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BEHAVIOUR OF SANDY CLAY RANDOMLY REINFORCED WITH POLYPROPYLENE FIBRES

Summary. This paper presents some results of laboratory investigations conducted on the behaviour of sandy clay mixed with discrete, randomly oriented synthetic fibres of short length. The influence of fibres on the shear resistance of sandy clay was studied by means of direct shear tests. The fibre reinforcement effect on the compressibility of the sandy clay was also studied by means of oedometer tests. Both unreinforced (control) and fibre-reinforced sandy clay samples were tested at the same water content and the results analysed. It was found that a low quantity (0.25% by the dry unit weight of soil) of short length (25mm) polypropylene fibres increases the shear resistance and modifies significantly the shear stress-displacement behaviour of the sandy clay. There is an increase in both apparent cohesion and angle of shearing resistance of clayey soil due to fibres. The one-dimensional compressibility behaviour of fibre-reinforced and unreinforced sandy clay is quite similar.

WŁASNOŚCI GLINY PIASZCZYSTEJ WZMOCNIONEJ STATYSTYCZNIE ROZMIESZCZONYMI WŁÓKNAMI POLIPROPYLENU

Streszczenie. Artykuł ten przedstawia pewne wyniki badań laboratoryjnych prowadzonych nad własnościami gliny piaszczystej zmieszanej z krótkimi, dyskretnymi, przypadkowo zorientowanymi włóknami syntetycznymi. Wpływ tych włókien na wytrzymałość na ścinanie gliny piaszczystej został zbadany w próbach bezpośredniego ścinania. Wpływ wzmocnienia przez włókna na ściśliwość gliny piaszczystej został zbadany również za pomocą badań edometrem. Próbki gliny piaszczystej zarówno niewzmocnionej (kontrolne) oraz wzmocnionej włóknami były badane przy tej samej wilgotności, a wyniki badań zostały przeanalizowane. Stwierdzono, że niewielka ilość (0,25% ciężaru właściwego gruntu w stanie suchym) krótkich (25 mm) włókien polipropylenu zwiększa wytrzymałość na ścinanie oraz modyfikuje w istotny sposób zależność przesunięcia od naprężenia ścinającego gliny piaszczystej. Wartości zarówno spójności pozornej, jak i kąta wytrzymałości na ścinanie gruntu gliniastego rosną pod wpływem włókien. Jednowymiarowa ściśliwość gliny piaszczystej wzmocnionej włóknami i niewzmnocnionej jest dość podobna.

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1. Introduction

The reinforced soil is well present in Nature and it is a technique almost as old as the Civilization. The great diversity of reinforcing elements that have been used all over the world to reinforce the soil originated experimental and analytical investigations about two large groups of reinforcing soil techniques: the so-called Macroreinforced and Microreinforced soil, as suggested by Gregory and Chill [1] and Pinto [2]. The Microreinforced soil consists of small elements randomly mixed with soil. These reinforcing elements can have a variety of forms (mesh elements, fibres, continuous filaments) and can be made of both synthetic and natural materials. The reuse of materials can also be possible, provided they do not represent an environmental hazard.

The present study focuses on the use of short, monofilament, randomly oriented polypropylene fibres to reinforce a cohesive soil. The test materials, experimental procedure and analytical techniques used in the study are presented. The main objective was to compare the shear resistance and deformation behaviour of unreinforced and fibre-reinforced sandy clay.

2. Test materials

The soil used was a cohesive soil. It is classified as sandy clay of medium plasticity (CL) according to Unified Soil Classification System [3]. The main properties of the sandy clay used in this study are summarised in Table 1. The synthetic fibres used are made of polypropylene and were supplied by a local manufacturer. The fibre length and fibre percentage was 25 mm and 0.25%, respectively. The percentage of fibres used to reinforce the sandy clay samples was determined as a weight percentage of the soil's dry unit weight. The main properties of the fibres are summarised in Table 2.

