The use of geosynthetics for strengthening the soil base: a laboratory experiment to develop practical skills of postgraduate students

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ABSTRACT: In this article, the authors present a laboratory experiment, which was conducted with postgraduate students in the Research and Production Center *ENU-Lab* at *L.N. Gumilyov* Eurasian National University, Astana, Kazakhstan. The originality of the experiment lies in the combination of experimental modelling of subsidence soil and in determining the peculiarities of changes in strength and deformation properties in soil bases reinforced by geosynthetics. This experiment allows students to practice skills in geological investigations through the assessment of soil collapsing. A test programme and a compression apparatus manual have been developed to help students cope with the task. Upon completion, the students presented a comparative analysis of the data and plotted the dependence of changes in the height of the specimen on the load, and determined the coefficient of collapsing before and after reinforcement. The experimental activities of students during the experiment were also evaluated and compared with the aim of planning additional express courses to improve the quality of knowledge and skills.

INTRODUCTION

The system analysis in education allows for creating a sequence of disciplines studied by students and for its alignment with the required competencies. This is achieved through a logical connection of previously studied disciplines and further improvement of knowledge [1].

One of the features of the educational programme for postgraduate students is research work, during which the student acquires practical skills and methods of experimentation in solving scientific and technical problems [2]. In most cases, experimental studies are complex because they are devoted to the study of a set of parameters of a process. Thus, the study of reinforced soil is an important area in geotechnics, requiring research on the influence of various properties of geosynthetic materials on soil properties [3].

It should also be highlighted that the territory of the Republic of Kazakhstan is characterised by one of the most problematic engineering and geological conditions [4]. Also, almost a third of all areas of the territory of the republic are occupied by collapsible soils [5]. When construction is undertaken, the weight of the construction and the soils' own weight create a downward pressure, and when soaking these soils provide additional drawdown deformation caused by a radical change in the soil structure [6], which needs to be addressed. One of the effective methods of designing structures on collapsible soils is the reinforcement of foundation soils.

The use of different types of geosynthetics in road construction has been reported in previous studies; for example, Pershakov et all presented their functional interaction with other layers in the structure of road covering [7]. As indicated in yet another study, the use of various geosynthetics for the reinforcement of unpaved roads was found to have a relevant reinforcing effect only when used under a thin aggregate layer on a soft subgrade (formation) level [8].

Investigations of the first reinforcement layer depth for the sand subbase of a road by one type of geotextiles and two different geogrid specimens demonstrated the effects of different types of reinforcements for different first reinforcement layer locations. It was observed that the bearing ratio and load-settlement behaviour changed significantly with the first reinforcement depth [9]. Other studies presented some positive filtration properties of nonwoven geotextiles, due to which they have found wide application in road construction in Norway [10]. The economic effect was also noted and could be achieved by reinforcing the soil with geosynthetic materials for improving the performance of unpaved roads in rural areas [11].

In the literature review conducted by the authors of this article, special attention was paid to various methods for analysing changes in the properties of geosynthetic-reinforced soil. Many of the proposed methods are used to improve the strength properties of the soil. Therefore, one of the professional tasks of a geotechnical engineer is to assign the most effective structural solutions for the *foundation-soil base* system. So, the formation of theoretical and practical readiness of postgraduate students for building design in difficult soil conditions is an important element in studying.

In the experimental project for postgraduate students outlined in this article, a simulation of collapsible soils with *quasi-soil* using quick lime was conducted to establish the features of changes in deformation properties on the compression device of quasi-collapsible soil reinforced with geosynthetic material. The experience gained by the students involved in the experiment using one of the methods to improve soil bases is beneficial in their preparedness for professional practice. Hence, it is appropriate to include this type of projects in educational programmes for laboratory courses and research work for postgraduate students.

METHODS AND MATERIALS

The aim of the experiment for postgraduate students was to justify the use of reinforcement material for a strengthened soil base on collapsible soil. Empirical research methods were used in this work. The experiment consisted of four main steps as shown in Figure 1.

