STRENGTH AND BEARING CAPACITY IMPROVEMENT OF A POORLY GRADED SAND THROUGH FIBER REINFORCEMENT

HAZIRBABA Kenan [1]

Abstract

The effects of polyolefin type fiber as a reinforcement additive on the friction angle and CBR performance of a poorly graded sand were evaluated. A systematic experimental investigation was conducted on unreinforced and reinforced samples of the soil. Direct shear tests were performed at various fiber content to quantify the improvement of the maximum and residual friction angles. Similarly, CBR performance tests were run to investigate the optimum fiber content. From both direct shear and CBR testing, the best performance of the soil was consistently obtained at 0.35% fiber content.

Keywords: Fiber reinforcement of sand, CBR performance testing, direct shear testing, soil improvement

1. Introduction

For soil stabilization and improvement purposes, fibers have been used extensively due to their low cost, light weight, and significant contribution to strength gain. The addition of fiber increases the load bearing capacity of soil; and improves the shear modulus and liquefaction resistance (Freitag, 1986; Maher and Ho, 1994). Previous investigations showed that the improvement of soil properties is a function of the type, length, content, and orientation of the fiber (Gray and Al-Refeai, 1986). Fletcher and Humphries (1991) evaluated the effect of blending discrete polypropylene fibers with MH-type silt in terms of California Bearing Ratio (CBR) values and found that the addition of fiber improved the bearing capacity of the soil by as much as 133% increase in CBR values. Grogan and Johnson (1994) investigated the use of fiber with lime modified clay, cement modified sand, and a silty sand in terms of performance under applied traffic load. Road sections with and without fiber reinforcement were constructed and subjected to truck traffic tests. The results showed that the inclusion of fiber allowed up to 90% more traffic passes until failure in the clay, 60% passes until failure in the modified sand, and some enhanced traffic performance was reported for the silty sand. Ahlrich and Tidwell (1994) attempted to stabilize a plastic clay and a uniform clean sand by the addition of monofilament and fibrillated fibers. They found that the plastic clay could not be effectively stabilized by either of the fiber types investigated while both fiber types appreciably improved the strength properties of the sand. Additionally, they concluded that the optimum

[1] HAZIRBABA Kenan, Khalifa University, PO Box 127788, Abu Dhabi, UAE, +971(2)501-8487, kenan.hazirbaba@kustar.ac.ae

performance in the sand was obtained with 5.08 mm monofilament fiber at a dosage rate of 0.5% by dry weight. Webster and Santoni (1997) reported a range of optimum dosage rates between 0.6% and 1% for fiber reinforcement of poorly graded sand. Dosages above 1% tended to create a “sponge effect” in the samples where larger deformations were required for development of the sample’s load support capabilities.

In this study, the use of fiber to improve the bearing capacity of a poorly graded sand was investigated through an experimental program.

2. Experimental program

The experimental program was designed to investigate the strength and bearing capacity improvement of a poorly graded sand through fiber reinforcement. A series of direct shear and CBR tests were conducted on natural (i.e., without fiber) soil samples and soil samples with varying fiber content.

2.1 Materials

The soil used in this study is a poorly graded clean sand. Basic soil index properties of the soil are given in Table 1. The soil is classified as SP-type material according to the Unified Soil Classification System. The particle size distribution is shown in Fig.1.

The fiber used is polyolefin type fiber. This type was chosen because of its availability, resistance to ultraviolet degradation, chemical stability, and reasonably high strength characteristics. The index properties of the fiber used are listed in Table 2. The dosage rates investigated were: 0% (i.e., natural soil without reinforcement), 0.1%, 0.2%, 0.35%, 0.5%, and 1% by dry weight of the soil sample. The dosage in this study was limited to 1% due to the greater costs of fiber at higher dosages.

2.2 Sample preparation

A review of the available literature about the testing of laboratory samples of fiber-stabilized soils indicates that test results are highly dependent on sample preparation. The two critical factors affecting sample preparation are moisture control and mixing procedures (Tingle et al., 1999). In this study, for direct shear testing samples were constituted by thoroughly mixing dry soil with the fiber at predetermined amounts. For CBR testing, however, the samples were prepared at the optimum moisture content of 6%. In this case, dry soil and water were mixed in a plastic container manually. To ensure a uniform distribution of the moisture throughout the sample, soil-liquid mixtures were stored in the sealed container for about 18 hours prior to compaction. It is important to introduce fibers to the mixture at the final step. Tingle et al. (1999) reported that adding water after fibers may cause the fibers to stick together during mixing. Thus, fibers at the desired amounts were added just before compaction. Extreme care was taken during the mixing process to ensure a uniform mixture.

