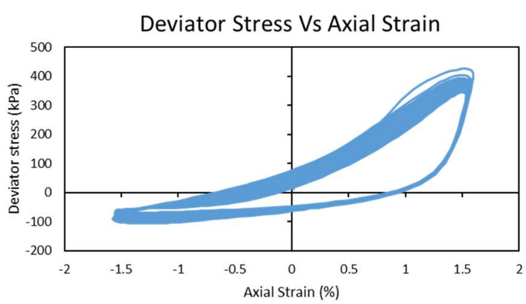

(c)

Figure 8: Effect of confining pressure variation for pure (a) 50 kPa (b) 100 kPa (c) 150 kPa

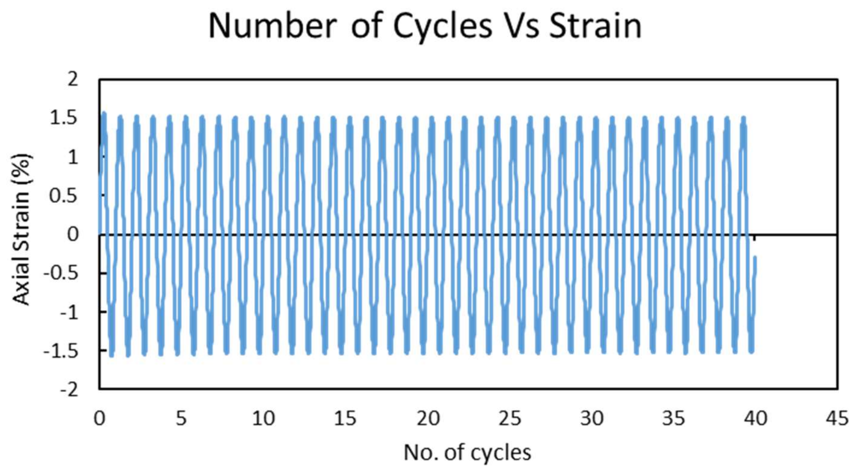

Figure 9: Axial Strain vs Number of cycles

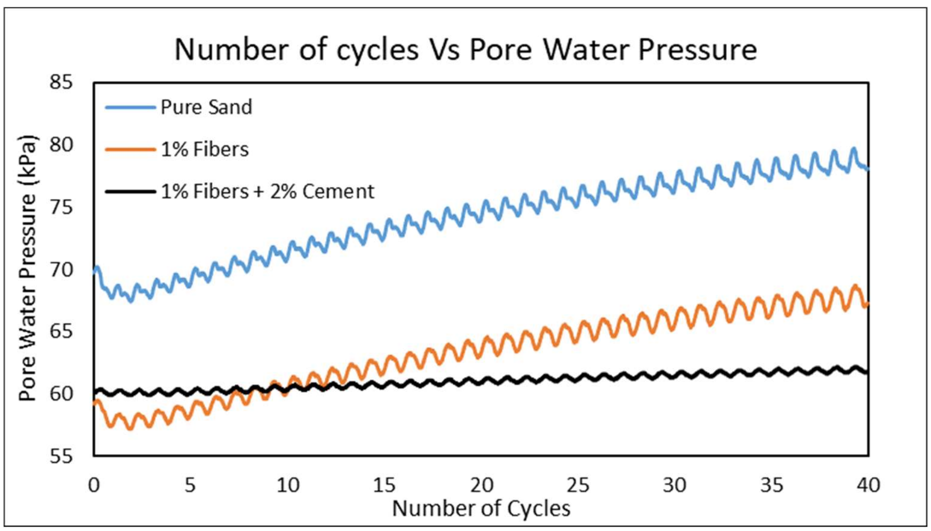

Figure 10: Comparison of Pore Water Pressure

V. Conclusion

Strain controlled cyclic tests have been conducted on medium dense sand of Mirpur to evaluate the liquefaction susceptibility. Tests with different confining pressures were conducted on sand samples, Polypropylene (PP) fibers and Ordinary Portland Cement (OPC) additives were used as liquefaction remediation measures.

It was concluded that, to produce axial strain of same level in the sample, higher value of deviator stress is needed for fiber and fiber reinforced cemented specimens. In addition, stress degradation with the increasing number of cycles decreased with the addition of fiber and cement additives.

Generation of excess pore water pressure was reduced by 15%, when 1% fibers were added to Mirpur Sand. The excess pore water pressure generation was further decreased by an approximately 25%, when 1% fibers and 2% cement additives were added to the pure sand specimen.

VI. Acknowledgements

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References

[1] A. Marto, C.S. Tan, M. Makhtar, S.N. Jusoh, 2016. *Cyclic Behavior of Johor Sand*. International Journal of GEOMATE. 10 (21), 1891-1898.

[2] J.R. Colin, 2015. *Static and Dynamic Response of Silty Toyoura Sand with PVA Fiber and Cement Additives*,'' M.S thesis. Dept. Civil Eng. Western Ontario Uni. Ontario, Canada.

[3] S.S. Kumar, A.M. Krishna, A. Dey, 2017. *Evaluation of Dynamic Properties of Sandy Soil at High Cyclic Strains*. Soil Dynamics and Earthquake Engineering. 10 (5), 157-167.

[4] V. Fioravante, D. Giretti, G. Abate, et al. 2013. *Earthquake Geotechnical Engineering Aspects of the 2012 Emilia-Romagna Earthquake (Italy)*. International Conference on Case Histories in Geotechnical Engineering. 5. https://scholarsmine.mst.edu/icchge/7icchge/session12/5

[5] Y.B. Sonmezer, 2019. Investigation of the Liquefaction Potential of Fiber-Reinforced Sand. Geomechanics and Engineering, 18 (5), 503-513.
DOI:10.12989/GAE.2019.18.5.503.

[6] A. Sami, O. Akin, 2004. *Reduction of Liquefaction Susceptibility under Existing Structures by Permeation Grouting*. Fifth International Conference on Case Histories in Geotechnical Engineering. 13-17.

[7] https://earthquake.usgs.gov/earthquakes/eventpage/us60005mqp/executive

[8] D.H. Hsiao, V.T. Phan, 2016. *Evaluation of static and dynamic properties of sand–fines mixtures through the state and equivalent state parameters*. Soil Dynamics and Earthquake Engineering. 84, 134–44.

[9] B. Yuxia, L. Jin, S. Zezhuo, B. Fan, Q. Changqing, Q. Wei, 2019. *Effects of Polypropylene Fiber on the Liquefaction Resistance of Saturated Sand in Ring Shear Tests*. Applied Sciences. 9 (19), 1-17.

[10] S.S. Kutanaei, A.J. Choobbasti, 2016. *Triaxial behavior of fiber-reinforced cemented sand*. Journal of Adhesion Science and Technology, 30 (6), 579-593.
DOI: 10.1080/01694243.2015.1110073

[11] J. Zhang, Z. Yang, Q. Yang, G. Yang, G. Li, J. Liu, 2021. *Liquefaction behavior of fiber-reinforced sand based on cyclic triaxial tests*. Geosynthetics International, 0 (0), 1-11.

[12] P.F. Amini, R. Noorzad, 2018. *Energy-based evaluation of liquefaction of fiber-reinforced sand using cyclic triaxial testing*. Soil Dyn. Earthq. Eng., 104, 45-53. https://doi.org/10.1016/j.soildyn.2017.09.026.

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