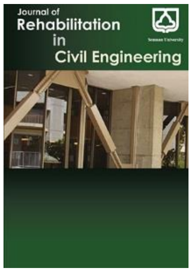
Journal of Rehabilitation in Civil Engineering 11-3 (2023) 107-121



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Evaluation of Dynamic Properties of Fiber Reinforced Sandy Soil at High Cyclic Strains

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ARTICLE INFO

Article history:
Received: 09 January 2022
Revised: 01 October 2022
Accepted: 06 December 2022

Keywords:
Polypropylene fiber;
Cyclic triaxial;
Reinforced sand;
Shear modulus;
Damping ratio.

ABSTRACT

In the recent development of synthetic and natural fiber in the industry of cement materials, polypropylene fiber become cheap and globally available. Due to its high mixability with soil and high tensile strength, it has been used for strengthening the soil. In the current investigation, cyclic triaxial experiments were performed to examine the dynamic response of fiber reinforcement in a poorly graded sand subjected to cyclic loading. Fiber reinforced sand (FR) mixtures are prepared by short polypropylene fiber of 6 mm length with different percentages of fibers (0.25%, 0.5%, and 1.0%) and compared with unreinforced sand (UR) All the samples were tested at confining pressure of 50 kPa. All samples were tested at three different axial strains 0.075%, 0.5%, and 1.125%, respectively under no drainage condition. Maximum shear modulus is found at 18.16 MPa for sand with 0.5% fiber and the damping ratio found decreased with increasing fiber content and reduced to 15% for sand with 1.0% fiber content. Also, the effect of shear strain and repetitive loading cycle on damping and shear modulus behavior is presented in this study.

1. Introduction

Different types of fibers have been used in soils and construction materials from early ages. fibers can improve many engineering properties such as flexural strength, toughness, thermal resistance, impact resistance, and fatigue strength [1-2]. Dalvand et.al.[3] shows that the inclusion of steel fiber and poly polypropylene fibers can

How to cite this article:
Kundu, P., Padmanabhan, G., & Gupta, N. (2023). Evaluation of Dynamic Properties of Fiber Reinforced Sandy Soil at High Cyclic Strains. Journal of Rehabilitation in Civil Engineering, 11(3), 107-121.
https://doi.org/10.22075/JRCE.2022.25782.1593

increase tensile strength, flexural strength, and impact strength of cementitious composites. Fiber reinforcement is an innovative technique and gained much importance in improving the performance of problematic soil deposits over the last decades. Initial time researchers focused on improving the shear strength of sand with the inclusion of natural and synthetic fibers [4-6]. On the other side, researchers [7-9] have investigated the effect of fiber reinforcement on sands in improving the resistance against dynamic events such as liquefaction and landslides. Major research was focused on understanding the static and dynamic soil properties of soils treated with fibers [10-13]. However, dynamic soil properties of fiber-reinforced sand were not completely understood, due to the advent of new innovative and sustainable fiber products.

Gray et al. [14] and Gray and Al-Refeai [15] performed series of direct shear and triaxial experiments on dry reinforced sand treated with natural and synthetic fiber. It is concluded that sand shear strength is proportional to concentration of the experimented fiber, whereas fiber length has less influence in improving the shear strength. Consoli et al. [16] shows that randomly distributed polypropylene fiber undergoes large plastic deformation before failure and subjected to tension even under isotropic compressive loading. Maher and Member [17] carried out torsional shear and resonant column tests to understand the performance and dynamic response of fiber reinforced sand. Authors found that dynamic modulus increased with increasing fiber content up to a limiting weight fraction, however, at higher confining stress fiber has very less contribution at damping and shear modulus. Heineck et al. [18] were the first to investigate the effect of fiber reinforcement on sands at large strains, this preliminary investigation found the post peak-strength deterioration. However, the study was further extended and discussed using ring shear experiments by Consoli et al. [16] and concluded that strength reduction was minimum, even after attaining very large displacements. Li et al. [20] studied the small-strain shear modulus of fiber-reinforced sand samples with different particle shapes and gradation characteristics through resonant column apparatus. The authors proposed empirical expression and found good validation to estimate the dynamic shear modulus Gmax, fiber inclusions resulted in decreased dynamic shear modulus of sands. A series of triaxial compressive tests were performed by Khebizi et al. [21] on fiber treated and untreated sand with different fiber content, sand density and confining pressure. These factors correspond to increased shear strength and dilation of sand particles; however, it is found to increase with an increase in the above-mentioned parameters.

