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Dynamic Behavior of a Clayey Sand Reinforced with Polypropylene Fiber

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It is a well-identified fact that more elaborate laboratory studies should be carried out for evaluation of dynamic properties of different types of soils. Regardless of the mechanisms affecting the mechanical behaviour of the soils, past studies reveal that existence of fiber positively affects the strength of either cohesive or non-cohesive soils. A short literature survey provides numerous studies on the stress-strain behaviour of fine/coarse soils, reinforced by polypropylene fiber. On the other hand, studies concerning fiber reinforced soils subjected to dynamic loading are relatively rare. Therefore, in this research it was intended to investigate the effects of polypropylene fiber inclusion on the dynamic behavior of a clayey sand soil, within an experimental framework. In this scope, a number of cyclic triaxial compression tests were conducted to assess the effect of fiber presence. The effects of fiber length and content were experimentally evaluated. Hence, the variation of shear modulus ratio and damping ratio values by shear deformation was plotted to observe the effects of fiber length and inclusion level as well. The results are presented along with detailed evaluations.

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1. Introduction

When foundation soils with poor engineering properties are encountered, before construction, improvement of soils is a possible and plausible approach. Hence, many types of ground improvement methods were investigated in literature [1–3].

Particularly, in recent years, many types of geosynthetics were used for providing improvements in engineering properties of soils. Polypropylene fiber, which is a kind of geosynthetics, is also used for reinforcement. It increases shear and tensile strength of soil, while positively influencing the stress-strain behavior. Besides, past studies reveal that, studies in various disciplines utilize numerous kinds of fibers in different application areas [4–7]. Recent studies also reveal that, soil strength and axial deformation is increased by fiber inclusion, resulting in a more ductile behavior [8–10].

It was underlined that the rate of strength increase is influenced by fiber content, fiber type and aspect ratio of the fiber used [11]. While fiber can be used to improve the engineering properties of soils, its use along with binding chemicals is another concern in geotechnical engineering. These binding agents, such as cement, increase the strength and brittleness of the soil in hand, however, their contribution to tensile strength is inconsiderable.

In case the stabilized soils are subjected to earthquake loading, or lateral displacements occur, they should have a sufficient bending strength [12]. Inclusion of fiber in the soil generally causes an increase the tensile strength of soils [13].

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Fiber existence in the soil can also affect crack propagation pattern. Nahlawi and Kodikara [14] underlined that formation of possible cracks in the soils is significantly affected by fiber inclusion. Hamidi and Hooresfand [15] investigated the effect of cement-polypropylene fiber treatment on sand specimens by triaxial tests. In their study, cement content and curing period were 3% and 7 days, respectively. The fiber inclusion levels were at 0.5 and 1%, by percentage of total weight of specimen. The specimens were tested under confining pressures of 100, 300 and 500 kPa. The results show that fiber inclusion had caused an increase in peak and residual shear strength, along with a more brittle tendency.

In the literature, a number of researchers focused on the changes in dynamic parameters of different types of soils by fiber inclusion. Boominathan and Hari [16] carried out a series of cyclic triaxial tests for evaluation of the dynamic strength of fiber/fly ash mixtures. Test results on specimens tested under low confining pressures revealed that, fiber inclusion has markedly increased the liquefaction resistance. These results were approved by testing different types of materials and testing procedures, under dynamic and undrained loading conditions. It was experienced that number of cycles to liquefaction was higher, with fiber inclusion [17, 18].

In addition, dynamic shear modulus is also remarkably affected by fiber inclusion level and increases with increasing fiber content. Noorzad and Amini [19] investigated the liquefaction resistance and shear modulus of loose and medium dense sands, reinforced with randomly distributed fibers. The authors selected fiber inclusion level, fiber length, relative density and confining pressure as dependent variables. Results obtained by laboratory testing revealed that fiber admixture increases the liquefaction resistance. With increasing fiber content and length, the number of cycles to liquefaction was increased. The researchers emphasized that the reinforcement was more effective in dense granular soils, compared to loose soils. Change in shear modulii of soils by fiber inclusion was investigated and it was evident that the shear modulus of soils was increased with increasing fiber inclusion level.