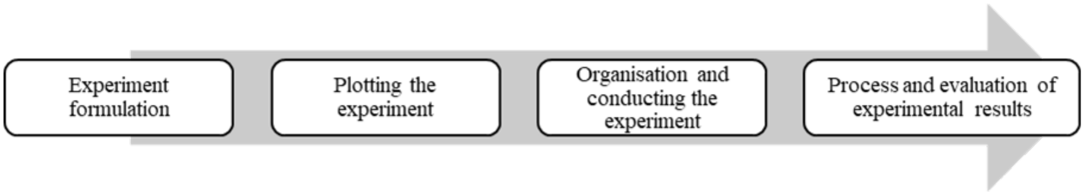


Figure 1: Flow chart of the experiment activities.

A pavement design with an asphalt concrete surface with a gravel base was considered in the investigation. When sampling undisturbed collapsible soil structure, it is difficult to preserve its natural state. Therefore, there are errors in laboratory tests, which affect the reliability of the test results. In this regard, it was artificial soil that was modelled according to the method proposed by Mustakimov [12], which would be similar in its properties to collapsible or *quasi-collapsible soil*.

After soaking, quenching and complete drying of samples of quicklime and soil of disturbed structure, pores and structurally unstable bonds are formed [13]. Also, at repeated soaking and under load they were destroyed, which subsequently led to large deformation of samples (collapsible). The first cycle of experiments was conducted under laboratory conditions to determine the effect of the percentage of quicklime and disturbed soil on quasi-soil collapsible. The second part was conducted to determine the effect of quasi-textile reinforcement on collapsibility. Non-woven geotextile was chosen as a reinforcing element.

The methodology of the odometer experiments with standard cut-off rings consisted of:

1. Preparation of the mixture. A mixture of disturbed loam and air binder-quicklime (CaO) was used to prepare quasi-sedimentary soil. The mixtures were made with the following dosages in ratios of quicklime-soil: 40%-60% (sample 1), 50%-50% (sample 2) and 60%-40% (sample 3).
2. a) Laying the mixture. The mixture of these components was placed dry in standard odometer shear rings with d = 20 mm (Figure 2a).
   b) Soaking the mixture. Soaking until full water saturation was carried out and the lime was quenched with a significant increase in the volume of the sample in the ring. The increase in the volume of artificially made samples at quenching of lime was in the range of 70-90% due to the formation of macropores (Figure 2b).
3. Sample drying. After complete quenching, the samples were subjected to drying in heating ovens.
4. Installing a shear ring with a dried sample into the odometer.
5. Conducting an experiment on the odometer (Figure 3). After installing the rings in the odometer, the samples were subjected to uniaxial compression. At that, loading was performed in stages and each loading was withheld until the settlements were stabilised (stabilisation condition was 0.01 mm/min).

a) b

Figure 2: Samples: a) before soaking; and b) after soaking.

Figure 3: Testing of quasi-soil samples on a uniaxial compression apparatus.

The load applied was 1 kg at a time up to 5 kg. To obtain collapsing, the specimen was soaked at 3 kg during the experiment. After each loading, strain values were taken with clock-type indicators. A coefficient of relative collapsing was used to describe the degree of quasi-soil collapsing.