Table 1

Sandy clay properties

Property	CL
Specific gravity, G_s (-)	2.78
Percent finer than #200 sieve (%)	53
Liquid limit, w_L (%)	35
Plasticity index, I_P (%)	19
Soil friction angle, ϕ' (°)	33
Cohesion, c' (kN/m^2)	8.5

Table 2

Fibre properties

Property	Fibres
Specific gravity, G_f (-)	0.91
Denier (g/ 9000 m)	6
Tensile strength, σ_t (MN/m^2)	200
Young's modulus, E (GN/m^2)	1.5
Elongation at break, ε_f (%)	300
Moisture absorption (%)	0
Colour	White

3. Experimental procedure

Direct shear tests were carried out on unreinforced and fibre-reinforced sandy clay samples in order to study the fibre influence on the shear stress-displacement behaviour of clayey soil. Fibre-reinforced samples were prepared by mixing the hydrated sandy clay (water content of 17%) with fibres by hand until the fibres were uniformly distributed and randomly oriented throughout the soil. The fibre-reinforced and unreinforced samples were compacted in accordance with the procedure for a standard Proctor test, using a standard Proctor mould, and test samples were trimmed into a 60 mm diameter shear box. The standard direct shear tests were carried out as consolidated-drained (CD) tests, at a constant shear displacement rate of 0.04 mm/min and at normal stresses ranging from about 35 to 295 kN/m^2 up to a total displacement of 10 mm (corresponds to the maximum shear strain allowed from the shear apparatus, which is of about 20%).

Oedometer tests were carried out on unreinforced and fibre reinforced sandy clay samples in order to study the fibre influence on the one-dimensional consolidation behaviour of clayey soil. The test samples were prepared in the same way as the direct shear ones. The oedometer tests were carried out on a consolidation cell of the fixed ring type (cutting ring), 63.5 mm in internal diameter and 20 mm in height.

4. Analysis of test results

The results of the direct shear tests show that the fibre-reinforcement significantly influences the shear stress-displacement behaviour of sandy clay. Typical curves relating shear stress and shear displacement for unreinforced and fibre-reinforced sandy clay samples are shown in Figure 1.

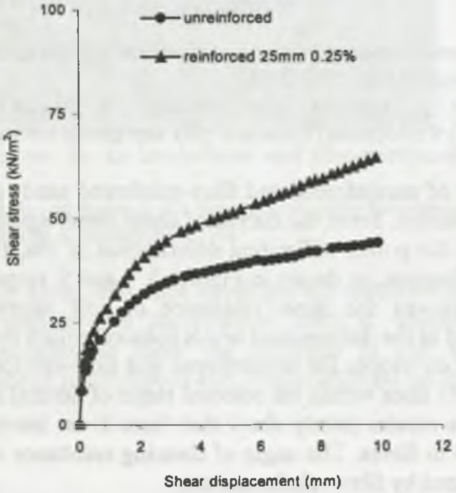

Fig. 1. Shear stress-displacement relationship of unreinforced and fibre-reinforced sandy clay at a normal stress of 50 kN/m^2

Rys. 1. Zależność przesunięcia od naprężenia ścinającego dla gliny piaszczystej niewzmocnionej i wzmocnionej włóknami przy naprężeniu normalnym 50 kN/m^2

Fibre-reinforcement increased the shear stress of the sandy clay at all shear displacements, even at very small values. As can be observed in Fig. 1 the shear stress is always increasing up to the maximum deformation allowed from the shear apparatus. It seems that this increasing trend is caused by a progressive tensile mobilisation of the fibres when the reinforced sandy clay is subject to shear deformations. Figure 1 also shows a linear relationship between shear stress and displacement of fibre-reinforced soil from 8% deformation on (about 4 mm shear displacement), which might indicate that the behaviour is governed mainly by the fibres.

The fibre-reinforcement also modifies the variation in sample thickness during shear displacement. The general shape of shear displacement and thickness variation curves of the unreinforced and fibre-reinforced sandy clay samples in direct shear tests are showed in Fig. 2. While for unreinforced sandy clay the curve shows a progressive decrease in the sample thickness during shear, for fibre-reinforced soil the sample thickness first decreases and then it increases in the course of shearing. This thickness increase may be termed by dilatancy, term usually used to describe the increase in volume of a dense sand during shearing. The rate of dilatancy is constant from 8% deformation on (4 mm displacement), as can be observed in Fig. 2.

