MATEC Web of Conferences 196, 03023 (2018) https://doi.org/10.1051/matecconf/201819603023
XXVII R-S-P Seminar 2018, Theoretical Foundation of Civil Engineering

Application of geotextile ropes in slope erosion protection

Giang Nguyen[1,2] *, *Jan* Broda[2], and *Joanna* Grzybowska-Pietras[2]

[1]University of Žilina, Faculty of Civil Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia
[2]University of Bielsko-Biela, Willowa 2, 43-309 Bielsko-Biala, Poland

Abstract. Paper deals with application of geotextile ropes in erosion protection of slope of gravel pit in Nieboczowy, Poland. For protection of the slope the segments formed from thick ropes were applied. The ropes with the diameter of 120 mm were produced by the Kemafil technology. Ropes were made from strips of stitch-bonded nonwoven produced from a mixture of recycled natural and synthetic fibres and strips of wool needle-punched nonwoven. The protected slope had the length of 4 to 6 m, slope inclination from 1:1 to 1:1.8 and total area of approximately 150 m^2. It will be shown that installed ropes restrain soil so there is no slope failure in protected section even in case of low soil shear strength parameters and unfavourable hydraulic conditions. Generally slope surface in protected section is without rills and gullies. This case also shows that plants are very good anti-erosion measure. Thanks ropes installed on the slope, favourable conditions for plants growth are created and maintained.

1 Introduction

Soil erosion is serious problem and effects nature as so as various artificial slopes. There are many factors determining soil erosion such as climate, soil characteristics, topography, ground cover, duration of soil exposure and human activities. Various techniques are applied to protect a slope from erosion. There are some techniques using geosynthetics as anti-erosion measures such as Husker Fortrac 3D® [1-2] or Presto GEOWEB® [3]. These techniques not only protect slope erosion but also stabilize slope surface. However such geosynthetics do not keep water which can be provided to vegetation on the slope during a drought.

In addition to mentioned technologies, new geotextile ropes were invented few years ago. The innovative geotextile ropes were built from meandrically arranged thick ropes which were connected into segments with additional linking chains. The geotextile ropes were successfully used for the stabilization of the slopes in disused lignite mine, as well as for the protection of the drainage slope, terrace slope and road side ditches [4-10].

For the manufacturing of the ropes, the Kemafil technology and various materials (easily available on the local market) were used [5]. It was revealed that the pre-consumer or post-consumer textile wastes can serve as a valuable raw material for the manufacturing the

* Corresponding author: giang.nguyen@fstav.uniza.sk

geotextile ropes. The production of geotextile ropes extends the life of the fibres and is an interesting alternative to troublesome methods of waste textiles disposal.

This paper introduces application of geotextile ropes in erosion protection of slope of gravel pit in Nieboczowy, Poland.

2 Site characterisation

Investigations were performed in abandoned gravel pit Nieboczowy located near Raciborz in southern Poland. The area is located close to the Czech-Polish border in Silesia in the north part of Moravian Gate, the depression between the Carpathian Mountains in the east and the Sudetes in the west. The site belongs to the floodplain of the Oder river, the second largest river in Poland. The valley is rich in sand and gravel deposits. The abundant deposits are located shallowly under the soil and a thin layer of sand or clay and possess big thickness exceeding locally 15 m. Due to high demand for mineral aggregates the rich gravel deposits are intensively exploited.

In gravel pit Nieboczowy, after several years of exploitation, the deposits were exhausted and the extraction of gravel was interrupted. As a result of mining deep extraction pit with a depth of approximately 10 m was formed. The pit was naturally filled with water to form small pond (Fig.1).

On the banks of the pit steep unstable slopes prone to local sliding and slipping were generated. In the north-facing bank of the excavation on the surface of native ground the artificial embankment with a high ca. 4 m was formed. The embankment erected from overburden material mined during mine operation coupled with the steep slope cut in native ground was especially unstable and endangered by local sliding (Fig.1).

Fig.1. The disused excavation of the gravel pit Nieboczowy
(left: a pond with slide; right: a plane translational slip of north-facing bank).

