Soil improvement using polyester fibres

Giang Nguyen\textsuperscript{a, b} *, Eva Hrubešová\textsuperscript{c}, Adam Voltr\textsuperscript{c}

\textsuperscript{a}Faculty of Civil Engineering, University of Žilina, Univerzitná 8215/1, Žilina 010 26, Slovakia
\textsuperscript{b}Faculty of Materials, Civil and Environmental Engineering, University of Bielsko-Biela, Willowa 2, 43-309 Bielsko-Biela, Poland
\textsuperscript{c}Faculty of Civil Engineering, VŠB - Technical University of Ostrava, Ludvíka Poděště 1875/17, 708 33 Ostrava – Poruba, Czech Republic

Abstract

The paper deals with soil improvement using polyester fibres of length 70mm mixed in soil SC as random reinforcement in amount of 0.5\%, 1.0\% and 1.5\%. Improvement of soil was measured by direct shear tests, using shear box of size 0.3m x 0.3m x 0.15m. It will be shown that for tested soil, optimal amount of fibres is 1.0\%, when increase of angle of internal friction was up to 6.0\% (from 45.3\% to 51.3\%) and increase of cohesion was up to 17.5kPa (from 0 kPa to 17.5 kPa) in comparison with soil without fibres.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)

Keywords: Polyester fibres; Soil improvement; Random reinforcement; Direct shear test; Angle of internal friction; Cohesion.

1. Introduction

In geotechnical practice, there are many cases when it is necessary to improve soils. There are also many methods to improve soils, including using natural and synthetic fibres. A simple review of soil reinforcement by using natural and synthetic fibres is introduced in [1]. By the authors, availability, economical benefits, easy to work, rapid to perform and feasibility of using in all weather conditions are the general advantages of short fibre composite soils. The authors also state that strength and stiffness of the composite soil is improved by fibre reinforcement. They concluded that the increase in strength and stiffness was reported to be a function of: fibre characteristics such as aspect ratio, skin friction, weight fraction and modulus of elasticity; of sand characteristics such as shape, particle

* Corresponding author. Tel.: +421-41-513-5759; fax: +421-41-5135510.
E-mail address: giang.nguyen@fstav.uniza.sk
size and gradation; of test condition such as confining stress. On the basis of predictive models presented in the
paper, they state that it is clear that the strength of fibre reinforced soil increases with increase in aspect ratio, fibre
content, fibre modulus and soil fibre surface friction. Direct shear test, unconfined compression tests and
conventional triaxial compression tests have demonstrated that shear strength is increase and post-peak strength loss
is reduced when discrete fibres are mixed with the soil.

Because there are various kinds of soils to be improved and we can use various kinds of fibres with different
properties, it is always necessary to carry out the tests to find improvement rate. In this paper we will introduce
results of direct shear tests, carried out on soil specimens with polyester fibres.

Concerning direct shear tests, there are many documents dealing with them, e. g. Slovak Technical Standard STN
72 1030 [2] (abbreviation STN); Polish Standard PN-88/B-04481 [3] (abbreviation PN); document of European
Technical Committee ETC5-F2.97 [4]; ISO/TS 17892-10:2004 [5]; British Standard BS 1377: Part 7:1990 [6];
American Standards ASTM Designation: D 3080-04 [7] (abbreviation ASTM) and AASHTO Designation: T 236-08
[8] (abbreviation AASHTO). From all mentioned documents, only PN prescribes to take into account continual
change in the shear area. The ASTM states that factors which incorporate assumptions regarding the actual
specimen surface area over which the shear and normal forces are measured can be applied to the calculated values
of shear or normal stress, or both. The STN does not mention on shear area changes during the shear. The AASHTO
does not present even formula for calculation of shear and normal stress. Rest of the documents remarks that shear
area changes during the shear normally are not taken into account.

We can expect that result shear stresses calculated by reduced shear area will be higher, making higher values of
shear strength parameters. Therefore we will also deal with influence of the continual change in the shear area on
values of soils shear strength parameters of soil specimens with polyester fibres.

2. Direct shear tests of soil mixed with polyester fibres

To examine improvement rate of soil mixed with polyester fibres, the soil SC with amount of fine particles
20.1%, sandy particles 63.0%, gravelly particles 14.9%, liquid limit 31.2%, plastic limit 14.1%, maximum dry
density 2091 kg.m⁻³ and optimal moisture content w_{opt} = 9% [9] had been used. Polyester fibres TEXZEM PES 200
from Bonar Geosynthetics a. s. had following properties: density 1.38 g.cm⁻³, melting point 240 °C, linear mass
density 2200 dtex, tensile strength 7.77 cN/dtex and elongation at break 10.6%. The fibres had length 70 mm and
white colour. Direct shear tests had been carried out using fully automatic large shearbox apparatus SHEARMATIC
300 from CONTROLS s. r. l.. Specimens size was 0.3 m x 0.3 m x 0.15 mm (specimens were compacted at the
maximum dry density 2091 kg.m⁻³ and optimal moisture content), consolidation time 20 min and shear speed
0.5 mm/min. Specimens without polyester fibres and with polyester fibres in amount of 0.5%, 1.0% and 1.5% of soil
dry mass had been tested at normal stresses 50 kPa, 100 kPa and 200 kPa. The tests were terminated when the
horizontal displacement has reached 20% of the width of the specimen. Calculation of maximum shear stress had
been carried out for two cases (see also [3]):