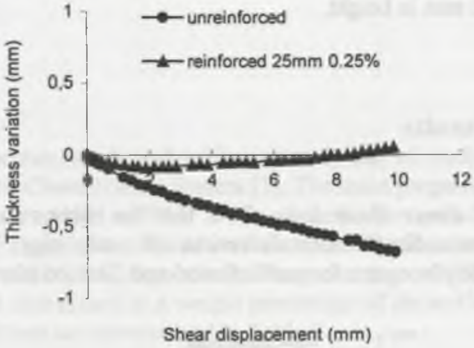

Fig. 2. Shear displacement-thickness variation relationships for unreinforced and fibre-reinforced sandy clay at a normal stress of 50 kN/m^2

Rys. 2. Zależność zmian przesunięcia przy ścinaniu od grubości dla gliny piaszczystej niewzmnocnionej i wzmocnionej włóknami przy naprężeniu normalnym 50 kN/m^2

The shear resistance of unreinforced and fibre-reinforced sandy clay was determined by a limiting deformation criterion. From the curves of shear stress against shear displacement the values corresponding to the points of limiting deformation of 5%, 10% and 15% are read off and plotted on a Mohr diagram, as shown in Figures 3, 4 and 5, respectively. It was found that fibre-reinforcement improves the shear resistance of soft sandy clay and the level of improvement was related to the deformation levels induced within the soil.

The shear resistance envelopes for unreinforced and fibre-reinforced sandy clay appear to be represented by straight lines within the selected range of normal stresses, as can be seen in Figures 3, 4 and 5. The results clearly show that there is an increase in apparent cohesion value of clayey soil due to fibres. The angle of shearing resistance of sandy clay seems to be not significantly influenced by fibre-reinforcement.

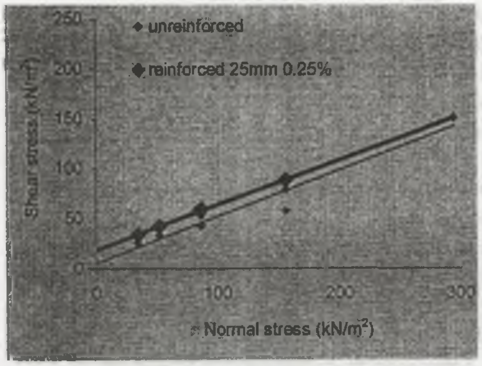

Fig. 3. Shear resistance envelopes for an unreinforced and fibre-reinforced sandy clay at limiting deformation of 5%

Rys. 3. Obwiednie wytrzymałości na ścinanie dla gliny piaszczystej niewzmnocnionej i wzmocnionej włóknami przy odkształceniu granicznym 5%

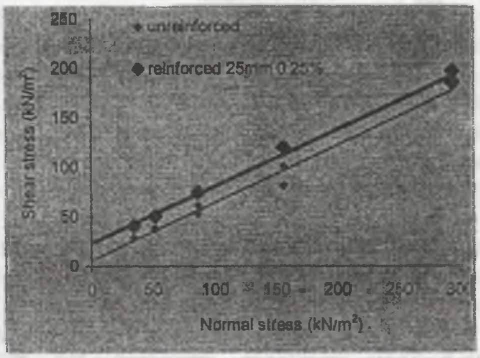

Fig. 4. Shear resistance envelopes for an unreinforced and fibre-reinforced sandy clay at limiting deformation of 10%

Rys. 4. Obwiednie wytrzymałości na ścinanie dla gliny piaszczystej niewzmnocnionej i wzmocnionej włóknami przy odkształceniu granicznym 10%

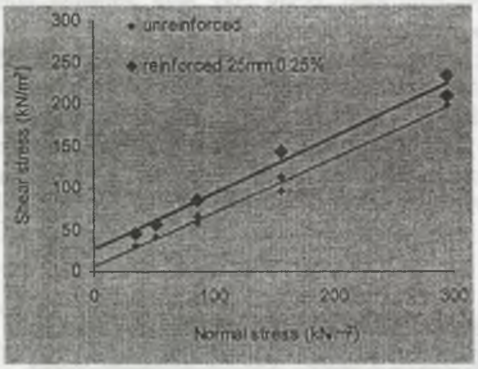

Fig. 5. Shear resistance envelopes for an unreinforced and fibre-reinforced sandy clay at limiting deformation of 15%