It is known that, either in laboratory conditions or in the field, fine grained soils undergo large amounts of strain softening based deformation, coupled with partial loss of strength. In the light of the above mentioned studies, an experimental framework was setup to investigate the effect of fiber inclusion on dynamic properties of a clayey sand. Specimens including randomly distributed fibers of varying length and content were subjected to dynamic triaxial testing to determine the stress-strain behavior under undrained conditions.

2. Materials and methods

2.1. Properties of materials

As mentioned in the preceding paragraphs, in this study, the behaviour of a fiber reinforced clayey sand under cyclic loading was investigated. Hence, the soil was treated with four different fiber contents and the lengths of fibres were selected as 6, 12 and 18 mm. The grain size distribution of soil blend was obtained in accordance with ASTM D6913-04 standards. The soil was classified as SC according to Unified Soil Classification System. Index properties and optimum moisture content of clay were determined in accordance with ASTM D4318-10 and ASTM D422 standards. Index properties of kaolin are shown in Table I.

TABLE I

Selected index and physical properties of kaolin clay.

Properties	Value	Related standard
Liquid limit, w_L [%]	56	ASTM D4318-10
Plastic limit, w_P [%]	30	ASTM D4318-10
Plasticity index, I_P [%]	26	ASTM D4318-10
Specific gravity	2.62	ASTM D854- 14
Optimum water content [%]	30	ASTM D698-07
Max. dry unit weight [kN/m^3]	13.0	ASTM D698-07

2.2. Specimen preparation method

Firstly, clay-sand blend was prepared and then blend was mixed with required amount of fiber. Dry mixture was wetted and mixed again to avoid fiber clumping. Thus, wet tamping method was opted for preparation of a specimen at a relative density of 75%. All experiments were carried out on saturated specimens having length and diameter of 100 and 50 mm at 100 kPa chamber pressure and sinusoidal cyclic loading was applied at 0.1 Hz frequency in undrained conditions.

The axial cyclic load was applied to the specimen through the piston connected to the air regulator. Dynamic triaxial test system is shown in Fig. 1. In undrained tests, axial strain less than 0.001% at single amplitude was applied for eleven cycle loading stages. Length and volume changes were measured before subsequent loading stage. This procedure was repeated in every loading stage and at least 40 loading stages were applied.

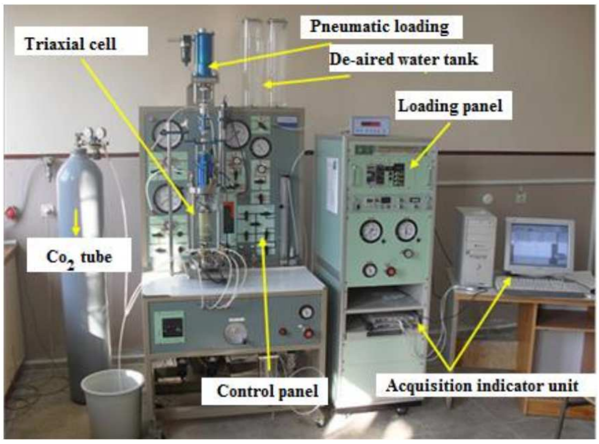

Fig. 1. The dynamic triaxial test system.

3. Test results

Cyclic triaxial tests were carried out for assessment of dynamic properties of a SC type soil. Figure 2 shows the dynamic shear modulus – shear strain relationships for specimens reinforced with 6 mm fiber, after fifth and tenth cycles. Maximum and minimum dynamic shear modulus were obtained by using fiber content of 0.25 and 2%, respectively. With increasing fiber content from 0.25 to 2%, dynamic shear modulus values were decreased by around 70%. According to the JGS 0542-2000 [20], dynamic shear modulus and strain values obtained after fifth and tenth loading cycles should be close to each other, which was confirmed by the results of present study (Fig. 2). However, as the fiber content is decreased, initial values of dynamic shear modulus are increased, and the effect of fiber content is more pronounced at lower strain levels (Fig. 2).

Analyzing the damping ratio values, it was observed that the effect of fiber content is more evident, regarding the number of cycles (Fig. 3).