Major research works were focused on assessing the dynamic soil properties of fiber-reinforced sand at large strain levels. Whereas, limited experimental studies were carried out to investigate the influence of polypropylene fiber in enhancing the dynamic soil properties of sand at low strain levels. This paper presents the influence of polypropylene fiber-reinforced sand on dynamic soil properties for improving the resistance against seismic events. A series of strain-controlled cyclic triaxial test results of unreinforced and polypropylene fiber reinforced sand at three different proportions (0.25%, 0.5%, and 1.0%) and three levels of strain amplitude (0.075%, 0.5%, and 1.125%).

2. Materials and Testing Procedure

2.1 Materials

2.1.1 Sand

Sand was collected from the local market which is used for building construction. Preliminary tests like particle size analysis, specific gravity, and maximum and minimum void ratio tests were carried out as per relevant Indian standards to classify the soil and determine its physical characteristics. The grain size distribution curve of the collected sand was determined as per IS 2720 (Part 4) – 1983 and shown in Fig. 1. The sand is classified as poorly graded sand (SP) as per USCS soil classification system. The index properties of the same sand are listed in Table 1.

2.1.2 Polypropylene Fiber

Short polypropylene fiber of 6 mm length as shown in Fig. 2, commercially available in market was used in this experimental study. The mechanical property of the fiber was listed in Table 2.

2.2 Experimental Procedure

2.2.1 Compaction Test

Sand after oven drying at 110°C for 24 hours, mixed homogeneously with different fiber combinations of 0.25%, 0.5% and 1.0% by total dry weight of the sand sample. The percentage of fibers is weighted accordingly to the required reinforcement content and mixed with a known quantity of water and compacted in a mold as per standard proctor compaction test guidelines specified in IS 2720 (Part 7) – 1980. The fibers are mixed thoroughly by hand and added at a small increment to achieve a uniform mixture. Special care has been taken so that there would not any bunching of fiber in the soil mixture. The number of blows required for each sample was calculated by computing the compactive energy imparted in the unit volume of sample tested in a large shear box of diameter 100 mm and height of 100 mm. The compaction was done in three layers using the Standard Proctor hammer and by imparting 25 blows per layer.

2.2.2 Cyclic Triaxial Test

All the samples for cyclic triaxial test were prepared in a mold of 50 mm diameter and 100 mm height.Schematic diagram of cyclic triaxial test setup is presented in Fig.(3) . Water corresponds to the maximum moisture content, obtained from the compaction test Fig. (4), mixed with the oven-dried soil with different fiber content of 0.25%,0.5%, and 1.0%. Further, the soil was compacted in the mold in three layers by imparting 42 blows per layer. All the samples were tested at a constant effective confining pressure of 50 kPa. Each sample was tested for three different axial strains 0.075%, 0.5%, and 1.125%, respectively. All the experiments were performed with an applied 10 cycles of sinusoidal loading with a dynamic frequency of 1 Hz. The undrained condition was maintained throughout the experiments.

3. Results and Discussions

3.1 Compaction Test

The optimum moisture content (OMC) and maximum dry density (MDD) were obtained from the standard proctor compaction test IS 2720 (Part 7) – 1980. Experiments were carried out for untreated and treated sand with varying percentages of fiber content (0.25%, 0.5%, and 1.0%). The results were presented in Fig. 4 and also listed in Table 3. From the experiments, it is observed that the maximum dry density of the soil will decrease if fiber content is used more than 0.25%. Presented results found a similar trend as shown by Al-Refeai and Al-Suhaibani [22].

3.2 Shear Modulus

A typical hysteresis loop for first six loading cycles was obtained from cyclic triaxial test for 0.25% fiber reinforced sand at 0.5% axial strain is shown in Fig. 5. It showed that maximum stiffness degradation takes place in the initial six cycles. The variation of shear modulus (G) with different loading cycles is shown in Fig. 7. It can be seen from Fig. 7, that modulus degradation is observed up to the sixth cycle after that it remains constant, and a similar trend has been found by Sadeghi and Beigi (2014) for clayey sand deposits. It can be also observed from Fig. 6, that among all the mixtures, sand with 0.5% fiber attains the maximum shear modulus i.e.,18.16 MPa is higher than the shear modulus obtained from sand with 1.0% fiber (i.e.,15.86MPa) under the effective confining stress of 50 kPa, as reported by Bozyigit et al. [24], the dynamic shear modulus decreases by using fiber content beyond 0.25% when 12 mm fiber is used on clayey soil. There is no increase in shear modulus if the fiber content increase beyond 0.5% and also a decreasing trend has been observed when sand with 1.0% fiber content has been used.