a) without taking into account continual change in the shear area:

\[ \tau = \frac{P}{a.a} \]  \hspace{1cm} (1)

where: \( P \) [kN] is the horizontal shear force and \( a \) [m] is the specimen size.

b) taking into account continual change in the shear area:

\[ \tau = \frac{P}{a.(a-r)} \] \hspace{1cm} (2)

where: \( P \) [kN] is the horizontal shear force; \( a \) [m] is the specimen size and \( r \) [m] is shear displacement.

The maximal values of shear stress obtained from direct shear tests for above mentioned case a) and case b) can
be seen in the Tab. 1 and Tab. 2. Their differences can be seen in the Tab. 3.
Table 1. Maximal values of shear stress without taking into account continual change in the shear area (case a).

| Normal stress (kPa) | Maximal values of shear stress for specimens with various amounts of fibres (kPa) |
|---------------------|------------------------------------------------------------------|
|                     | 0%                  | 0.5%               | 1.0%               | 1.5%               |
| 50                  | 48.7                | 60.8               | 86.6               | 82.5               |
| 100                 | 104.1               | 127.2              | 133.8              | 142.5              |
| 200                 | 201.2               | 231.3              | 271.0              | 269.0              |

Table 2. Maximal values of shear stress taking into account continual change in the shear area (case b).

| Normal stress (kPa) | Maximal values of shear stress for specimens with various amounts of fibres (kPa) |
|---------------------|------------------------------------------------------------------|
|                     | 0%                  | 0.5%               | 1.0%               | 1.5%               |
| 50                  | 51.2                | 63.8               | 92.9               | 86.7               |
| 100                 | 113.2               | 137.6              | 155.5              | 169.2              |
| 200                 | 227.9               | 285.8              | 329.0              | 303.7              |

Table 3. Differences between maximal values of shear stress obtained from case a) and b).

| Normal stress (kPa) | Differences between maximal values of shear stress for specimens with various amounts of fibres obtained from case a) and b) in kPa and in % (numbers in parentheses) |
|---------------------|------------------------------------------------------------------|
|                     | 0%                  | 0.5%               | 1.0%               | 1.5%               |
| 50                  | 2.5 (5.1%)          | 3.0 (4.9%)         | 6.3 (7.3%)         | 4.2 (5.1%)         |
| 100                 | 9.1 (18.7%)         | 10.4 (18.6%)       | 21.7 (16.2%)       | 26.7 (18.7%)       |
| 200                 | 26.7 (13.3%)        | 54.5 (23.6%)       | 58.0 (21.4%)       | 34.7 (12.9%)       |

As we can see from the Tab. 3, differences between maximal values of shear stress obtained with and without taking into account continual change in the shear area are not negligible. The difference is larger for higher normal stress and has reached e. g. value up to 58 kPa (21.4%).

Values of shear strength parameters of soil obtained without and with continual change in the shear area can be seen in the Tab. 4 and soil improvement by various amounts of fibres can be seen in the Tab. 5.

Table 4. Values of shear strength parameters of soil obtained without and with continual change in the shear area and their differences.

| Amount of fibres (%) | Values of shear strength parameters and their differences                                                                 |
|----------------------|-------------------------------------------------------------------------------------------------------------------------|
|                      | Without change in the shear area | With change in the shear area | Differences                                                                 |
|                      | $\phi$ (°) | c (kPa) | $\phi$ (°) | c (kPa) | $\phi$ (°) | c (kPa) |
| 0                    | 45.25 (45.27) | 0.0 (-0.13) | 48.48 (49.54) | 0 (-6.47) | 3.2 (7.1%) | 0 (0%) |
| 0.5                  | 48.2       | 8.8     | 54.62 (55.93) | 0 (-10.54) | 6.3 (13.1%) | -8.8 (-100.0%) |
| 1.0                  | 51.3       | 17.5    | 57.9       | 5.4      | 6.5 (12.9%) | -12.0 (-69.0%) |
| 1.5                  | 51.2       | 19.1    | 55.1       | 18.9     | 3.9 (7.6%) | -0.2 (-0.8%) |

