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Contribution of vegetation to the shearing resistance of soil

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Abstract. Erosion and shallow landslides are the most common type of instabilities that occur during the life cycle of earth structures and the operation of traffic infrastructure. Vegetation has a significant contribution to their minimization, although we are still lacking a holistic approach to include the geo-ecological conditions and connect them with the hydro-meteorological hazards. Laboratory research was carried out to examine the relationship between the slope vegetation and the occurrence of erosion or shallow landslides, which included monitoring of slopes – made of soil materials placed in metal cases at certain angle – during simulation of a rainfall. A typical life cycle of slope in road infrastructure was simulated and monitored, i.e., its behaviour without vegetation, with green vegetation and with dry vegetation, under different real climate scenarios: cycles of intense rainfalls followed by a dry period. This was followed by sampling and laboratory testing of the materials. Some of the results on the impact of vegetation on changes of the shearing resistance obtained in this research are given below.

Keywords: Slopes; Vegetation; Rainfalls; Shearing resistance parameters

1 INTRODUCTION

The construction of traffic infrastructure inevitably entails slope design. Although slopes are considered to be a safe and permanent solution, their stability can still be undermined by external or atmospheric influences. Surface erosion is one of the most common challenges that often leads to global stability impairment in shallow or deep format. Several solutions are used to improve the stability and increase the safety of slopes, and one of them is the application of vegetation, as part of bioengineering measures. In addition to improving the resistance to erosion and increasing the stability of slopes, vegetation also contributes to the preservation of the environment, advancement of the animal and plant life and, without a doubt, improved aesthetic appearance by merging the traffic infrastructure with its surroundings. Nevertheless, despite centuries of empirical implementation of the benefits, we are still lacking a holistic approach to include the geo-ecological conditions and connect them with the relevant hydro-meteorological hazards.

2 RESEARCH METHODOLOGY

Considering the forementioned challenges, the Geotechnical Laboratory within the Faculty of Civil Engineering in Skopje, R. N. Macedonia, has carried out tests which included physical models and laboratory tests. In other words, we've conducted research to explore the relationship between the grass vegetation on earthwork slopes and the instances of erosion or shallow landslides caused by rainfalls. We performed experiments on model slopes and monitored their condition under a rainfall, both for slopes with and without vegetation, using two materials (silty and sandy) taken from a cut at km 11+500 of an expressway under construction in R. N. Macedonia. We've carried out plenty of activities and tests, starting with defining their physical and mechanical properties (Fig. 1).

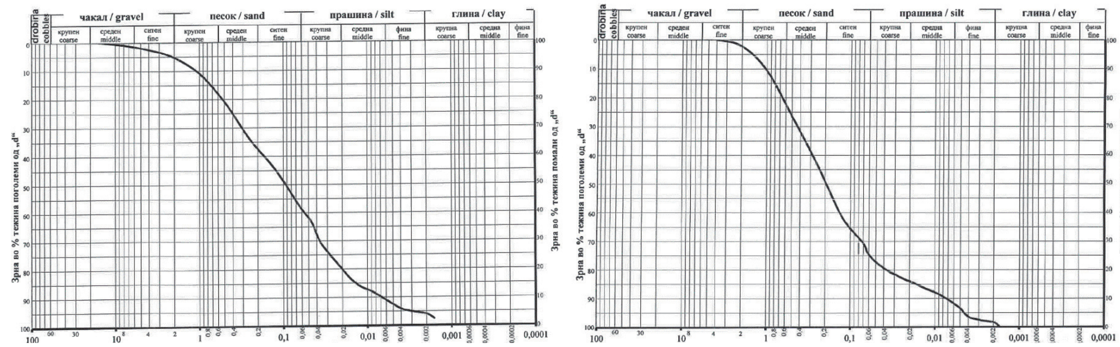

Figure 1 Granulometric content of the used silty (left) and sandy (right) material

Respecting the determined in situ bulk density, the materials were placed in metal cases with following dimensions: Length x Width x Height = 1.0 x 0.5 x 0.2 m (Fig. 2). The drainage of cases was made possible on the upper and lower part at the lower end of the case (making use of cut and placed pipe, respectively), placed on an adaptable stand that enabled performing tests with various slope inclinations: in this particular case, the inclination was adjusted to be the same as the one provided within the design. Sensors for measuring moisture, temperature and suction were placed in the middle of the layers in two positions along the slopes. In this experiment we used the same type of multi-species grass mixture that is commonly found on the site planned for the slope construction: *Poa Pratensis* – 7 %, *Lolium Perenne* – 20 %, *Rosmarinus officinalis* – 30 %, and *Lolium Pooideae* – 43 %. The laboratory rainfall simulation was provided by four sprinklers with moisturizing capacity and pressure adjusted to the amount of water typical for precipitation in that country region, with a return period of 100 years: 33.6 mm/m^2 per hour.