3.3 Damping Ratio

From Fig. 6, it can be seen that as the number of cycles increases, the area under the hysteresis loop is decreased, which may influence by the increase in excess pore water pressure. Therefore, the damping is decreased with increasing cycles. There is less influence of fiber content on the damping ratio for smaller shear strain Fig. 8. Damping ratio of untreated sand is comparatively higher than treated sand for all the sand mixtures as shown in Fig. 8. Damping in sand is predominantly controlled by the intergranular friction, as it found reduced with increase in fiber content. The reason is sand exhibit a higher coefficient of friction than polypropylene fiber. Also, from Fig.8, it can be seen that the maximum damping observed in untreated sand is 24% as compared to the minimum of 15% for sand with 1.0% fiber mix at 1.125% axial strain. Similar results were presented by Bozyigit et al. [24] for a fiber length of 12 mm used in clayey soil.

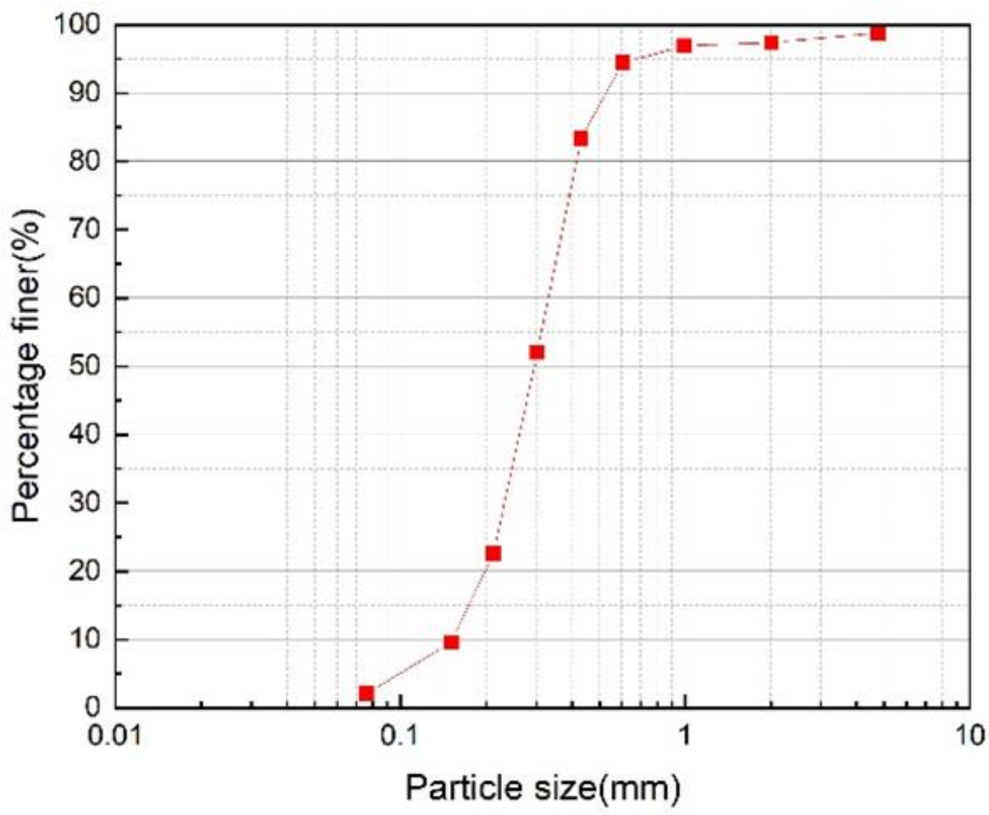


Fig 1. Grain size distribution of locally available sand.

Fig 2. Polypropylene fiber (6 mm).

