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Assessment of the artificial fiber contribution on the shear strength parameters of soils

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ABSTRACT

Soil stabilization is one of the methods of soil improvement that has been used since ancient times in human history. Soil mass reinforced with randomly distributed discrete fibers is one of the techniques for improving the properties of soils. Reinforcing the soil with randomly distributed discrete fibers has attracted the attention of many researchers over the past few decades. For this purpose, many studies have been carried out with fibers obtained from synthetic, natural and waste materials. Studies on soil reinforced with discrete fibers have revealed the effect of fibers are beneficial to strength parameters of soils. In this study multivariate regression analysis were performed by using data from literature to formulate the effect of fibers on the soil. The formulas obtained from multivariate regression analyses are in harmony with the values of unconfined compression and shear strength.

Introduction

As is known, almost all types of structures, from high-rise buildings to the construction of roads, railways, tunnels and viaducts, are built either on the soil or in the soil. In this regard, the structures are in constant interaction with the soil. Unfortunately, the soil that is supposed to carry the constructed structure may not always have sufficient engineering properties. The fact that the soil has insufficient engineering properties may cause the existing soil to be discarded and a new filling to be made or it can bring up the construction of deep foundation. But it may not be possible to implement these solutions for economic reasons. At this point, engineers go to ways to improve the soil on the site.

Soil stabilization is one of the methods of soil improvement that has been used since ancient times in human history. The stabilization of soils has been performed for millennia. For instance, the Mesopotamians and Romans separately discovered that it was possible to improve the ability of pathways to carry traffic by mixing the weak soils with a stabilizing agent like pulverized limestone or calcium [1]. Random distribution of fibers on the ground also improves the strength parameters of the soil by simulating the behavior of plant roots [2]. Also in ancient civilizations, straw was a material used for reinforcing building blocks obtained from slurry [1]. At present, the reinforcing of the soil to improve its properties is attributed to the [3]. One of the methods of reinforcing the soil is use of fiber. Reinforcing the soil with randomly distributed discrete fibers has attracted the attention of many researchers over the past few decades. For this purpose, many studies have been carried out with fibers obtained from synthetic [4-9], natural [10-19] or waste materials [20-25] in order to study the effect of fibers on the engineering properties of the soil.

Literature Review

Uysal [5] carried out a laboratory study by mixing sand samples having different relative density values (20%, 30% and 40%) with kapolymer and virgin homopolymer fibers in ratios of 0.50%, 1.0% and 1.50% of the dry weight of the soil. Shear box tests were conducted in order to observe the effect of relative density and fiber content on the shear strength. It was observed that the samples having a high relative density has a higher shear strength, and the angle of internal friction also increases as the fiber ratio increases.

Wei et al. [12] performed laboratory tests by mixing a silty clay soil with both lime and fibers to investigate the mechanical properties of the soil. Wheat straw, rice straw, hemp and polypropylene fibers were added to the soil-lime mixtures. Unconfined compression and triaxial compression tests were performed on samples in order to examine the shear strength properties. The optimum fiber content was found to be 0.2% or 0.25% and the optimum fiber length was found to be 30%-40% of the sample diameter. Fiber reinforcement has significantly increased cohesion and slightly improved the angle of internal friction. When the performance of fiber varieties in cohesion increases was compared, it was determined that polypropylene, jute, rice straw and wheat straw were from the best to the lowest.

Özdemir [19] investigated the consistency limits, compaction characteristics, unconfined compression and freeze-thaw properties of fiber-clay samples obtained by adding natural (straw, hemp) and synthetic (polyester) fibers to a cohesive soil sample. It was observed that the unconfined compression strength of the samples increased with an increase in the percentage of fiber, and improvements in the unconfined compression strength after freezing and thawing also occurred when compared to natural clay. The samples with hemp additives exhibited superior behavior against freezing and thawing.

Pradhan et al. [26] investigated the effect of polypropylene fiber contribution on the shear strength and unconfined compression strength of cohesive soils. They observed that the addition of fibers increased the peak and residual shear strength as well as unconfined compression strength and CBR values.

Consoli et al. [27] carried out a study to determine the differences in the strength of artificially cemented sandy soil with and without fiber reinforcement. The controlling parameters evaluated were the amount of cement, porosity, moisture content, and voids/cement ratio. A series of unconfined compression tests were performed. Results show that the fiber addition increased the unconfined compression strength of the samples at all cement ratios.