3 Anti-erosion measures

For protection of the slope the geotextile segments formed from thick ropes were applied. The ropes with the diameter of 120 mm were produced by the Kemafil technology [11]. The ropes were manufactured from strips of wool needle-punched nonwoven and strips of stitch-bonded nonwoven made from a mixture of recycled natural and synthetic fibres obtained by the shredding and carding of post-consumer textile wastes. The part of the ropes made from recycled fibres was manufactured with addition of perennial ryegrass *(Lolium perenne*) seeds.

The ropes were meandrically arranged to form segments with the width of 1.8 m and the length of 6 m. In order to stabilize the segments, the subsequent turns of the ropes were connected with additional links made from thick polypropylene twine. Geotextiles ropes were used to secure a total area of approximately 150 m^2 in the most threatened part of the slope. The protected slope had the length of 4 to 6 m and the slope inclination from 1:1 to 1:1.8. The ropes were anchored in the crown of the slope and fastened at the surface with steel pins. The long “U-shaped” pins made from ribbed bars of diameters ϕ = 8 mm were used. To protect bigger section of the slope the subsequent segments of ropes were spread alongside one another. Slope with installed ropes can be seen in the Fig. 2 (left). Effectiveness of installed ropes can be seen in Fig. 2 (right). As we can see in Fig. 2 (right), there are many vegetation and no signs of erosion exist in the protected slope part.

Fig.2. Effectiveness of geotextile ropes as anti-erosion measure (left: slope state on 09.02.2016; right: slope state on 23.06.2016).

4 Slope stability determination

After 20 months from ropes installation, visitation of protected location took place on 22nd October 2017, during which soils samples were taken for further analyses. General view of the protected slope can be seen in the Fig. 3. Numbers on Fig. 3 mark soil samples locations which were chosen in the left, central and right part of the slope (horizontally) and in the central slope part (vertically). Generally, the slope is well protected and covered with rich plants.

Fig. 3. General view of the protected slope in Nieboczowy
(numbers mark soil samples locations, state of slope on 22.10.2017).

Details of soil samples locations No. 1, No. 2 and No. 3 with installed ropes can be seen in the Fig. 4. It is obviously that the upper soil layer of thickness about 20cm (cover layer) seams different from the lower layer. From mentioned reason 2 soil samples from every location were taken and analysed. Specimens are marked based on location (No. 1, 2 or 3) and letter (letter “a” for upper layer and letter “b” for lower layer), so e. g. specimen marked as “1a” is taken from location No. 1 and it is soil from upper layer.

Determination of soil particles size distribution was carried out in accordance with the BS 1377: 1990. Part 2 (wet sieving method and sedimentation by the hydrometer method) [12]. Grain size diagrams of soils in protected section can be seen in Fig. 5.

Fig. 4. Detail of soil samples locations No. 1, No. 2 and No. 3 (from left to right)

Soil basic parameters such as water content (w), liquid limits (w_L) and plastic limits (w_P) were also determined in accordance with mentioned standard. Based on obtained values, soils classifications were carried out in accordance with the British Standard BS 5930:2015 [13]. Soils classifications and properties are posted in Tab. 1. Further parameters in the Tab. 1 were calculated in accordance with PN-81/B-03020 [14] and well-known formulas in soil mechanics.

