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Triaxial testing of granular soils reinforced with discrete polypropylene fibres

Gunther E. Bauer & Alexandru Oancea
Carleton University, Ottawa, Ont., Canada

ABSTRACT: Discrete polypropylene fibres were mixed with four types of soil. The influence of fibre length and content were investigated for strength and compression behaviour in a triaxial apparatus. The shear strength of the composite increased with fibre content but so did the corresponding strain to reach peak strength. Fibre length beyond 50 mm had little effect on additional strength increase, but the increase in fibre content caused a decrease in the secant modulus.

1 MATERIALS

1.1 *Soils*

Four types of soil were investigated: a silty sand, a sandy silt, a medium sand and a uniform sand. The grain size distribution is show in Figure 1 and the physical properties are given in Table 1. The maximum dry unit weight was obtained from modified Proctor compaction tests. These four types of soils were chosen to give a good range of grandular materials.

1.2 *Fibres*

A high strength polypropylene fibre was used since it is commercially available in various lengths as secondary reinforcing in concrete. These fibres are fibrillated (bundled), chemically inert and posses a high ultimate tensile stress (93 Mpa). In this investigation they were used in their unbundled (separated) configuration. The length was varied from 63 mm to 126 mm and the concentrations of fibre weight to dry weight of soil was 0.1, 0.2, 0.3 and 0.5%.

2 TRIAXIAL TESTS

The dry soil and the specified amount of fibres were mixed in a dry stage before water was added. This uniform mixture was compacted in a mold to make

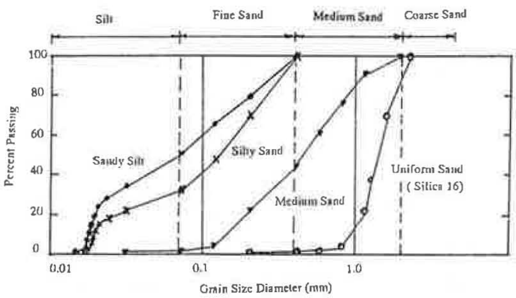

Fig.1. Grain size distribution of test soils

Table 1 Physical properties of test soils

Soil	D_{50}	Cu	Density	Opt Moisture	ϕ
	(mm)		(kN/m^3)	(%)	(°)
Sandy silt	0.075	6.11	20.0	10.5	37
Silty sand	0.140	9.21	19.0	9.8	41
Medium Sand	0.480	4.29	20.2	9.1	41
Uniform sand	1.500	1.68	16.0	3.5	39

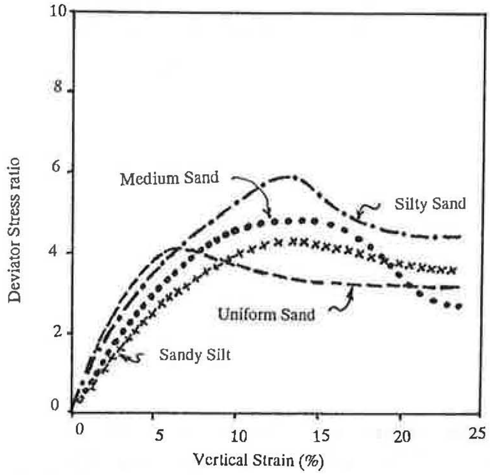

Fig.2. Ratio of deviator stress vs. axial strain of granular soils

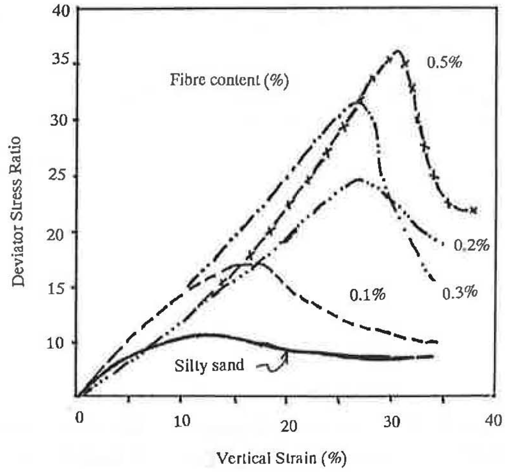

Fig. 4. Ratio of deviator stress vs. axial strain of composite with different fibre conten