Erosion and occurrence of shallow landslides on the modelled slopes in such settings were monitored visually during an hour of rainfall and an appropriate period after it, for different slope conditions: fallow slope, i.e., without vegetation (soon after placing the materials in cases); with green vegetation (40 days after the placing); and with dry vegetation (120 days after the placing). At the same time, the erosion for all of them was measured on the lower part of metal cases, where two containers were placed: the first one (placed below the cut on the upper part) collected the eroded material and water from the slope surface, while the other (placed below the pipe on the lower part) collected the filtered water that flowed through the soil.

Figure 2 Cases with modelled fallow slope (left), cases with slope with green vegetation (middle) and case(s) with dry vegetation (right)

The test also included examination of the granulometric composition of eroded material. Important were also the periods when the sprinkling was started, when the beginning of erosion or sliding of the material was observed, and the time the water started to flow down the pipe. After stopping the simulated rainfall, the timing of cessation of erosion and stopping of the water runoff was determined, with measuring of the mass or volume of eroded material and water in containers below the cases. In addition to physical modelling, numerical modelling of slopes was performed using the Slide 6.0 and PLAXIS 2D software with determination of the factor of safety for each slope, while some of input parameters were calibrated according to the properties, quantities, and timings measured within the laboratory experiments.

3 LABORATORY TESTS

Each stage of slope testing (without vegetation, with green vegetation and with dry vegetation) was followed by sampling for geotechnical laboratory tests. Thus, the shear strength parameters were determined through the direct shear test of saturated samples with dimensions of 60 x 60 mm (base) and 20 mm (height). The test was carried out with controlled deformation and velocity of v = 0.05 mm/min, as a consolidated drained test with three unusual normal stresses: 25 kPa, 50 kPa and 100 kPa. Low values of normal stresses were chosen to simulate loads that occur in a case of shallow sliding surfaces, i.e., at small depth, and to examine the form and the shape of the failure envelope.

At the same time, parameters for slopes with vegetation were tested for samples taken near the ground surface (named as "top" in tables 1 and 2) and from the deeper part of the slope ("bottom" in tables 1 and 2), i.e., at the distal part of the root system, in order to determine the influence of density, distribution and thickness of the roots on the shearing resistance parameters. Findings are shown in tables 1 and 2, both for the angle of internal friction and the calculated cohesion of applied materials.

Table 1. Change in parameters of the shearing resistance of silty material after cycles of intense rainfalls in conditions with green and dry vegetation vs. conditions without vegetation (top = soil sample taken from the upper part of the root system; bottom = from the lower part of the root system)

Type of slope	Angle of internal friction φ [deg]				Cohesion c [kPa]			
	top	bottom	average	change Δφ	top	bottom	average	change Δc
Without vegetation	26.5				18.0			
With green vegetation	23.6	23.2	23.4	-3.1	21.8	22.0	21.9	3.9
With dry vegetation	17.0	15.2	16.1	-10.4	23.0	27.5	25.3	7.3

Table 2. Change in parameters of the shearing resistance of sandy material after cycles of intense rainfalls in conditions of green and dry vegetation vs. conditions without vegetation (top = soil sample taken from the upper part of the root system; bottom = from the lower part of the root system)

Type of slope	Angle of internal friction φ [deg]				Cohesion c [kPa]			
	top	bottom	average	change Δφ	top	bottom	average	change Δc
Without vegetation	32.5				17.0			
With green vegetation	29.7	31.2	30.5	-2.1	23.5	22.8	23.2	6.2
With dry vegetation	24.4	25.5	25.0	-7.6	24.0	24.0	24.0	7.0

When considering the cohesion c, it is evident that the contribution of grass roots to the increase of cohesion values varies along the depth of the soil-root continuum. At the same time, the increases in cohesion are larger in presence of vegetation, with cohesion increasing from 18 kPa to 21.9 kPa and 25.3 kPa with green and dry vegetation, respectively (for silty material), and from 17 kPa to 23.2 kPa and 24 kPa, respectively for green and dry vegetation (for sandy material). It is worth mentioning that these registered amounts of increased cohesion are higher than some usually found in the scientific literature (~2-5 kPa; e.g., Norris et al. 2008). Given the type of materials and the representation of fractions, the root of green vegetation increases the cohesion of the sandy material significantly more when compared to the silty material, after which it slightly increases for both of them – 1 kPa roughly – in a case of dry vegetation.

4 DISCUSSION

The increased intensity of adverse weather and unfavourable climatic variations will contribute to the frequent loss of soil strength and occurrence of erosion. Protection should be designed in such a way that it can withstand frequent and increased flows. These tests, in which methods that provide the most rational information were applied, are useful for initial researches, but they may also be carried out on large scale or in actual field conditions in the future research studies. They can be used to determine the ways changes in moisture (due to evaporation or infiltration of a rainwater) affect the state of stress and strain in soils. They are also convenient for the development of early warning systems in real time, during dry periods.