RESULTS AND DISCUSSIONS

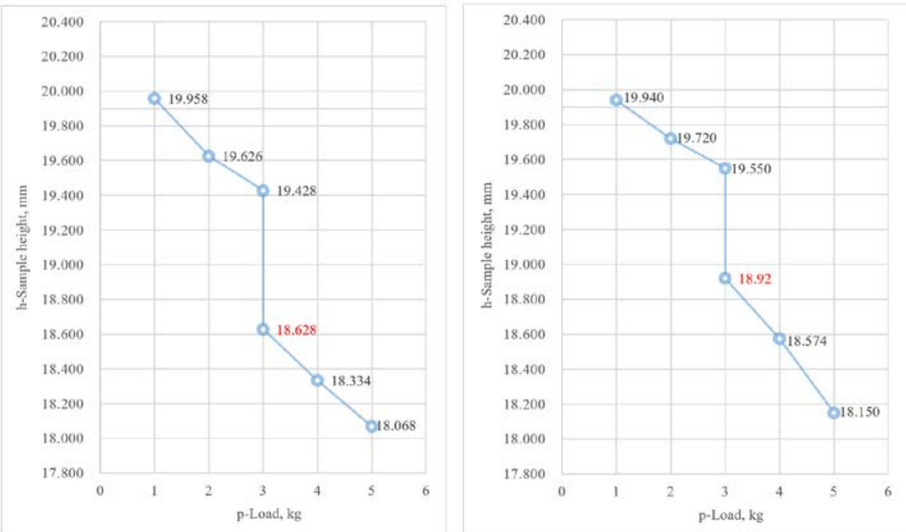
Effectiveness of Using Geosynthetics for a Strengthened Soil Base

The value of the coefficient of relative subsidence of the three samples showed that subsidence was increased when the content of quicklime increased [12]. Processed results after the quasi-collapsible soil test for the sample (loam 40% - quicklime 60%) are presented in Table 1.

Table 1: Processed results after the quasi-collapsible soil tests.

Load, kg	Time, minutes	Indicator		$\Delta h \times 0.002 - h$	
		Without geotextile	Reinforced by geotextile	Without geotextile	Reinforced by geotextile
Loam 40% - quicklime 60%					
1	15	21	30	19.958	19.94
2	15	187	140	19.626	19.72
3	15	286	265	19.428	19.55
3 (soaked)	45	666	540	18.628	18.92
4	15	833	713	18.334	18.574
5	15	966	925	18.068	18.15

The results presented in Figure 4 indicate that geotextile-reinforced quasi-sagging soil gives less rock-hard collapsibility during soaking than quasi-soil without geotextile.



a) b)

Figure 4: Dependence of change in sample height on load with soaking at 3 kg for soil ratio: a) without geotextile; and b) with geotextile.

Thus, reinforcement of quasi-sagging soil with geomaterials allows for increasing the bearing capacity of soil and improving its deformation properties (Table 2).

Table 2: Changes in relative collapse of quasi-soil.

Percentage proportion of soil and lime in quasi-soil	Coefficient of relative collapsing without geotextile reinforcement, ε_{sl}	Coefficient of relative collapsing with geotextile reinforcement, ε_{sl}
Soil 60% - Quicklime 40%	$\varepsilon_{sl} = 0.03 > 0.01$	$\varepsilon_{sl} = 0.021 > 0.01$
Soil 50% - Quicklime 50%	$\varepsilon_{sl} = 0.035 > 0.01$	$\varepsilon_{sl} = 0.03 > 0.01$
Soil 40% - Quicklime 60%	$\varepsilon_{sl} = 0.04 > 0.01$	$\varepsilon_{sl} = 0.0315 > 0.01$

Evaluation Results

Each stage of the experiment is characterised by the acquisition of practical skills and abilities of postgraduate students: modelling the soil and identifying changing properties during soaking (soil density, porosity, degree of wetness); the selection of the temperature of drying; work on the compression apparatus; determining the coefficient of relative collapsing; assessment of the effectiveness of reinforcement.

The evaluation of the experiment for postgraduate students was carried out according to a set of criteria. Grades were expressed in points from 1 to 10, with a grade of 1 indicating lack of compliance and a score of 10 meaning full compliance with the criteria. The postgraduate students were evaluated at each stage of the experiment, which is presented in Table 3. Research competencies were treated as criteria: K1 - ability to reproduce theoretical knowledge; K2 - independence in conducting the experiment; K3 - ability to set directions and build research logic; K4 - applying research methods, demonstrating skills in organising an experiment, software; K5 - the ability to interpret the results of the study, formulate conclusions, plan the continuation of research.