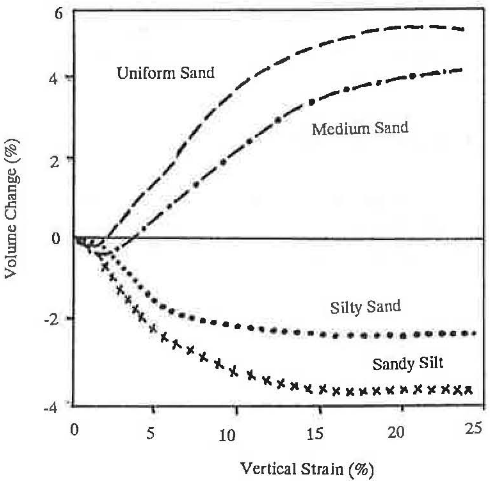

Fig. 3. Volume change vs. axial strain

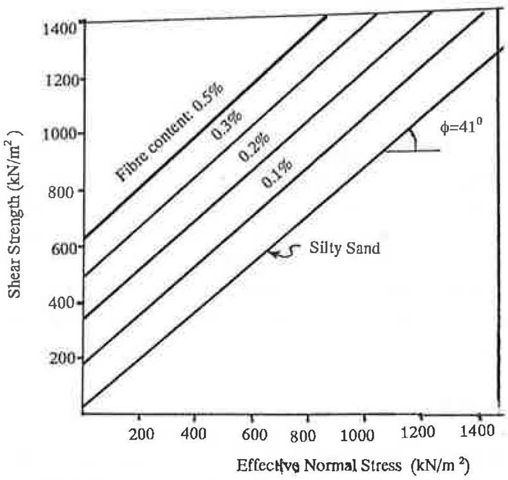

Fig. 5. Coulomb strength envelope for natural and reinforced silty sand

triaxial specimens of 100 mm in diameter and 200 mm in height. They were then saturated in a triaxial apparatus under a given back pressure. After consolidation they were sheared under drained conditions. The rate of strain was sufficiently slow in order not to generate any excess porewater which was monitored at the centre of the specimen. The volume change was also monitored. The confining pressure ranged from 50 to 600 kPa. Typical normalized stress-strain and volume change-strain relations for the four soils are given in Figures 2 and 3 respectively. A similar plot is shown for the silty sand in Figure 4. It is quite evident that the peak deviator stress ratio increased with an increase in fibre content. For example, unreinforced silty sand yielded a stress ratio of 5.1 at about 12.5% of strain, whereas the composite having a fibre content of 0.5% yielded a peak stress ratio of 32 at 31% of strain. Therefore, the increase in peak stress of the composites was associatd with an increase in peak strain. Similar observations were made for the other three soils except the peak stress and corresponding strain increases were less pronounced than for the silty sand.

Table 2 Shear strength parameters with fibre content for silty sand

Fibre Content (%)	Angle of Shear resistance ϕ or ϕ_R °	Cohesion intercept C_R(kN/m^2)
0	41	0
0.1	41	180
0.2	41	342
0.3	41	492
0.5	41	688