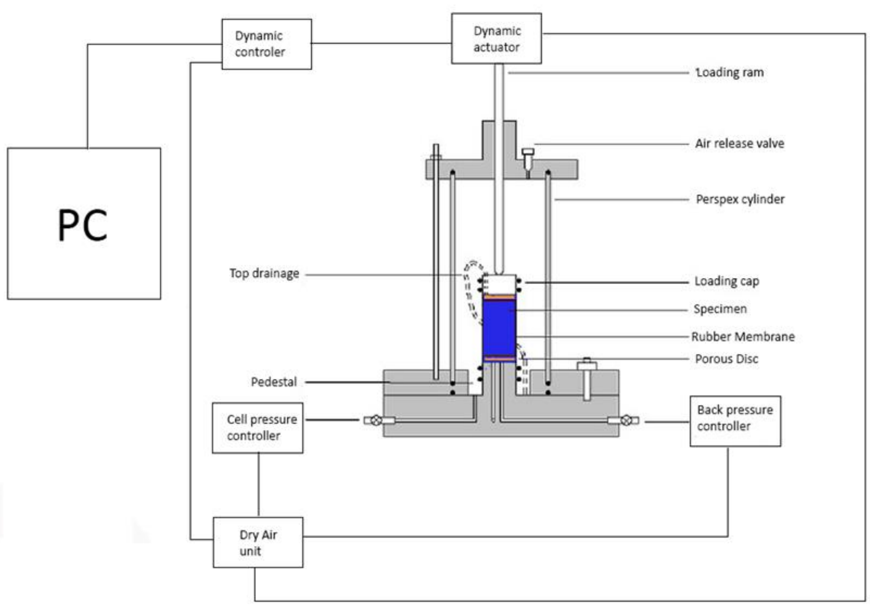


Fig 3. Schematic diagram of cyclic triaxial test setup.

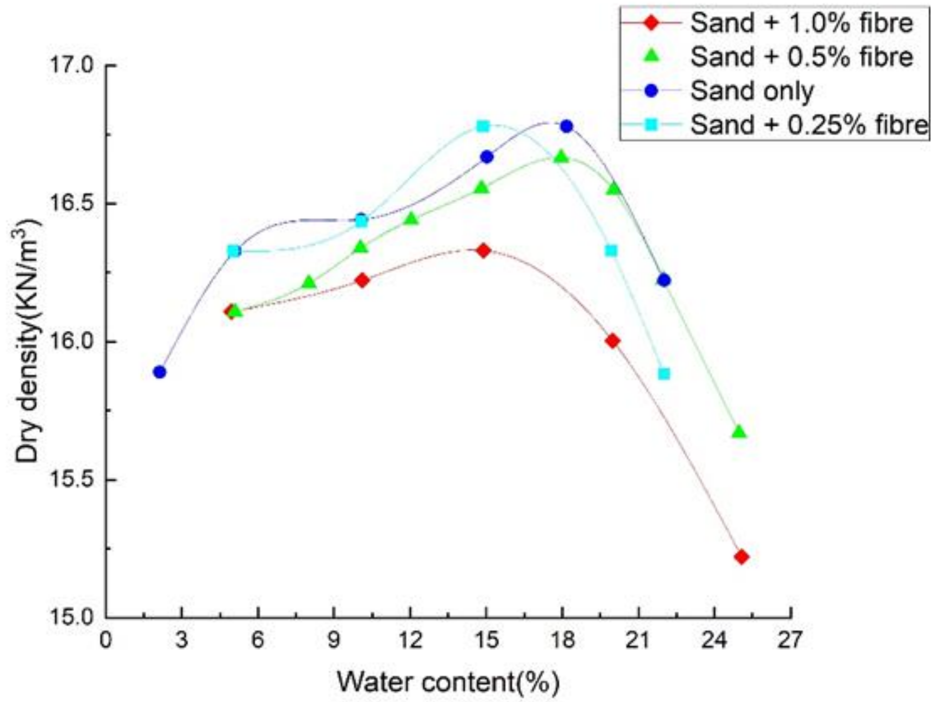


Fig 4. Relation between dry density and water content of fiber reinforced soil samples.

