Analysis of efficiency of fiber reinforced sand as a backfill of retaining walls

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ABSTRACT: For many years retaining walls remain popular type of structures in the transport and urban development. Sandy soils are mainly used to create ones. One of the main problems of such structures is large material cost to construct. The paper investigates the possibility of reduction of the facing material of retaining walls by applying the method of discrete reinforcement of sandy soils by polypropylene fibers. The studies found that the introduction of discrete fibers into sand has positive effect on shear parameters: specific cohesion and angle of internal friction. To evaluate the effectiveness of fiber reinforcement technology when constructing retaining walls numerical simulation using software «PLAXIS-2D» was made for test problems. The results show that the discrete soil reinforcement by polypropylene fibers can be an effective solution to reduce material consumption and increase the profitability retaining walls.
KEYWORDS: soil strength properties, retaining wall, fiber reinforcement, numerical modeling

1 INTRODUCTION

1.1 *Review of existing researches*

Currently reinforced walls have become a popular type of retaining structures in terms of decrease the earth pressure and displacements of the walls. Metal mesh, various natural or synthetic additives can be used as the reinforcement. The main advantages of reinforced retaining walls are their fundamental simplicity, ease of construction, efficiency (Bartolomey et al. 1999). In addition to the linear reinforcement there is a technology there randomly distributed discrete fiber are introduced into the soil. This technique is called fiber reinforcement (Hejazi & Sheikhzadeh 2012, Kuznetsova et al. 2012). Fiber reinforced soil has improved strength characteristics, so one of its potential applications is to use as backfill of different retaining structures (Kuznetsova & Ponomaryov 2015).

Concept of fiber reinforcement was considered in some studies on earth-retaining problems. The first example of mass application of randomly oriented fibers for reinforcing retaining walls and protection of natural slopes was a polyester fiber named as “Texsol”. “Texsol” is the technology of soil reinforcement, patented by the French government, which is the mix of soil particles and polymer yarns. The mixture is obtained by passing the soil through a pneumatic or a mechanical system simultaneously with the fibers (LeFlaive & Liausu 1986).

Literature review shows that fiber reinforcement can be used for reinforcement of slopes and retaining walls in combination with linear geosynthetic materials. Park and Tan concluded that the use of polypropylene fibers of 60 mm in combination with geogrid reinforced silty sand soil wall reduces the earth pressure and displacement of the wall and increases the stability of the wall (Park & Tan 2005).

Some researchers examined the use of fibers to improve properties of cement-stabilized soils. Nasr studied behavior of strip footing on fiber-reinforced cemented sand adjacent to sheet pile wall. Numerical and experimental results clearly showed that fiber inclusion into the cemented soil significantly reduces the lateral deflection of the sheet pile wall and increases the ultimate bearing capacity of footing (Nasr 2014).

Though concept of fiber reinforcing soil was originated in ancient times it is still a relatively new technique in geotechnical projects and requires father investigation. It seems that technology of soil discrete reinforcement can be an effective solution of earth-retaining problems (Spirin et al. 2016).

1.2 *The research aim, object and tasks*

When constructing structures for different purposes the main purpose is to ensure safety with lower costs. The aim of the paper is to investigate the possibility of reducing the facing material of retaining walls due to the decrease of the active earth pressure by applying the method of discrete reinforcement. The object of the research is a backfill of retaining wall. Authors propose the use of sand reinforced with polypropylene fiber as a backfill.

Research objectives include experimental laboratory studies to determine the physical and mechanical properties of sand and fiber sand, analytical calculations and numerical modeling of retaining walls with the backfill of sand and fiber reinforced sand.

2 EXPERIMENTAL INVESTIGATION

2.1 *Material used for the testing*

Uniform fine sand of optimal water content and fixed particle size distribution was used in this study. Bulk volume density of sand was 1490 kg/m^3.

Polypropylene (PP) fiber of 12 mm was used as reinforcement. Usually this fiber is used for the discrete reinforcement of concrete to improve its strength properties, reduce shrinkage for improving the crack resistance of concrete structures.

The content of reinforcement was 0.0, 0.5, 1.0 and 1.5% of polypropylene fibers by weight of dry soil. Fibers were randomly placed by mixing to form fiber reinforced sand (Kuznetsova & Ponomaryov 2014).

2.2 *Experimental program and results*

The first stage of the study was laboratory tests to determine physical and mechanical characteristics of the sand and fiber reinforced sand.