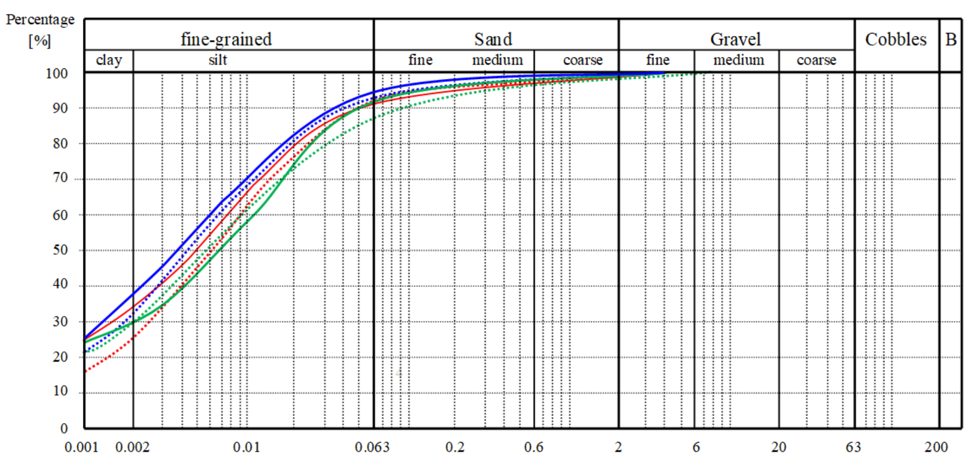

Fig. 5. Grain size distribution diagram of soils: Red dash line and solid line (location No. 1, top and down sample); Blue dash line and solid line (location No. 2, top and down sample); Green dash line and solid line (location No. 3, top and down sample).

Table 1. Soil properties and factors of safety of slope for case without ropes.

Specimen number	*1a*	1b	*2a*	2b	*3a*	3b
Location	*No. 1 (upper)*	No. 1 (lower)	*No. 2 (upper)*	No. 2 (lower)	*No. 3 (upper)*	No. 3 (lower)
Graphical presentation	*Red dash line*	Red solid line	*Blue dash line*	Blue solid line	*Green dash line*	Green solid line
Soil classification by BS 5930:2015	*CH*	CH	*CH*	CH	*CH*	CI
Clayey fraction amount [%]	*28.7*	34.9	*32.1*	35.1	*30.7*	30.9
Silty fraction amount [%]	*63.3*	55.9	*61.3*	61.4	*56.7*	62.9
Sandy fraction amount [%]	*7.8*	9.0	*6.5*	3.5	*12.4*	6.2
Gravelly fraction amount [%]	*0.2*	0.2	*0.1*	0.0	*0.2*	0.0
Water content (w) [%]	*37.9*	26.7	*32.9*	28.5	*32.8*	24.9
Plastic limit w_P [%]	*26.2*	19.6	*24.4*	20.8	*20.6*	19.1
Liquid limit w_L [%]	*52.5*	51.9	*56.9*	59.3	*53.1*	48.9
Plasticity index I_P [%]	*26.3*	32.3	*32.5*	38.5	*32.5*	29.7
Liquidity index I_L [-]	*0.45*	0.22	*0.27*	0.20	*0.38*	0.20
Soil unit weight γ [kN.m^{-3}]	*17.575*	18.271	*18.142*	18.332	*17.787*	18.346
Unit weight of solid particles γ_s [kN.m^{-3}]	*26.800*	27.000	*27.000*	27.000	*27.000*	27.000
Unit weight of dry soil γ_d [kN.m^{-3}]	*12.744*	14.420	*13.650*	14.262	*13.390*	14.680
Porosity n [-]	*0.52*	0.46	*0.49*	0.47	*0.50*	0.45
Saturated soil unit weight γ_{sat} [kN.m^{-3}]	*17.889*	18.990	*18.501*	18.890	*18.335*	19.156
Effective soil unit weight γ' [kN.m^{-3}]	*8.079*	9.180	*8.691*	9.080	*8.525*	9.346
Effective angle of internal friction φ' [°]	*10.8*	14.5	*13.7*	14.8	*11.9*	14.8
Factor of safety F_s for m = 0 [-]	*0.19*	0.25	*0.24*	0.26	*0.21*	0.26
Factor of safety F_s for m = 1 [-]	*0.08*	0.12	*0.11*	0.12	*0.09*	0.12

Grain size diagram of soils taken in three places are close to each other and classifications of soils are very similar (CH and CI). Only specimen of number 3b (location No. 3, lower layer) is classified as CI (clay of intermediate plasticity). However, its liquid limit (w_L = 48.9%) is very close to 50%, which is the limit value between CI and CH (see Tab. 1). Large amount of silty fraction in soils (from 55.9% up to 63.3%) shows their sensibility to erosion.

For soils from upper layers (specimens 1a, 2a and 3a) water content is higher (from 32.8% to 37.9%). This may be evidence that ropes possess ability to hold water and to provide it to growing plants. Consequently higher water content of upper layers gives higher liquidity indexes (0.45, 0.27 and 0.38) and then lower angle of internal friction and lower factor of safety. So larger water content is favourable for plants growth, but on the other hand is not favourable for slope stability. However, thanks installed ropes (mentioned in following text), slope remains stable; water content of soil in slope can remain high providing plant suitable condition to grow so erosion is restricted.