3 SHEAR STRENGTH

The strength of a fully drained soil is conveniently expressed by the Coulomb strength equation as

$$s = c' + \sigma' \tan \phi' \quad (1)$$

where c' and ϕ' are the effective parameters for cohesion and the angle of shearing resistance respectively and σ' is the effective normal stress. Several researchers (Fatani et al, 1991; Gray and Ohashi, 1983 and Jewell and Wroth, 1987) have modified this equation to incorporate the effect of the reinforcing fibres as follows:

$$S_R = C_R + \sigma' \tan \phi_R \quad (2)$$

where the subscript R refers to the strength parameters of the reinforced composite. Figure 5 gives the strength envelopes for the silty sand together with those of the composite having various fibre contents. The increase in fibre concentration will only increase the cohesion intercept, C_R, whereas the angle of shearing resistance remains the same as that of the unreinforced soil. The results are summarized in Table 2. The other soils have shown similar straight line failure envelopes over the confining pressures tested. Table 3 shows a summary of the shear strength parameters of the other three soils for their natural and reinforced states.

4 SECANT MODULUS

The secant modulus is an indication of the "stiffness" or "compressibility" of the soil. The secant modulus is defined as the straight line between the origin of the diviator stress/vertical strain curve and a point on the plot at a given vertical strain. The secant

Table 3 Shear strength parameters of natural and fibre reinforced soils

Soil	Fibre content (%)	Angle of shearing resistance (ϕ or ϕ_R °)	Cohesion intercept (kN/m^2)
sandy silt	0	37	80
	0.1	37	158
Medium sand	0	41	0
	0.1	40	80
Uniform sand	0	39	0
	0.1	39	44
	0.3	38	142

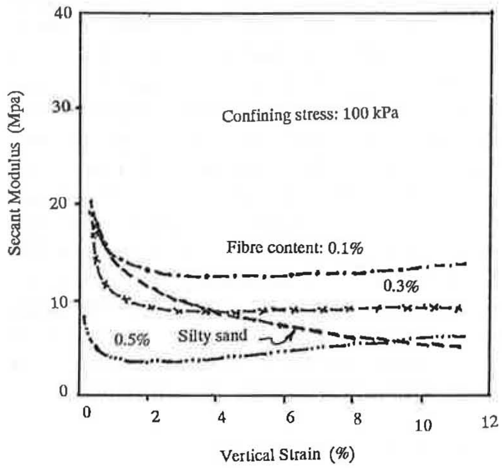

Fig.6. Secant modulus variation for silty sand and composite with different fibre content

modulus, of course, is only a constant for a material which behaves linearly elastic. Soils rarely behave in such a fashion except, maybe, at very small initial strains. Figure 6 shows the variation of the secant modulus with vertical strain for the natural silty sand speciments together with that of the composite specimens at fibre contents of 0.1, 0.3 and 0.5%. The secant modulus decreases with strain for the unreinforced soil whereas the moduli of the reinforced composite remain fairly constant beyond about 2% of vertical strain. An increase in fibre content will yield a decrease in the modulus or, in other words, the compression of the composite increases with an increase in fibre content. Similar observations were made for higher confining pressures. The behaviou with strain of the secant modulus of the other three soils was similar, except of course, with respect to absolute values.

5 DISCUSSION AND CONCLUSIONS

The addition of discrete randomly dispersed polypropylene fibres to a granular material caused an increase in shear strength. This shear strength can be conveniently expressed as a linear relation using the Mohr-Coulomb strength equation for confirming pressures ranging from 50 to 600 kPa. This increase was given as a cohesion intercept since the angle of shearing resistance remained unchanged for the composite regardless of fibre content.

Increasing the fibre length from 76 mm to 126 mm had little effect on the shear strength or the compressibility of the composite for a given fibre concentration. The increase in fibre content, however, yielded a higher compressibility as indicated by a decrease in secant modulus. The secant modulus of the soils tested is, therefore, not only a function of the confining pressure but also dependent on the fibre content. Regardless of confining pressure and fibre content, the secant modulus of the four types of composite assumed constant values beyond a vertical strain of about 2%, whereas all moduli of the natural soils continued to decrease with vertical strain. The maximum decrease of modulus for all natural and reinforced soil speciments occurred within the initial 2% of vertical strain.

ACKNOWLEDGEMENT

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