Tab.1: Index properties of the investigated sand

Soil Index Properties	
Specific Gravity	2.64
Maximum Void Ratio	0.65
Minimum Void Ratio	0.44
D_{10} (mm)	0.10
D_{30} (mm)	0.12
D_{60} (mm)	0.14
USCS Soil Classification	SP

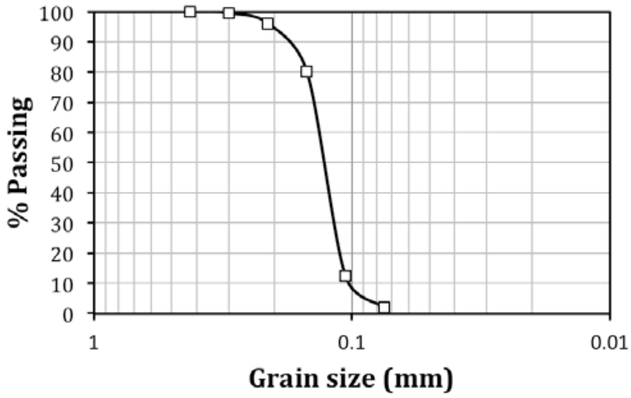

Fig. 1: Grain size distribution of the studied sand

Tab.2: Index properties of the fibers used

Material Properties	
Base resin	Polyolefin
Length	30 mm
Tensile Strength	533 MPa
Surface Texture	Continuously embossed
No. of Fibers per kg	>70,000
Young's Moudulus	7.1 GPa
Specific Gravity	0.91
Melting Point	150-165 ^{o}C
Ignition Point	Over 450 ^{o}C

2.3 Direct shear tests

Due to its simplicity and repeatability direct shear test is commonly used in geotechnical practice for determining the strength parameters of soil (i.e., cohesion and friction angle). A series of direct shear tests were conducted to quantify the strength gain of the studied sand with inclusion of fiber. Direct shear box tests were performed in general accordance with ASTM D3080M-11.

2.4 CBR tests

CBR values are commonly used in mechanistic design and as indicator of strength and bearing capacity of a subgrade soil, sub-base, and base course material for use in road and airfield pavements. The CBR of a soil is the ratio obtained by dividing the stress required to cause a standard piston to penetrate 2.54 mm, 5.08 mm, 7.62 mm, 10.16 mm, and 12.70 mm into the soil by a standard penetration stress at each depth of penetration (ASTM D 1883-07). The CBR may be thought of as an index value comparing the strength of the soil to that of crushed rock. CBR tests in this study were performed in accordance with ASTM D 1883-07. For a reliable CBR value, an average of minimum two CBR tests is recommended (Hazirbaba and Gullu, 2010). Thus, each CBR value reported in this paper is presenting the average value from two replicate samples.

3. Results and Discussion

3.1 Results of direct shear tests

For each dosage rate, four separate direct shear tests were performed. The levels of applied normal stress were 55 kPa, 110 kPa, 220 kPa, and 440 kPa. Fig. 2 presents the results of the natural soil samples without reinforcement (i.e., clean sand). Determination of the strength parameters was based on the maximum shear stress (Fig. 2a) and the residual shear stress (Fig. 2b). The maximum friction angle and residual friction angle of clean sand were found to be 38.2-degree and 35.5-degree, respectively. The results of clean sand samples were used as baseline for comparison with the results of fiber-reinforced samples. The results from all of the direct shear tests are combined and presented in Fig. 3. The variation in friction angle as a function of the fiber content shows an interesting trend. The inclusion of fiber causes the maximum friction angle to decrease up to 0.2% fiber content, as shown in Fig 3a. The trend is reversed at 0.35% fiber content indicating a relatively significant increase in the maximum friction angle; reaching up to 41.3-degree. Further addition of fiber beyond 0.35% was found to decrease the friction angle again down to a level close to or below the value of clean sand. Similar trend was observed with the residual friction angle, as displayed in Fig3b.