When using 12 mm long fiber and fiber content of 0.25 and 0.50%, dynamic shear modulus values were in the vicinity of 80 Mpa after 5 and 10 cycles of loading. Contrary to this, when using fiber contents of 1 and 2%, dynamic shear modulus values were around 55 Mpa (Fig. 4). According to the test results, at small strains, different clusters of shear moduli were obtained for 0.25% / 0.50% and 1% / 2%. It should be mentioned that, dynamic shear modulus values obtained at fiber contents of 0.25 and 0.50% were approximately 50% higher.

Figure 5 shows shear strain – damping ratio relationships of specimens including 12 mm fiber. The results show that damping ratio was decreased by increasing fiber content from 0.25 to 1%, however, after 1%, a reverse behaviour is observed (Fig. 5).

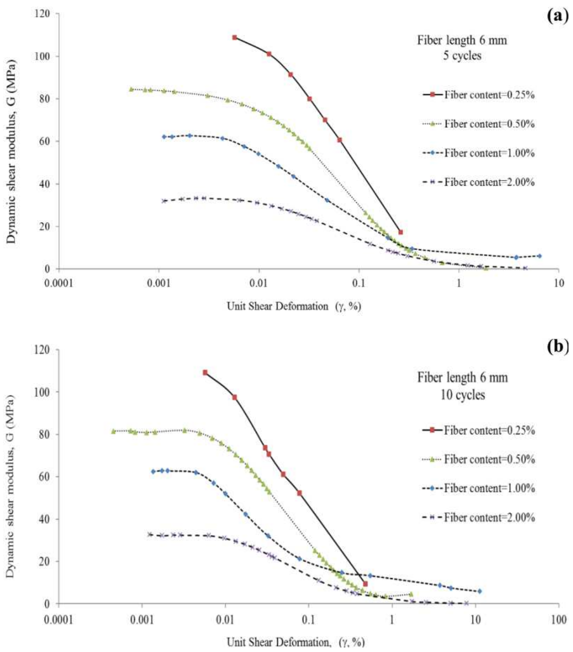

Fig. 2. Dynamic shear modulus vs strain values after (a) 5th and (b) 10th loading cycles.

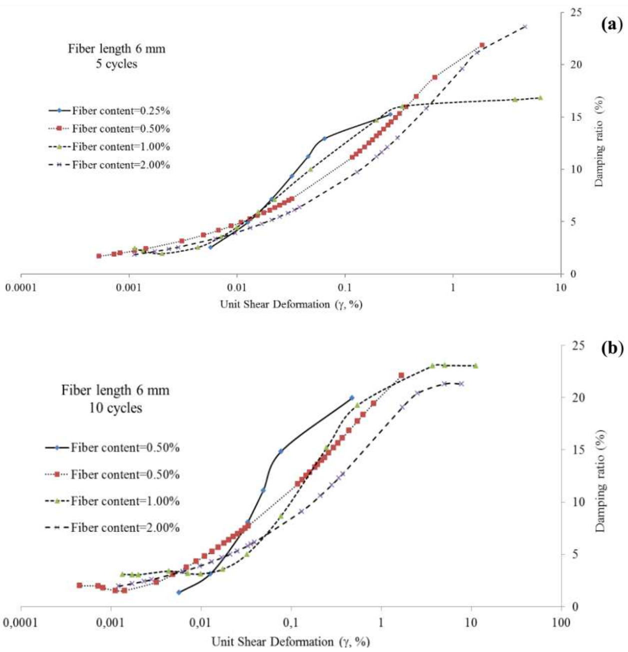

Fig. 3. Damping ratio vs strain values after (a) 5th and (b) 10th loading cycles.

In the scope of this study, the maximum fiber length was 18 mm. Dynamic shear modulus – unit axial strain and damping ratio – unit axial strain relationships obtained by testing specimens reinforced with 18 mm fiber at four different contents were given in Figs. 6 and 7, respectively. Maximum and minimum dynamic shear modulus values of 65 MPa and 30 MPa were obtained by testing specimens with fiber contents of 0.50 and 1%, respectively.