In accordance with the technology laying of backfill should be carried out when soil moisture content provides the achieving of required density which is achieved by the lowest labour inputs. To determine the optimal moisture content standard compaction test was carried out. The determination of maximum density showed that the introduction of polypropylene fibers reduces the soil compactibility and, therefore, reduces the maximum density of dry soil on average of 6-8% (see Figures 1-2). Optimal water content value does not depend on the presence of reinforcing fibers and is 8.5% (Fig. 1). Further tests to determine the strength parameters of sand and fiber sand composites were carried out with the optimum soil moisture.

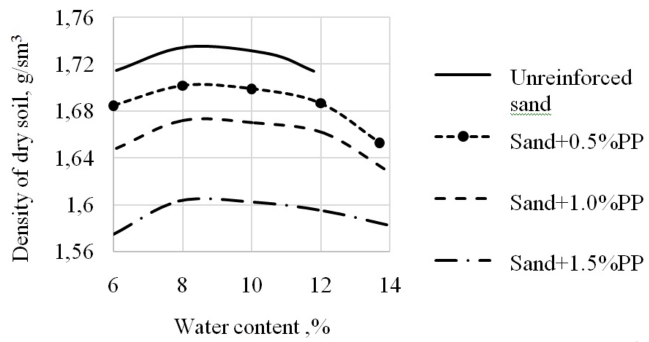

Figure 1. Dependences of dry soil density on soil water content for unreinforced and fiber reinforced sand

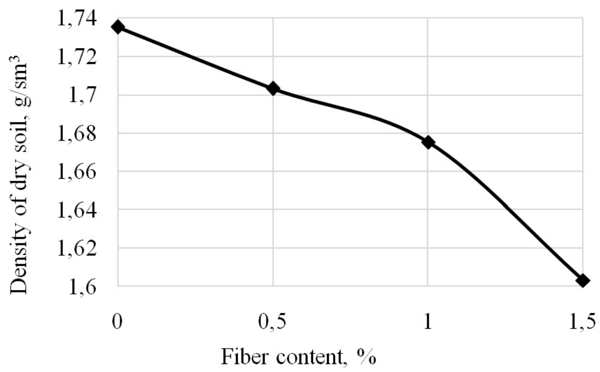

Figure 2. Dependences of dry soil density on fiber content

Tests to determine the mechanical characteristics were performed in triaxial device. The tests were carried out according Russian standards. The specimens diameter was 38 mm and height was 76 mm. Consolidated drained tests were conducted at various levels of confining pressure (100, 200, 300 kPa). The experimental data were obtained using an automated software package for the testing system. The experimental data were obtained using an automated software package for the testing system.

The test results are shown in Table 1. Studies found that the introduction of discrete fibers into sand has positive effect on shear parameters: specific cohesion and angle of internal friction.

Table 1. Soil strength parameters on the results of triaxial tests.

Material	Strength parameters		Relative parameters	
	φ, °	*c*, kPa	Δφ	Δ*c*
Sand	35.0	20	1	1
Sand+0.5%	39.3	67	1.12	3.35
Sand+1.0%	42.6	75	1.22	3.75
Sand+1.5%	49.4	37	1.41	1.85

To illustrate the tests results the Mohr-Coulomb criterion is given for unreinforced sand and sand reinforced with 0.5% of polypropylene fiber (Fig. 3).

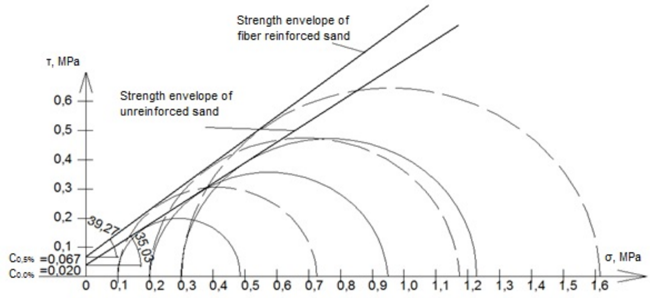

Figure 3. Mohr-Coulomb diagram for unreinforced sand and sand reinforced with 0.5% of polypropylene fiber after triaxial testing.

When loading soils are working mainly on the shear plane where the load-bearing capacity is the lowest (Sipidin & Sidorov 1963). Therefore, the shear strength is a defining characteristic of the soil strength. The graphs clearly show that the reinforced specimen has higher strength characteristics as compared with unreinforced one. This is because that when polypropylene fibers are included into the soil internal adhesion increases due to contacting of sand and discrete fibers (Diambra & Ibraim 2010).