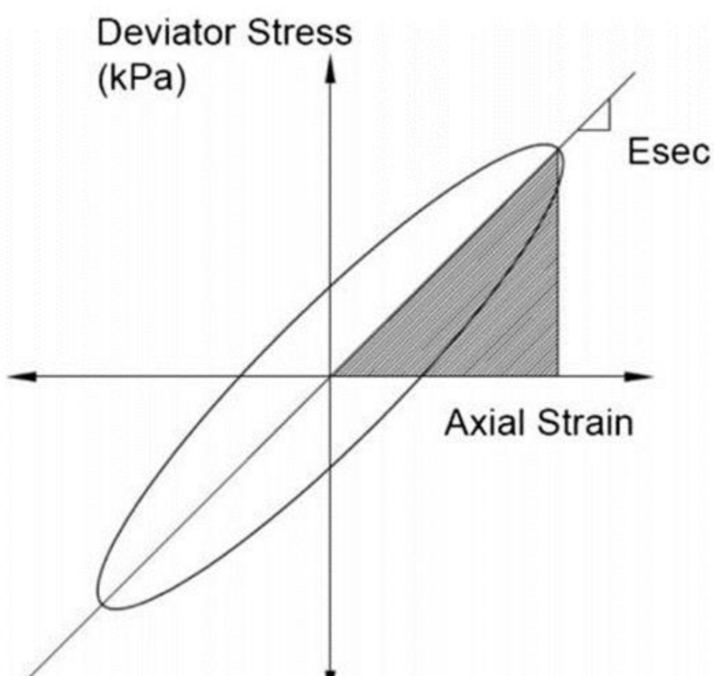


Fig 5. Typical hysteresis loop.

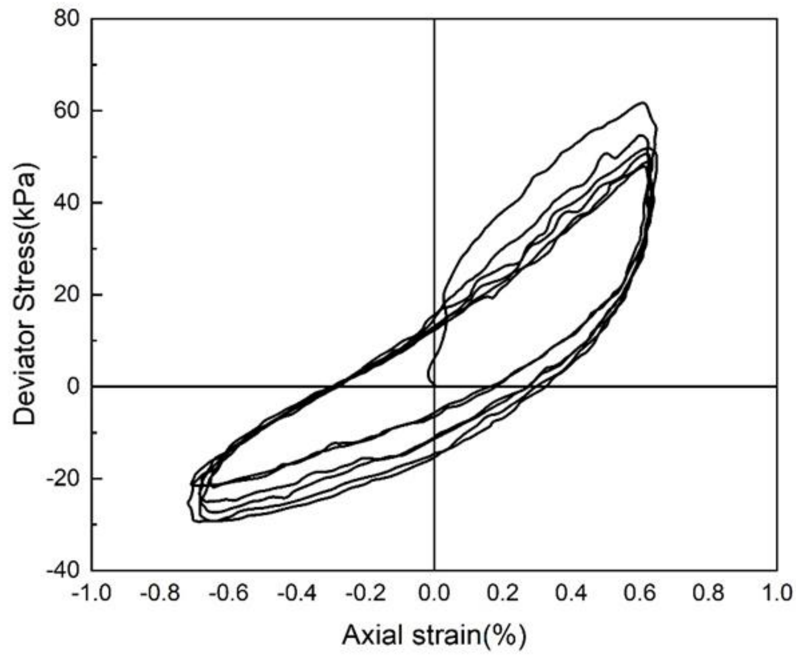
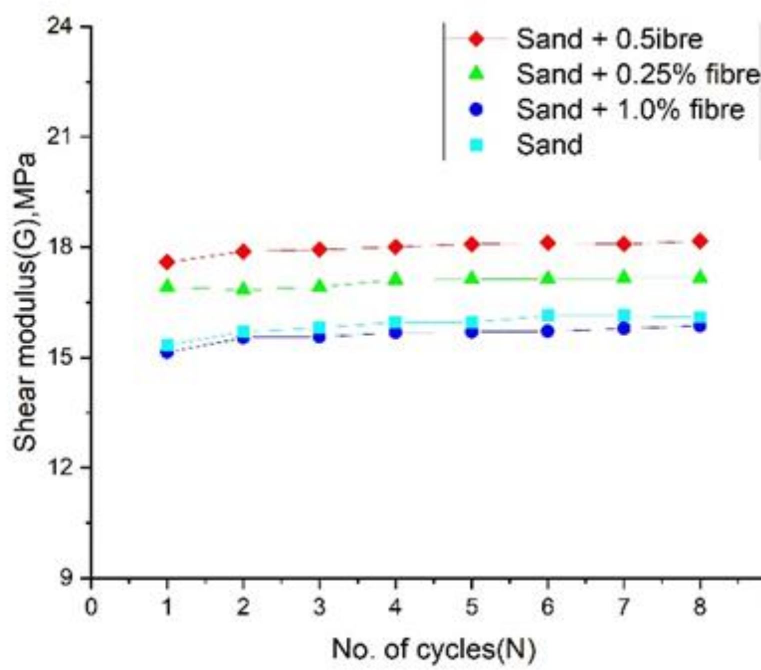
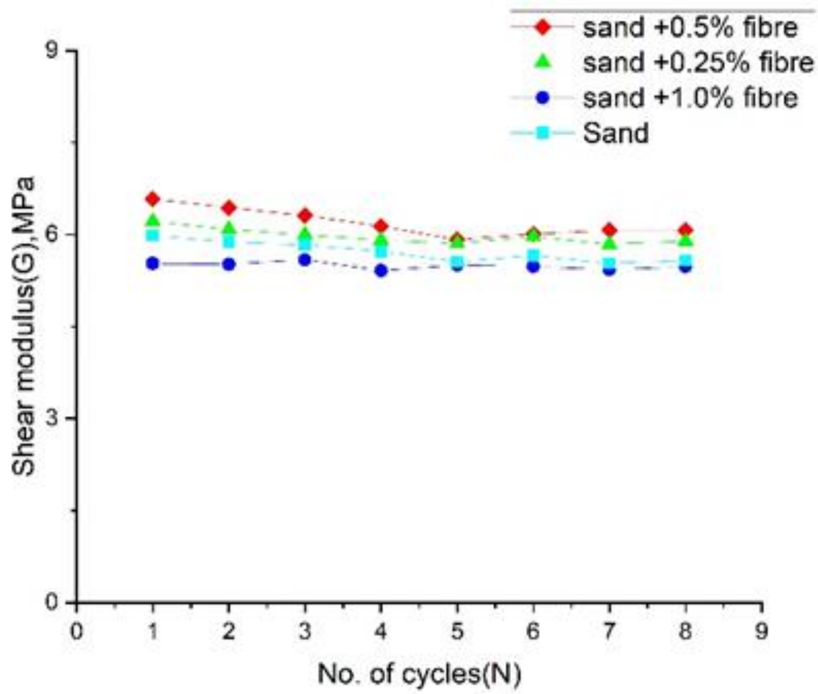