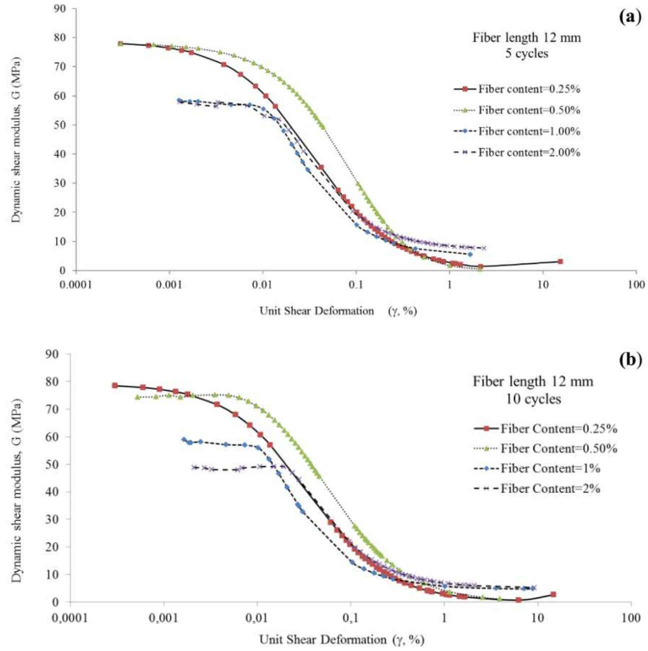

Fig. 4. Dynamic shear modulus vs strain values after (a) 5th and (b) 10th loading cycles.

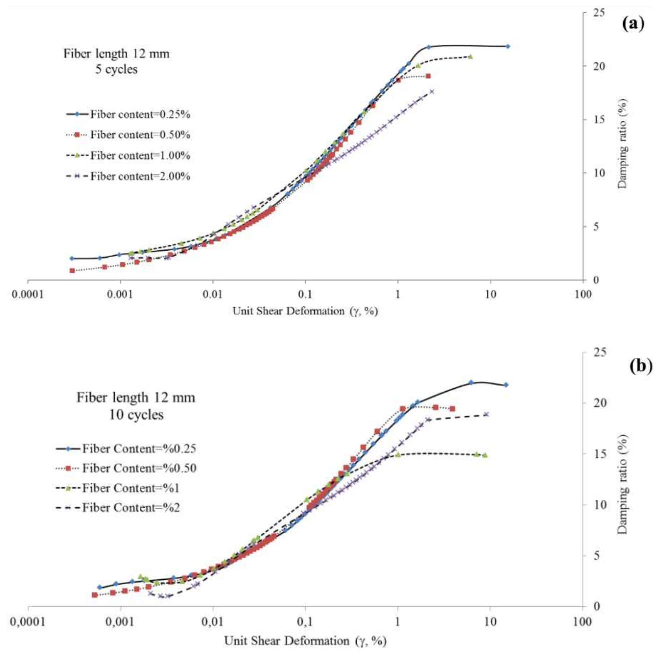

Fig. 5. Damping ratio vs strain values after (a) 5th and (b) 10th loading cycles.

Changes in damping ratios were similar after 5 and 10 cycles of loading. The values ranged from 16% to 20% (Fig. 7). While damping ratio decreases at fiber contents ranging between 0.25% to 1%, an increasing tendency is experienced beyond 1%.

Fiber length is another important parameter which also influenced the behaviour of fiber reinforced soils. For four different fiber inclusion levels, the effect of fiber length was evaluated. Specimens prepared using 6 mm