Test results show that due to the combined action of the sand and the fibers non-cohesive soil acquires apparent specific cohesion and increased shear strength. The optimum percent of reinforcement is 0.5% by weight of dry soil. When reinforcement percent is 1% the material consumption increases in 2 times, and soil characteristics vary on average by 8-10% with respect to reinforcement of 0.5%. When introducing 1.5% of fiber the specific cohesion of soil varies slightly, since it is difficult to ensure uniform mixing with such content of polypropylene fiber.

3 NUMERICAL SIMULATION

In the next phase of the study the stability analysis of the retaining wall was carried out. Retaining walls work in difficult geological conditions and take significant horizontal forces of active earth pressure. To reduce the horizontal pressure is possible by using soil having specific cohesion as backfill. According to the standards backfill materials should have good drainage properties at the same time. Therefore, the use of fiber reinforced sand can be an effective solution to ensure safety and reduce costs when constructing retaining walls.

Design model of retaining wall is shown in Figure 4. The calculation was made for the pressure from the soil own weight. Unreinforced sand and fiber reinforced sand with optimum moisture content were simulated as wall backfill. The fiber content was 0.5 % by weight of dry soil as the optimum in concordance with laboratory tests results. Height of retaining wall was varied and equaled to 3, 6, 9, and 12 m.

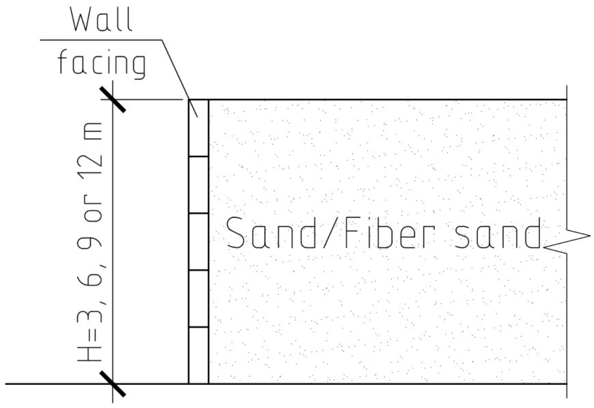

Figure 4. Design model of retaining wall.

Numerical simulation of retaining wall was performed by finite element analysis using the software package “PLAXIS-2D”. Elastoplastic Mohr-Coulomb model was used when calculating. The model parameters were taken according laboratory tests results. Numerical simulation results are shown in Table 2.

Table 2. The values of active earth pressure based on the results of numerical simulation.

Backfill	Height of retaining wall, m			
material	3.0	6.0	9.0	12.0
Sand	0.3	0.7	12.2	47.95
Sand+0.5%	0.3	0.52	0.67	0.82

The calculation for determining the active earth pressure of retaining wall backfill found that the use of soil reinforcement when constructing retaining walls is efficiently, since the value of the active earth pressure is greatly reduced. Retaining wall with a height of 3.0 m is exception. Fiber sand is most appropriate to apply for high retaining walls.

4 RESEARCH RESULTS AND CONCLUSION

The possibility of reducing the active earth pressure on retaining wall was investigated by applying the method of discrete reinforcement. It was found that:

1. Inclusion of polypropylene fibers as reinforcing elements into the soil reduces the soil compactability of 6-8%. The optimum moisture content does not depend on presence of the reinforcing fibers and it equals to 8.5%.
2. Discrete soil reinforcement technology provides a significant increase in the soil strength characteristics. Non-cohesive soil acquires apparent specific cohesion and increased shear strength due to the combined action of the sand and the fibers. The analysis of laboratory testing results shows that the optimal percentage of reinforcement is 0.5% by

weight of dry soil. When reinforcement percent is 1% the material consumption increases in 2 times, and soil characteristics vary on average by 8-10% with respect to reinforcement of 0.5%. When introducing 1.5% of fiber the specific cohesion of soil varies slightly, since it is difficult to ensure uniform mixing with such content of polypropylene fiber.

3. The calculation for determining the active earth pressure of retaining wall backfill found that the use of soil reinforcement when constructing retaining walls is efficiently, since the value of the active earth pressure is greatly reduced. Retaining wall with a height of 3.0 m is exception. Fiber sand is most appropriate to apply for high retaining walls (height of 6 meters or more).

Thus, the fiber reinforcement of soils can be an effective solution to reduce the thickness of the wall facing without loss of stability and safety. Technique proposed by the authors can be useful to decrease material consumption and increase the profitability of high retaining walls.

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