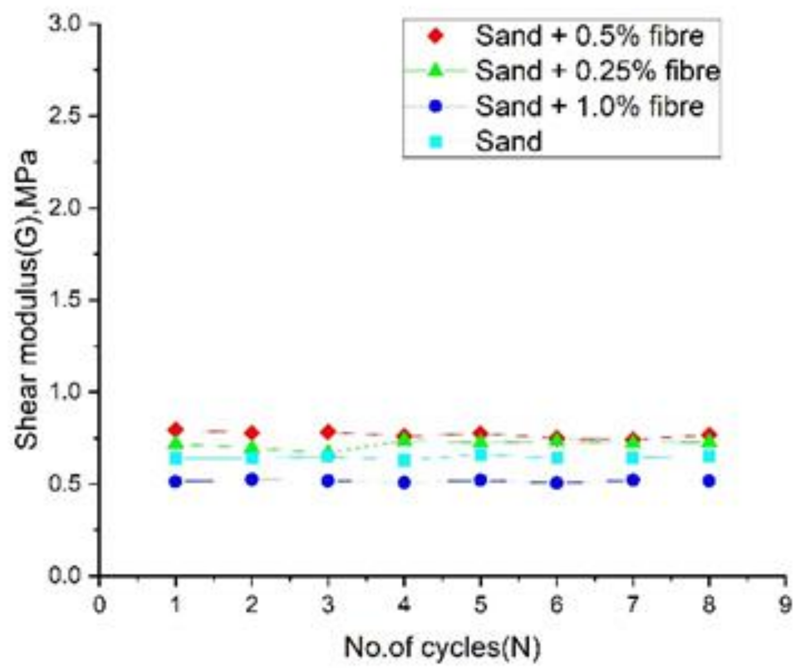
Fig 6. Stress-strain loops for 6 loading cycles for sand with 0.25% fiber with MDD =16.7KN/m3 and OMC=15%.