The percent variation in maximum and residual values of friction angle due to the fiber reinforcement is shown in Fig. 4. The zero line in this figure indicates the baseline, which is the level of unreinforced clean sand. The area above zero-line (i.e., postitive percent improvement) represents the strength gain region while the area below zero-line (i.e., negative percent improvement) denotes the strength loss region. It is clear that inclusion of fiber is beneficial only at 0.35% dosage rate in terms of both maximum and residual friction angle values. The maximum friction angle is improved by 8% whereas the improvement of residual friction angle was limited to about 4%. Another dosage rate that showed improvement was 1% fiber content; the improvement at this dosage rate occurs only in the maximum friction angle by about 2% with a slight loss in the residual friction angle. All other dosage rates (i.e., 0.1%, 0.2%, and 0.5%) exhibited detrimental effect on the maximum and residual friction angle values; a strength loss between 2 and 6% in comparison with unreinforced sand occurred due to the inclusion of fiber. Thus, based on direct shear tests, the optimum dosage rate of fiber for improvement of both the maximum and residual friction angles is defined as 0.35%

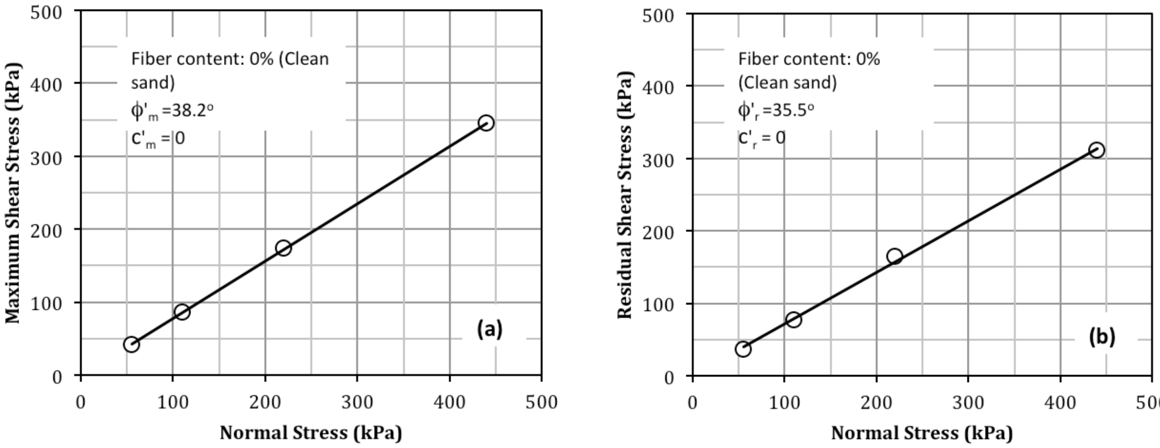

Fig. 2: Results of direct shear tests from unreinforced sand samples

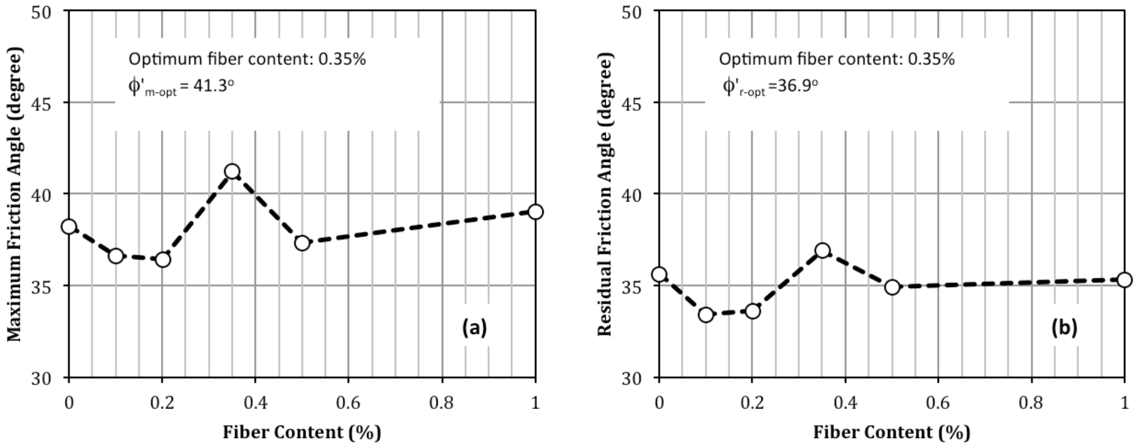

Fig. 3: Variation of maximum and residual friction angles with fiber content

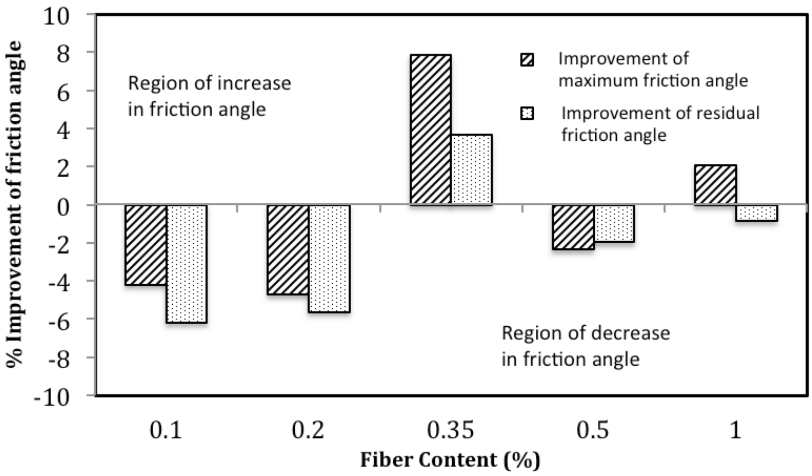

Fig. 4: Percent improvement of the friction angle

3.2 Results of CBR tests