Material and Method

Current state of the art on fiber addition to soils shows that synthetic fiber reinforcement of soils has positive effects on the unconfined compressive strength and shear strength parameters of soils.

In this study, the effects of synthetic fiber addition on the unconfined compression strength, cohesion and internal friction angle of soils were formulated by multivariate regression analysis method. In order to formulate the fiber effects with multivariate regression analysis, the relative density and fiber percent in sandy soils, and the fiber percent and length parameters in cohesive soils were selected from the data in the previous studies and the unconfined compressive strength and shear strength parameters were tried to be determined by regression analysis. The data used in the analyses are given in Table 1.

Table 1. A summary of the data used from literature

Soil type	Dr (%)	FiberPercent (%)	Fiber Length (mm)	Φ (°)	Soil type	FiberPercent (%)	Fiber Length (mm)	q_u(kPa)
SP	20	0	0	28	CL	0	0	157
SP	30	0	0	31	CL	0.5	2	340
SP	40	0	0	33	CL	1	2	380
SP	20	0.5	15	31	CL	1.5	2	397
SP	20	1	15	33	CL	0.5	5	301
SP	20	1.5	15	34	CL	1	5	340
SP	30	0.5	15	33	CL	1.5	5	345
SP	30	1	15	34	**Soil type**	**FiberPercent (%)**	**Fiber Length (mm)**	**c(kPa)**
SP	30	1.5	15	36	CL	0	0	291
SP	40	0.5	15	36	CL	0.2	12	301
SP	40	1	15	38	CL	0.25	12	331
SP	40	1.5	15	39	CL	0.3	12	307
SP	20	0.5	15	29	CL	0.2	19	326
SP	20	1	15	30	CL	0.25	19	358
SP	20	1.5	15	32	CL	0.3	19	344
SP	30	0.5	15	32	**Soil type**	**FiberPercent (%)**	**Fiber Length (mm)**	**Φ (°)**
SP	30	1	15	33	CL	0	0	32
SP	30	1.5	15	35	CL	0.2	12	32
SP	40	0.5	15	34	CL	0.25	12	33
SP	40	1	15	35	CL	0.3	12	31
SP	40	1.5	15	37	CL	0.2	19	32
SP	40	0.5	15	36	CL	0.25	19	33
SP	40	1	15	38	CL	0.3	19	33

Results and Discussion

Based on the multiple variate regression analyses, the following equations were obtained for the relationship between fiber percent, fiber length and relative density with the internal angle of friction (**Φ**, °), cohesion (c, kPa) and undrained compressive strength:

$$q_u = a + bF_p + cF_L + d(F_p{}^2) + e(F_p.F_L) + f(F_L{}^2) \tag{1}$$

In this equation, q_u represents undrained compressive strength in kPa whereas F_p, and F_L denotes fiber percent and fiber length. The constant parameters of *a, b, c, d, e* and *f* will be taken as 157, 179.7 81.67, -57, -4.333 and -13.13, respectively. For the relationship between fiber percent and relative density with the internal angle of friction (**Φ**, °) of cohesionless soils:

$$\mathbf{\Phi} = g + hF_p + iD_r \tag{2}$$

where F_p, and D_r denotes fiber percent and soil relative density (divided by 100). The constant parameters of *g, h, i* will be taken as: 22.95, 26.57, and 3.106, respectively. The coefficient of determination is found as 0.90 for the suggested formula. For the relationship between fiber percent and fiber length with the cohesion (c, kPa) of cohesive soils:

$$\mathbf{c} = j + kF_p + lF_L + m\left(F_p{}^2\right) + n\left(F_L{}^2\right) \tag{3}$$

The constant parameters of *j, k, l, m* and *n* will be taken as: 291, 5120, -86.48, -1e+04, 2.926 respectively. The coefficient of determination is found as 0.99 for the suggested formula.

Conclusion

Researchers conducted laboratory tests in order to investigate the mechanical behavior of fiber reinforced soils. Based on the carried-out tests, it was observed that reinforcing soil with fibers, the peak strength loss is decreased, and thus the behavior of the material changed from brittle to ductile, the swelling pressure and desiccation cracks decreased, in short, the behavior of the soil improved in the desired direction. When compared to classical soil improvement techniques, the main advantage of mixing randomly distributed fibers is the maintenance of strength isotropy and absence of potential failure plane that can develop parallel to the oriented reinforcement [18]. By using the results of the previous laboratory tests reported in the literature, multivariate regression analyses were performed. Formulas were suggested to be used for the practical purposes for the site engineers and designers.

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