The values of shear strength parameter in parentheses (see also negative values of cohesion) in the Tab. 4 were obtained from values of shear stress from the Tab. 1 and Tab. 2. Since there is no reason to exclude particular test, it is necessary by [2] to calculate shear strength parameters, supposing $c = 0$ kPa (results are numbers before parentheses). High values of negative cohesion (-6.47 kPa and -10.54 kPa; with change in the shear area) maybe resulted from the fact that there are only 3 values of the normal stress (only 3 particular tests) so values of shear strength parameters are very sensitive to a small change of shear stress, which can be caused e. g. by measurement
uncertainty. So the PN [3] takes into account continual change in the shear area but prescribes to carry out at least 5 particular tests (5 values of the normal stress). The differences in values of shear strength parameters obtained with and without taking into account continual change in the shear area are relatively high (up to 13.1% for angle of internal friction). From the reason that it is proposed linear relationship between normal and shear stress, increase in values of angle of internal friction cause decrease in values of cohesion (see 2 last columns in the Tab. 4). We would like to note that when carried out only 3 particular tests (possible e. g. by [4], [5], [6], [7] and [8]); taking into account continual change in the shear area can provide inadequate high values of shear strength parameters.

Concerning soil improvement by various amounts of fibres, respecting above mentioned note, we can state that for tested soil and fibres, optimal amount of fibres is 1.0% (see bold numbers in the Tab. 5; “NA” means Not Applicable from the reason of division by zero). Increase of fibres amount to 1.5% causes negligible change in shear strength parameters.

| Soil improvement by various amounts of fibres | Increase of shear strength parameters by various amounts of fibres |
|---------------------------------------------|---------------------------------------------------------------|
|                                             | Without change in the shear area | With change in the shear area |
|                                             | $\phi$ (°) | $c$ (kPa) | $\phi$ (°) | $c$ (kPa) |
| Differences between 0.5% and 0%            | 3.0 (6.7%) | 8.8 (NA%) | 6.2 (12.7%) | 0 (0%)    |
| Differences between 1.0% and 0%            | 6.1 (13.5%) | 17.5 (NA%) | 9.5 (19.5%) | 5.4 (NA%) |
| Differences between 1.5% and 0%            | 6.0 (13.2%) | 19.1 (NA%) | 6.7 (13.7%) | 18.9 (NA%) |
| Differences between 1.0% and 0.5%          | 3.1 (6.4%) | 8.7 (98.2%) | 3.3 (6.1%) | 5.4 (NA%) |
| Differences between 1.5% and 0.5%          | 3.0 (6.1%) | 10.3 (117.2%) | 0.5 (0.9%) | 18.9 (NA%) |
| Differences between 1.5% and 1.0%          | -0.1 (-0.3%) | 1.6 (9.6%) | -2.8 (-4.9%) | 13.5 (251.1%) |

3. Conclusions

Using polyester fibres TEXZEM PES 200 considerable improves tested soil SC. It is shown that in this case, the optimal amount of fibres is 1.0%. We do not recommend taking into account continual change in the shear area when evaluating direct shear tests if only 3 particular tests had been carried out.

Acknowledgements

This contribution is supported by the grant project of ESF “Creation of scientific teams” CZ.1.07/2.3.00/20.0013 and also by the European Regional Development Fund and the Slovak state budget for the project “Research Centre of University of Žilina”, ITMS 26220220183. We would like to thank also company Bonar Geosynthetics a. s. for providing the fibres.

References

[1] Sayyed Mahdi Hejazi, Mohammad Sheikhzadeh, Sayyed Mahdi Abtahi, Ali Zadhoush, A simple review of soil reinforcement by using natural and synthetic fibers, Construction and Building Materials 20 (2012) 100-116.
[2] STN 72 1030: Laboratory methods of determination of soil shear strength by box shear apparatus (in Slovak language). Prague : Publishing house UNM, Praha, 1988.
[3] PN-88/B-04481: Building soils – Laboratory tests (in Polish language). Warszaw : Publishing house „Alfa”, 1988.
[4] Schuppener B., Boháč J., Dysli M.: Laboratory methods for direct shear tests. Document ETC5-F2.97.
[5] ISO/TS 17892-10:2004: Geotechnical investigation and testing. Laboratory testing of soil. Part 10 : Direct shear test. Geneva : International organization for standardization.
[6] BS 1377: Part 7:1990: British Standard Methods of test for Soils for civil engineering purposes. Part 7. Shear strength tests (total stress). London: British Standards Institution.
[7] ASTM D 3080 – 4: 2004, Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. West Conshohocken: ASTM International.
[8] AASHTO T 236-08: 2008, Standard Method of Test for Direct Shear Test of Soils under Consolidated Drained Conditions. Washington: American Association of State Highway and Transportation Officials.

[9] A. Voltr, Laboratory tests of soils improved by synthetics fibers. Diploma thesis (in Czech language), 2014.