The CBR tests were conducted on natural, untreated soil samples and samples with fiber contents of 0.2%, 0.35%, and 0.5%. The CBR performance as a function of the depth of penetration (at 2.54 mm and 5.08 mm penetration levels) is presented in Fig. 5. Testing of clean sand (i.e., without fiber reinforcement) yielded CBR values of 10 at 2.54 mm and 11 at 5.08 mm. Similar trend with slightly higher values of CBR were obtained from the samples of sand containing 0.2% fiber; CBR of 11 and 12 at 2.54 mm and 5.08 mm penetration, respectively. Interestingly, the trend was found to be reverse indicating higher values of CBR at 2.54 mm depth of penetration in the samples reinforced with 0.35% and 0.5% fiber content. The overall optimal CBR performance was obtained from the samples reinforced at 0.35% dosage of fiber; CBR values of 17 and 14 were achieved at 2.54 mm and 5.08 mm penetration levels, respectively.

The design CBR values for each of the investigated dosage of fiber were determined according to ASTM D1883-07 and presented in Fig. 6. Consistent with the finding from the direct shear tests, addition of fiber at a rate 0.35% by dry weight to the soil yields the best CBR performance.

4. Practical Implications

Effects of improvement with inclusion of fiber are quantified on a berainig capacity problem. A single square footing of 1.5 m by 1.5 m, founded on the studied poorly graded sand, is considered (Fig. 7). The bearing capacity was determined for two scenarios: (i) unreinforced sand, and (ii) 0.35% fiber reinforcement. The results of the analysis, as presented in Table 3, showed that fiber reinforcement of the sand at a dosage rate of 0.35% can increase the allowable bearing capacity by about 65% from 649 kPa to 1068 kPa when based on the maximum friction angle.

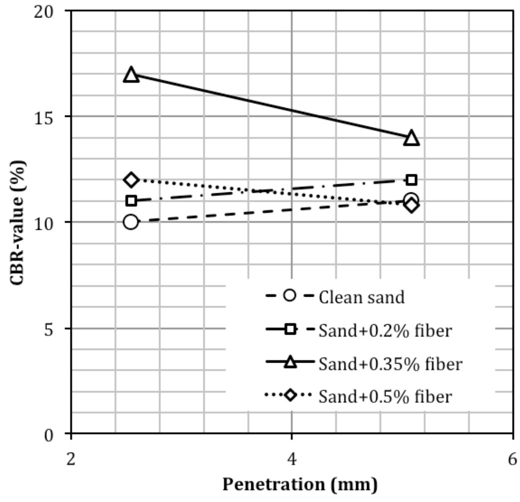

Fig. 5: CBR versus penetration performances of unreinforced and reinforced sand samples