Rys. 5. Obwiednie wytrzymałości na ścinanie dla gliny piaszczystej niewzmnocnionej i wzmocnionej włóknami przy odkształceniu granicznym 15%

Figures 6 and 7 show the shear resistance envelopes for unreinforced and fibre-reinforced sandy clay, respectively, varying the deformation level at which shear stresses were mobilized, that were constructed to show the influence of low and high deformation conditions on shear resistance of unreinforced and fibre-reinforced sandy clay.

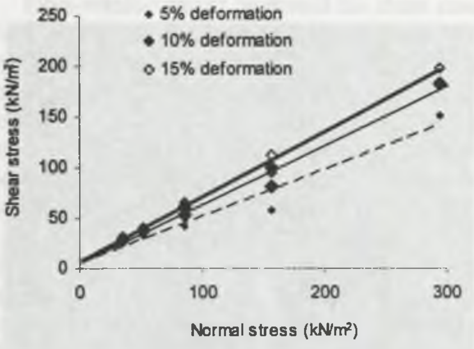

Fig. 6. Shear resistance envelopes for an unreinforced sandy clay, with different deformation levels

Rys. 6. Obwiednie wytrzymałości na ścinanie dla niewzmocnionej gliny piaszczystej, dla różnych poziomów odkształcenia

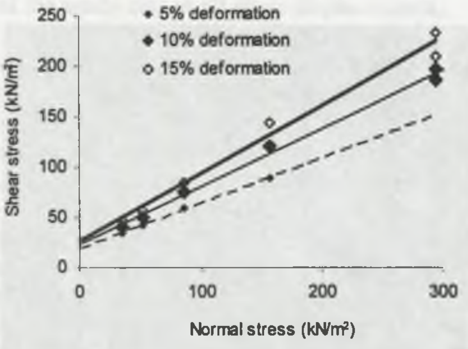

Fig. 7. Shear resistance envelopes for an fibre-reinforced sandy clay, with different deformation levels

Rys. 7. Obwiednie wytrzymałości na ścinanie dla gliny piaszczystej wzmocnionej włóknami, dla różnych poziomów odkształcenia

While on unreinforced sandy clay only the angle of shearing resistance vary with deformation level, on fibre-reinforced sandy clay both apparent cohesion and angle of shearing resistance shows a progressive increase.

From shear resistance envelopes showed in Figures 6 and 7, the ratio of increase in shear resistance to shear stress of unreinforced sandy clay due to fibre-reinforcement can be plotted against normal stress, as shown in Figure 8. It is clear that the fibre-reinforcement effect on shear resistance of sandy clay is especially significant for low normal stresses, for all deformation levels. Increases in shear resistance of sandy clay in the range of 20 to 50% due to fibre-reinforcement were observed in this study. Similar increase values, based upon the shear strength parameters, using fibre-reinforcement have been reported by other researchers [1] [4] [5].

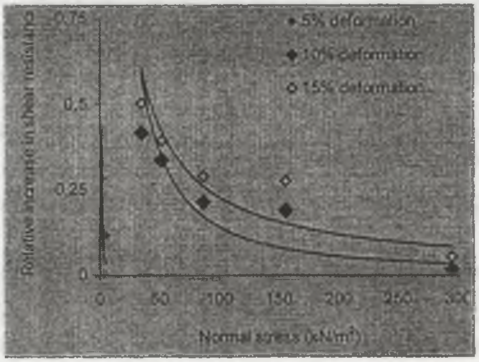

Fig. 8. Relationship between normal stress and ratio of increase in shear resistance to shear stress of unreinforced soil, at equal deformation conditions

Rys. 8. Zależność naprężenia normalnego od stosunku wytrzymałości na ścinanie do naprężenia ścinającego dla niewzmocnionego gruntu, przy jednakowych warunkach odkształcania