However, it is necessary to consider whether and how to properly select the plant types to be used as vegetation in practice, having in mind the type of substrate/soil, the type of root system developed by the plant, its suitability for sowing in specific soil types, as well as the impact of environmental conditions. This decision should be made taking into account the use of vegetation species that are native to the environment in which they are sown, as they are already adapted to the local conditions. Also, it would be appropriate to carry out a control test for 1000-year rainfall in order to obtain even more relevant results, i.e., conditions in which the maximum unfavourable load is applied to the slopes.

In addition to the presented example, it would also be suitable to carry out further research activities: to combine grass sowing with shrubs and/or trees planting (a mixture of several types of vegetation will enhance the slope stabilization), and to analyse differences between the manual grass sowing and the automated hydroseeding (an approach that saves time, human resources and quickly achieves the effect). Certainly, the time factor should also be taken into account, both from the perspective of rheological conditions, as well as the most recent advancement in the science, experiences and knowledge, including the development of tools that would be of great assistance to competent persons and institutions.

The conducted model tests revealed that slopes without vegetation and under rainfalls with a return period of 100 years showed a high degree of erosion (for the silty material) and shallow landslide (for the sandy soil). This effect of the rainfall vanished after the grass was planted, and was also absent even if it was dry. The direct shear tests showed that the cohesion increased in presence of vegetation, which is due to the reinforcing effects of the root system in the soil, when it acts as an "anchor". Besides the roots, the increase of c and decrease of ϕ is partly due to the change in the granulometric composition: the erosion carries fractions of fine (small) sand that were tested with application of direct shear test, while coarse sand grains were not suitable for tests (due to observing the criterion that the maximum grain size must be 1/5-1/10 of the minimum dimensions of the sample), resulting in small fractions that reduce the friction and increase the cohesion. However, as this instruction was followed for all the tested samples, it is obvious that the effect of reinforcement is greater than the effect of saturation, since it keeps the material intact. Also, a slight non-linearity of the failure envelope was observed in case of lower stresses (Simeonovski, 2022).

5 CONCLUSIONS

Slopes may require planting, afforestation or sowing with appropriate types of plants or trees, whether they are in the design or construction stage, or if they are permanent in nature or had undergone some physical changes. The relationship between the shear strength and the resistance to penetration of the soil along the slope gives rise to the concept of biodiversity, used in the context of protection of slopes against shallow landslides and erosion. The top part of the slope can be suitable for sowing grass or planting low-growing vegetation, while its toe can be well adapted to planting bushes or trees. Namely, the grass would protect the slope from surface erosion, but it would also be suitable for retention of sediments that would be produced by runoff during any kind of erosion. On the other hand, trees planted at the slope toe may be acting as its support (due to the increased weight), at the same time providing an arching effect thanks to their strong roots and enabling additional slope stability and higher parameters of shearing resistance in a larger soil volume (along the length, width and depth).

These conditions and hypotheses have initiated research and laboratory experiment in which a typical life cycle of a soil slope in road infrastructure was modelled and enabled monitoring the behaviour of a slope:

- without vegetation (which corresponds to the construction of embankment or excavation),
- with green vegetation (probably relevant during most part of slope's life-time),
- with dry vegetation (expected couple of months during each year, especially for the actual climate circumstances in most part of, but not only, Southern Europe).

The test was conducted for a certain climate scenario, i.e., intense rainfalls with a return period of 100 years.

These models have proved many benefits of the vegetation system, for example:

- securing slopes against surface erosion and preventing development of shallow sliding surfaces;
- increasing the values of the cohesion of materials with green and dry vegetation, as opposed to materials without vegetation – the obtained results are even higher than those presented so far in the literature;
- large reduction of the amounts of infiltrated water on slopes with vegetation;
- contribution of the grass to the slope stability in a case of shallow sliding surfaces can be small, but still existing and evident in prevention of failure development, maintaining the slope of sandy material in a state of equilibrium;
- when analysing the stability of slopes, it is recommended to use the nonlinear failure envelope, in accordance with measurements in laboratory tests.

Intense rainfalls have adverse effects on the stability of natural and artificial slopes, since the infiltrated water increases the moisture and pore pressure and develops filtration, thus reducing suction in unsaturated soil and leading to lower shearing resistance; however, our experimental findings showed that vegetation can largely contribute to improving the overall slope condition. The conducted test provides the basis for further research and confirmation/verification in field conditions; meanwhile, it provides the application of its findings by, among other things, the use of sensors for measuring suction on slopes and automated activation of the irrigation system in a case of exceeded suction values, in order to preserve verdant vegetation. Additionally, the vegetation provides conditions for keeping the water in the soil, which is crucial in semi-arid and subhumid environments in which the water retention is essential for efficient irrigation management.

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