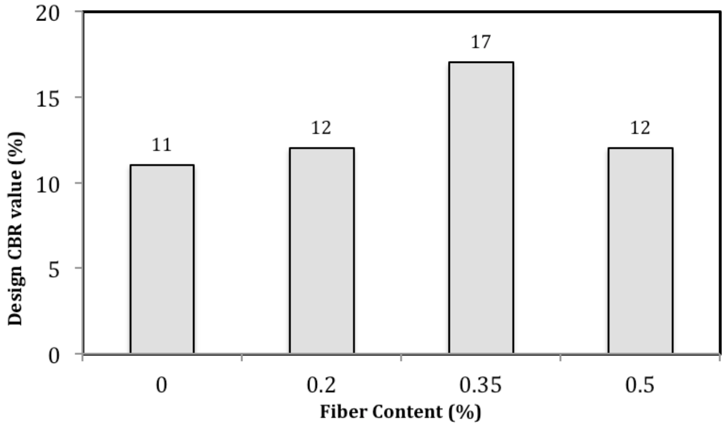

Fig. 6: Design CBR values at various fiber content

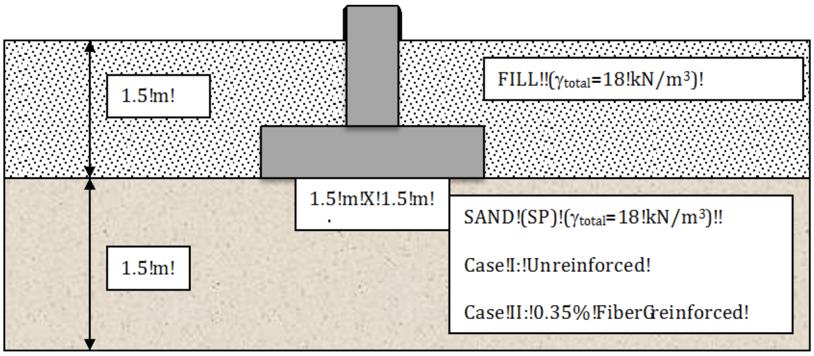

Fig. 7: Square footing founded on SP sand

Tab. 3: Allowable bearing capacity improvement due to reinforcement

Friction angle	Reinforcement	Allowable bearing capacity (kN/m^2)	Percent gain by inclusion of fibers
Maximum	0% (case I)	649	64.6 %
	0.35% (case II)	1,068.5	
Residual	0% (case I)	440.25	20.8 %
	0.35% (case II)	531.75	

5. Conclusions

In this study, the improvement in friction angle and CBR performance of a poorly-graded (SP-type) sand with the inclusion of polyolefin type fiber was investigated. Beneficial effects of fiber inclusion with the sand were found to occur at the dosage rate of 0.35%. Other dosage rates were not effective in improving the properties of the sand. The results at 0.35% fiber content are promising in that significant improvement of the strength and bearing capacity of the sand may be obtained. Thus, the use polyolefin type fiber as a reinforcing additive with the studied sand is recommended at 0.35% dosage.

References

[1] AHLRICH, R.C., TIDWELL, L.E. Contingency airfield construction: Mechanical stabilization using monofilament and fibrillated fibers. Technical report GL-94-2, 1994. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[2] ASTM D 1557–07. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort. 2007. West Conshohocken, PA, United States.

[3] ASTM D 1883–07. Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils. 2007. West Conshohocken, PA, United States.

[4] ASTM D 3080–11 Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. 2011. West Conshohocken, PA, United States.

[5] FLETCHER, C., HUMPHRIES, K. California bearing ratio improvement of remolded soils by the addition of polypropylene fiber reinforcement. *Transportation Research Record*, 1991. 1295, 80-86.

[6] FREITAG, D.R. Soil randomly reinforced with fibers. *Journal of Geotechnical Engineering*, 1986. ASCE 112 (8), 823-826.

[7] GRAY, D.H., AL-REFEAI, T. Behavior of fabric-versus fiber reinforced sand. *Journal of Geotechnical Engineering*, 1986. ASCE 112 (8), 804–820.

[8] GROGAN, W.P., JOHNSON, W.G, Stabilization of high plasticity clay and silty sand by inclusion of discrete fibrillated polypropylene fibers for use in pavement subgrades. 1994. Technical report CPAR-GL-94-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[9] HAZIRBABA, K., GULLU, H. California bearing ratio improvement and freeze-thaw performance of fine-grained soils treated with geofiber and synthetic fluid., *Cold Region Science and Technology*, 2010. 63, 50-60.

[10] MAHER, M.H., HO, Y.C. Mechanical properties of kaolinite/fiber soil composite. *Journal of Geotechnical Engineering*, 1994. ASCE 120 (8), 1381-1393.

[11] TINGLE, J.S., WEBSTER, S.L., SANTONI, R.L. Discrete fiber reinforcement of sands for expedient road construction. 1999. Technical Report GL-99-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[12] WEBSTER, S. L., SANTONI, R. L. Contingency airfield and road construction using geosynthetic fiber stabilization of sands. 1997. Technical Report GL-97-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.