The oedometer test results showed that no substantial differences were obtained in the compressibility behaviour of sandy clay when using fibre-reinforcement. The characteristic relationships between void ratio and effective stress in oedometer tests on unreinforced and fibre-reinforced sandy clay are shown in Figure 9, with effective stress represented on a logarithmic scale. It was found that initial recompression index of sandy clay decreased slightly due to presence of fibre-reinforcement. Similar compressibility and swelling indexes were obtained. These findings seem to be in conformity and can be explained: 1 - the fibre-reinforced sandy clay is deformed under one-dimensional compression and therefore doesn't have enough space to develop tensile strains in order to mobilise fibre tensile strength; 2 - a slight decrease in the initial void ratio and compressibility index for the reinforced sandy clay can be observed (Fig. 9) when compared with unreinforced sandy clay. Therefore, it seems that this behaviour is because the addition of fibres to sandy clay only affects the voids ratio, since the fibres occupy part of the voids volume.

However, the consolidation behaviour of sandy clay was influenced by the presence of fibre-reinforcement. The relationships between coefficient of consolidation and effective stress in oedometer tests on unreinforced and fibre-reinforced sandy clay are shown in Figure 10, with effective stress represented on a logarithmic scale. It can be seen that the fibre-reinforcement increases significantly the rate of consolidation (or permeability) of sandy clay for low effective stresses. For higher effective stresses the rate of consolidation of sandy clay is reduced significantly by the presence of fibres.

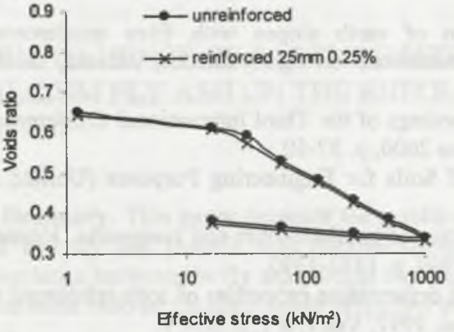

Fig. 9. Voids ratio-effective stress relationships of unreinforced and fibre-reinforced sandy clay

Rys. 9. Zależność wskaźnika porowatości od naprężenia rzeczywistego gliny piaszczystej niewzmocnionej i wzmocnionej włóknami

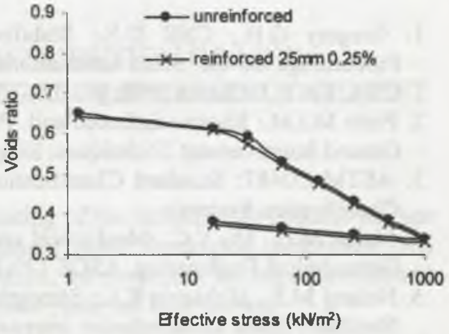

Fig. 10. Coefficient of consolidation-effective stress relationships of unreinforced and fibre-reinforced sandy clay

Rys. 10. Zależność współczynnika konsolidacji od naprężenia rzeczywistego gliny piaszczystej niewzmocnionej i wzmocnionej włóknami

5. Conclusion

The direct shear laboratory tests on fibre-reinforced and unreinforced sandy clay indicate that a substantial increase in shear resistance can be achieved with a low quantity (0.25% by dry unit weight of soil) of short length (25 mm), randomly oriented polypropylene fibres. Test results show that fibre-reinforcement modifies shear stress-displacement behaviour of sandy clay in a significant manner and improves its shear resistance. The level of improvement depends on the deformation level induced in the soil, the maximum improvement corresponding to higher deformation levels. It depends also on the normal stress level, and the improvement decreases with increase in the normal stress level. A significant increase in the apparent cohesion value of sandy clay due to fibres was found. The one-dimensional compressibility behaviour of fibre-reinforced and unreinforced sandy clay is quite similar. The consolidation properties indicate that fibre-reinforcement increases the permeability of sandy clay for low effective stresses and reduces it for higher effective stresses. However, it seems that a larger specimen size would be more suitable to investigate the influence of fibre-reinforcement on the behaviour of the sandy clay.

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