(i)

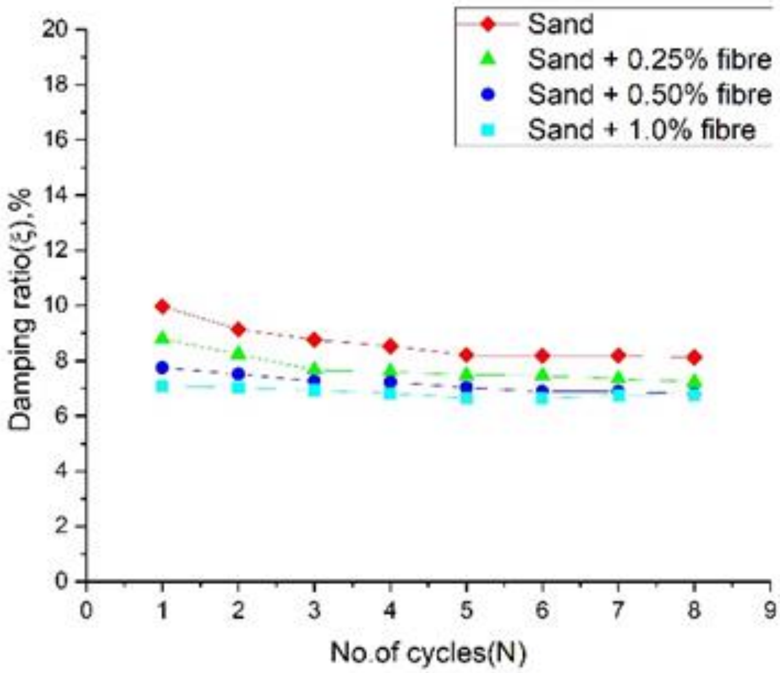


(ii)

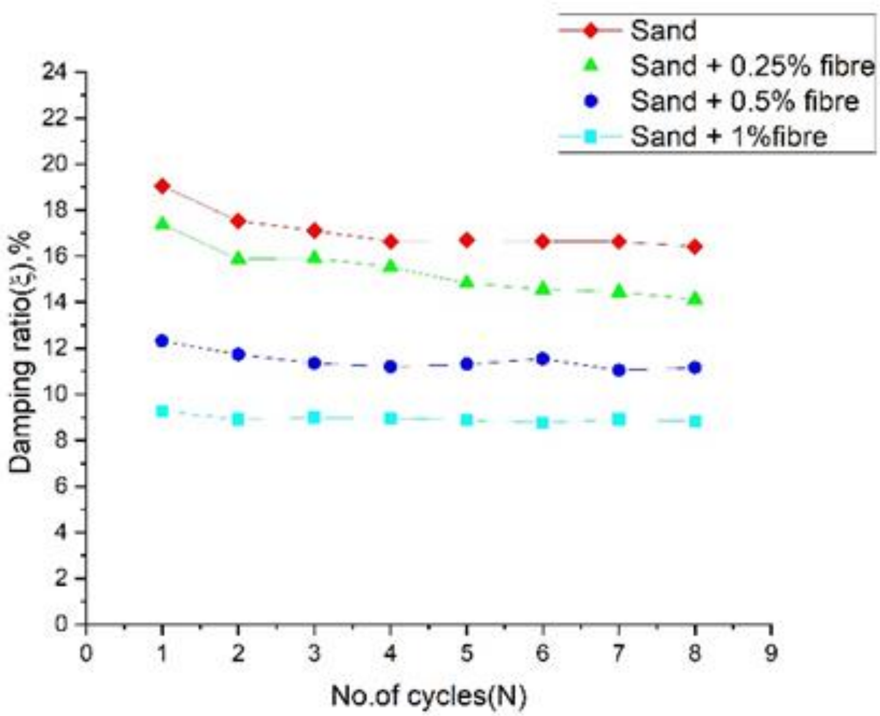


(iii)