To determine factor of safety of slope, soil shear strength parameters (effective angle of internal friction $\varphi'$and effective cohesion c') are needed. By [14], the shear strength parameters of soils can be obtained using diagrams in the standard, based on soil group and density index I_D (cohesionless soil) or liquidity index I_L (cohesive soils). The standard differs 4 groups of cohesive soils, from which group C (unconsolidated cohesive soils) suits our case. Instead of using the diagrams, one can use also formulas (as a function of I_D and I_L) posted in [15], giving the same soils shear strength parameters as diagrams. The formulas for soils of group C are as follows [15]:

$$\varphi' = 18.00 - 16 I_L \tag{1}$$

$$c' = 30x0.07^{I_L} \tag{2}$$

Taking into account the fact that cover soil wad added to subsoil, in slope stability analysis, values of effective cohesion c´ on contact between them (possible slide surface) are considered to be zero. Values of effective angle of internal friction φ´ are posted in Tab. 1. Analysis of slope failure can be carried out as a case of plane translational slip, posted in [16], see Fig. 6.

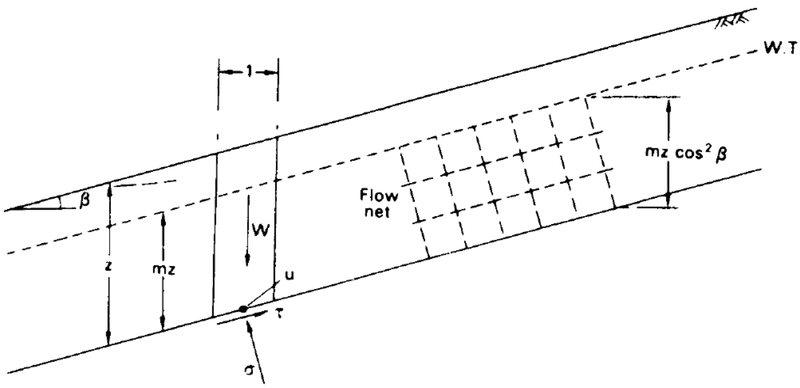

Fig. 6. Plane translational slip [16].

For this case, it is assumed that the potential failure surface is parallel to the surface of the slope and is at the depth that is small compared with the length of the slope. The slope can then be considered as being of infinitive length, with end effects being ignored. The slope is inclined at angle β to the horizontal (in our case we consider β = 45°) and the depth of the failure plane is *z*, as shown in Fig. 6 (thickness of cover layer containing ropes is about 20cm so a deep of failure surface in Fig. 6 is z = 0.28m). The water table is taken to be parallel to the slope at a height of *mz* ($0 < m < 1$) above the failure plane. Steady seepage is assumed to be taking place in a direction parallel to the slope. The forces on the sides of any vertical slice are equal and opposite, and the stress conditions are the same at every point on the failure plane. In terms of effective stress, the shear strength of the soil along the failure plane (using the critical-state strength) is [16]:

$$\tau_f = (\sigma - u)\tan\varphi'_{cv} \tag{3}$$

and factor of safety is:

$$F = \frac{\tau_f}{\tau} \tag{4}$$

The expressions for σ, τ and *u* are:

$$\sigma = \{(1-m)\gamma + m\gamma_{sat}\} z \cos^2\beta \tag{5}$$

$$\tau = \{(1-m)\gamma + m\gamma_{sat}\} z \sin\beta \cos\beta \tag{6}$$

$$u = mz\gamma_w \cos^2\beta \tag{7}$$

If the soil between the surface and the failure plane is not fully saturated (i. e. m = 0) then:

$$F = \frac{\tan \varphi'_{cv}}{\tan \beta} \tag{8}$$

If the water table coincides with the surface of the slope (i. e. m = 1) then:

$$F = \frac{\gamma' \tan \varphi'_{cv}}{\gamma_{sat} \tan \beta} \tag{9}$$

In formulas (5), (6), (7) and (9), γ is soil unit weight [kN.m^{-3}], γ' [kN.m^{-3}] is soil effective unit weight and γ_{sat} is unit weight of saturated soil.