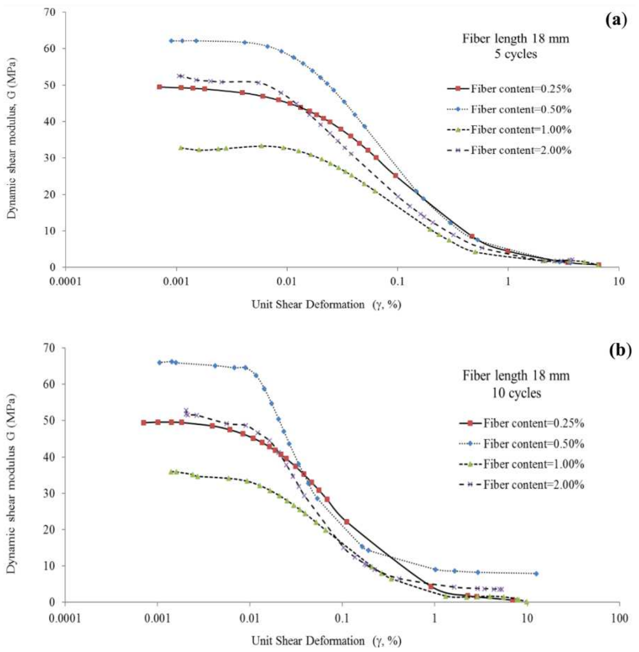

Fig. 6. Dynamic shear modulus vs strain values after (a) 5th and (b) 10th loading cycles.

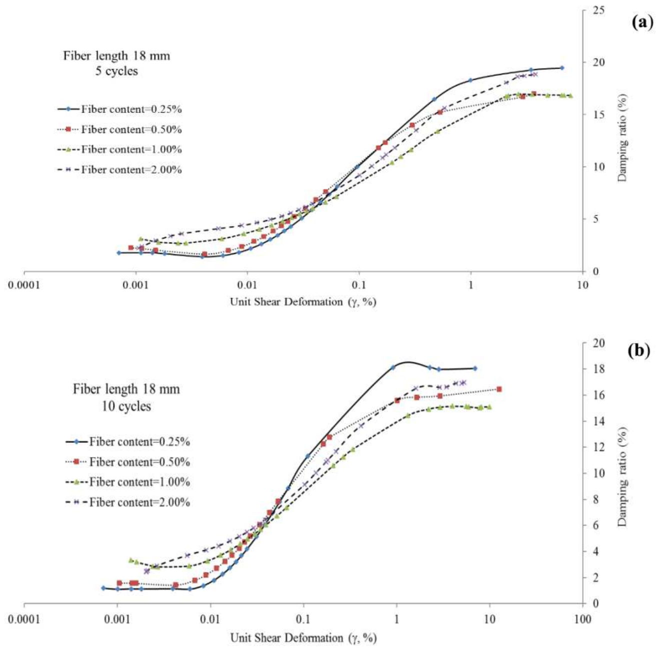

Fig. 7. Damping ratio vs strain values after (a) 5th and (b) 10th loading cycles.

fiber at 0.25% fiber content provided maximum dynamic shear modulus. On the other hand, minimum shear modulus was obtained by testing specimen reinforced with 18 mm fiber, at a fiber content of 2%. Considering the fiber length to evaluate the damping ratio values, maximum and minimum damping ratios were obtained by use of 6 mm and 18 mm long fiber, respectively.

4. Conclusions

This study presents the results of an experimental investigation into the dynamic behavior of a clayey sand reinforced with polypropylene fiber. The effects of fiber content and fiber length on the shear modulus and damping ratio was evaluated. Following are the results obtained by testing a sandy clay (SC) reinforced with polypropylene fiber:

- Four different fiber contents (0.25, 0.50, 1, 2%) and three different fiber lengths (6, 12, 18 mm) were used to investigate dynamic properties of a reinforced SC type soil.
- The effect of fiber content was evaluated by dynamic shear modulus – axial unit strain – damping ratio relationships. While increase in fiber content from 0.25 to 1%, caused an increase in dynamic shear modulus, beyond 1% fiber content, a reverse trend was experienced.
- The effect of fiber content on damping ratio was also evaluated. Experimental results show that damping ratio values ranged between 15 and 25%. Maximum and minimum damping ratio values were obtained by testing specimens reinforced using 6 mm fiber at a content of 0.25% and 18 mm fiber at a content of 2%, respectively.
- The results of this study also show that largest dynamic shear modulus values were obtained by reinforcing the soil by shorter fibers. Furthermore, damping ratio values were decreased with increasing length of fiber, similar to damping ratio values. Similar behaviour was obtained after 5 and 10 cycles of loading; largest damping ratio values were experienced by using fiber with length of 6 mm.

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