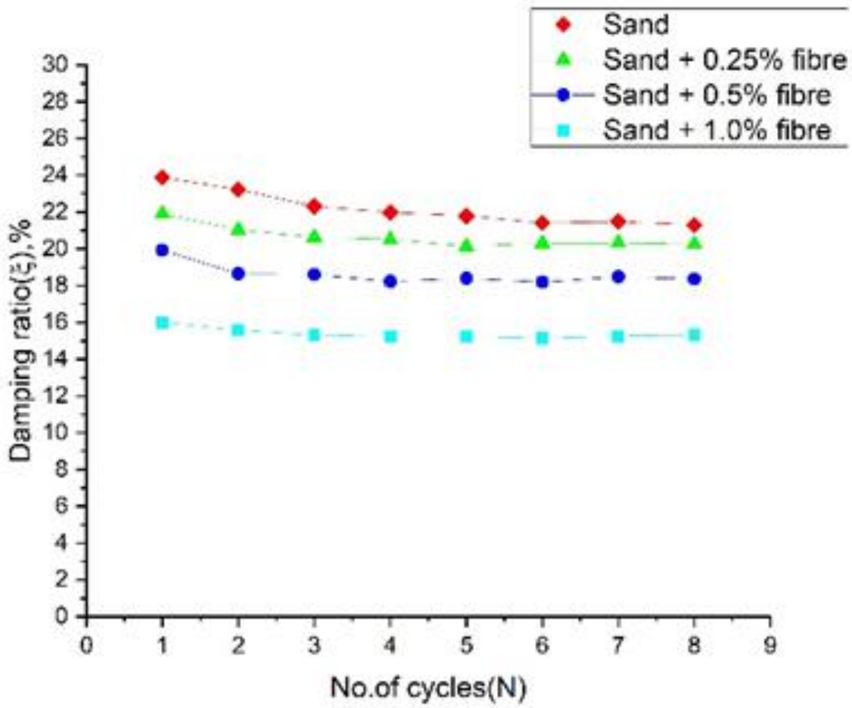
Fig 7. Variation of shear modulus with number of loading cycles for different percentage of fiber at shear strain (i)0.075%(ii)0.5% and (iii)1.125%.


Sand
Sand + 0.25% fibre
Sand + 0.50% fibre
Sand + 1.0% fibre
Damping ratio(ξ),%
No.of cycles(N)

(i)


Sand
Sand + 0.25% fibre
Sand + 0.5% fibre
Sand + 1%fibre
Damping ratio(ξ),%
No.of cycles(N)

(ii)



(iii)

Fig 8. Variation of damping ratio with number of loading cycles for different percentage of fiber at shear strain (i)0.075%(ii)0.5% and (iii)1.125%.

Table 1. Properties of sand.

Properties		Value
Specific Gravity (G_s)		2.65
Uniformity Co-efficient (C_u)		2.2
Co-efficient of Curvature (C_c)		0.98
Grain Size (mm)	D10	0.15
	D30	0.21
	D50	0.30
	D60	0.33
Maximum Void Ratio (e_{max})		0.84
Minimum Void Ratio (e_{min})		0.55
Unified Soil Classification		SP

Table 2. Properties of polypropylene fiber.

Properties	Description
Appearance	Short-cut staple fiber
Colour	Raw-white, white
Relative density (KN/m^3)	8.92
Length (mm)	6
Tensile strength (N/mm^2)	400-500
Elastic modulus, (N/mm^2)	4000
Specific surface area, (m^2/g)	0.2-0.3

Table 3. Optimum moisture content (OMC) and max. dry density (MDD) of fiber reinforced soil samples.

Sample	OMC (%)	MDD (KN/m^3)
Sand only	18	16.7
Sand+0.25% fiber	15	16.8
Sand+0.5% fiber	18	16.6
Sand+1.0% fiber	15	16.3

4. Conclusions

Based on the results of cyclic triaxial test conducted on the unreinforced and polypropylene fiber-treated sand, the following conclusion was reported,

1. The smaller size of polypropylene fiber (6 mm) is chosen to obtain a homogeneous mixture and less scope of segregation, also smaller particle means there will be less influence of size effect in the triaxial test.
2. Maximum dry density of soil will decrease as we increase the fiber content of the sand mixture, this behavior can be attributed to the reduction of unit weight of solids in the sand-fiber matrix.
3. Shear modulus (G) increased and damping ratio (D) decreased with increasing shear strain 0.50% fiber content was optimum to get maximum shear modulus. Beyond that shear modulus decreased which could be due to reduction in inter-particle bonding as

less sand will available in the sand-fiber mix at higher fiber content.

4. Damping ratio (D) decreased with increasing fiber content. The reason for this could be lower coefficient of friction of polypropylene fiber than sand alone. so unreinforced sand shows higher damping.
5. There is not much influence of loading cycle on the shear modulus and damping ratio. Both these parameter changes up to the 6th cycle then it almost stabilized. Also, the effect of fiber content highly influences the shear modulus at low strain and the damping ratio at high strain.
6. This study can used as a preliminary study of the dynamic response of short polypropylene reinforced poorly graded sand.

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