Factors of safety F_s calculated using formula (8) for m = 0 and (9) for m = 1 can be seen in Tab. 1. As we can, very large inclination of slope (45^o) in comparison with very low angle of internal friction (from 10.8° to 14.8°) cause instability of slop even in the case that soil between the surface and the failure plane is not fully saturated (m = 0). Thanks installed ropes, slope remains stable; water content of soil in slope can remain high and provide vegetation suitable condition to grow so erosion is restricted.

5 Conclusions

Erosion of slope in Nieboczowy is effectively restricted by geotextile ropes in combination with grass seeds. While the central part of the slope, where ropes are installed, is stable, the left and right part of the slope is severe effected by erosion.

As we can see in this case, installed ropes restrain so there is no slope failure in protected section even in the case soil shear strength parameters decrease and hydraulic conditions are not favourable (e. g. during a heavy rain). Generally slope surface is plane in protected section and installed ropes restrict creating rills and gullies. This case also shows that plants are very good anti-erosion measure. Thanks ropes installed on the slope, favourable conditions for vegetation growth are created and maintained.

Slope stability analysis shows that ropes effectively retained uncompacted soil with low values of angle of internal friction which could be failed without ropes. So we can expect universal rope using for various geotechnical conditions. Based on ropes cover soil properties and rope properties, distance between ropes can be optimized so application of ropes can be suitable also from economical point of view.

The authors gratefully acknowledge the funding by ERANET-CORNET consortium under the international research project PROGEO 2 “Geotextiles from Sustainable Raw Materials and Textile Waste, New Mobile Production Technology and New Application Fields in Drainage and Hydraulic Engineering” DZP/CORNET/1/20/2017.

References

1. http://www.huesker.com/
2. http://www.huesker.com/fileadmin/Media/Reports/EN/JR_E_F_Embankments_Bridging_of_Sinkjholes_Fortrac-A1-Polen.pdf
3. http://www.prestogeo.com/
4. M. Seeger, Knitting International **115** 28 (2009)
5. J. Broda, A. Gawłowski, M. Rom, R. Laszczak, A. Mitka, S. Przybyło, J. Grzybowska-Pietras, Tekstilec **59** 2 (2016)

6. J. Broda, S. Przybyło, K. Kobiela-Mendrek, M, Rom, , J. Grzybowska-Pietras, R. Laszczak, Int. Biodeterior. Biodegradation **115** 31-38 (2016)
7. J. Broda, A. Gawłowski, R. Laszczak, A. Mitka, S. Przybyło, J. Grzybowska-Pietras, M. Rom, Geotext Geomembranes, **45** 1 (2017) http://dx.doi.org/10.1016/j.geotexmem.2016.07.003
8. J. Broda, A. Gawłowski, S. Przybyło, D. Biniaś, M. Rom, J. Grzybowska-Pietras, R. Laszczak, J. Ind. Text. (Article first published online: March 20, 2017) https://doi.org/10.1177/1528083717695837
9. J. Broda, J. Grzybowska-Pietras, G. Nguyen, A. Gawłowski, R. Laszczak, S. Przybyło, IOP Conf. Ser.: Mater. Sci. Eng. **254** 192005
10. J. Broda, A. Gawłowski, J. Grzybowska-Pietras, M. Rom, S. Przybyło, R. Laszczak, Inżynieria Ekologiczna = Ecological Engineering **18** 1 (2017)
11. R. Arnold, A. M. Bartl, E. Hufnagl, Band- und Flechtindustrie **30**, 4-10, 76-81 (1993)
12. BS 1377 : 1990. Part 2 : Methods of test for soils for civil engineering purposes. Part 2. Classification tests, London : British Standards Institution, 1990.
13. BS 5930:2015 Code of practice for ground investigations, London: British Standards Institution, 2015.
14. PN-81/B-03020: Building soils. Foundation bases. Static calculation and design (in Polish language), Polish Committee for Standardization, Warsaw (1981)
15. J. Pieczyrak, *Introduction to geotechnics (in Polish language)* (Publishing house „Dolnośląskie Wydawnictwo Edukacyjne", Wrocław, 2014)
16. R. Craig, R. F. 2004. *Craig´s Soil Mechanics (*Spon Press, New York, 2004)