Table 3: Multi-criteria analysis.

Experiment activities	Indicator	Postgraduate student							
		1	2	3	4	5	6	7	8
Experiment formulation (Stage 1)	K1	10	9	10	10	9	10	10	10
	K3	10	9	10	9	10	10	10	9
	K4	9	9	9	9	9	9	9	9
Plotting the experiment (Stage 2)	K1	10	9	10	9	10	10	10	9
	K3	9	8	9	9	9	9	9	9
	K4	9	9	9	9	9	9	9	9
Organisation and conducting the experiment (Stage 3)	K1	9	8	9	9	9	9	9	9
	K3	9	7	9	9	9	9	9	9
	K4	9	8	9	9	9	9	9	9
Process and evaluation of experimental results (Stage 4)	K1	9	9	9	9	9	9	9	9
	K2	9	7	9	9	9	9	9	9
	K3	9	7	9	9	9	9	9	8
	K4	9	8	9	9	9	9	9	9
	K5	10	8	10	10	9	10	10	9

Using the method of paired comparison, an analysis of the criteria was carried out, the degree of preference was assigned to each pair of criteria and a matrix of paired comparisons was constructed (Table 4). Then weights were found for each criterion. The results of the obtained weights showed that significant skills in postgraduate students that lead to the effectiveness of the scientific experiment were the criteria in the following sequence: K1; K5; K3; K2; K4.

Table 4: Pairwise comparison.

	K1	K2	K3	K4	K5
K1	1	4	0.33	2	4
K2	0.25	1	2	4	0.2
K3	3.03030303	0.5	1	1	0.25
K4	0.5	0.25	1	1	0.2
K5	0.25	5	4	5	1

In addition, the postgraduate student performance at each stage of the experiment was analysed using the weighted summation method. Table 5 shows the calculation of the weighted sums, while in Figure 5 the performance of each student is presented and compared, with five students demonstrating a large set of theoretical and practical skills.

Table 5: Analysis of postgraduate student performance - calculation of the weighted sum.

		1	2	3	4	5	6	7	8
1	K1	3.1218	2.8096	3.1218	3.1218	2.8096	3.1218	3.1218	3.1218
	K3	1.8821	1.6939	1.8821	1.6939	1.8821	1.8821	1.8821	1.6939
	K4	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393
	Σ	5.6431	5.1427	5.6431	5.4549	5.3309	5.6431	5.6431	5.4549
2	K1	3.1218	2.8096	3.1218	2.8096	3.1218	3.1218	3.1218	2.8096
	K3	1.6939	1.5056	1.6939	1.6939	1.6939	1.6939	1.6939	1.6939
	K4	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393
	Σ	5.4549	4.9545	5.4549	5.1427	5.4549	5.4549	5.4549	5.1427
3	K1	2.8096	2.4974	2.8096	2.8096	2.8096	2.8096	2.8096	2.8096
	K3	1.6939	1.3174	1.6939	1.6939	1.6939	1.6939	1.6939	1.6939
	K4	0.6393	0.5682	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393
	Σ	5.1427	4.3831	5.1427	5.1427	5.1427	5.1427	5.1427	5.1427
4	K1	2.8096	2.8096	2.8096	2.8096	2.8096	2.8096	2.8096	2.8096
	K2	1.1691	0.9093	1.1691	1.1691	1.1691	1.1691	1.1691	1.1691
	K3	1.6939	1.3174	1.6939	1.6939	1.6939	1.6939	1.6939	1.5056
	K4	0.6393	0.5682	0.6393	0.6393	0.6393	0.6393	0.6393	0.6393
	K5	2.9868	2.3895	2.9868	2.9868	2.6881	2.9868	2.9868	2.6881
	Σ	9.2987	7.9941	9.2987	9.2987	9.0000	9.2987	9.2987	8.8118

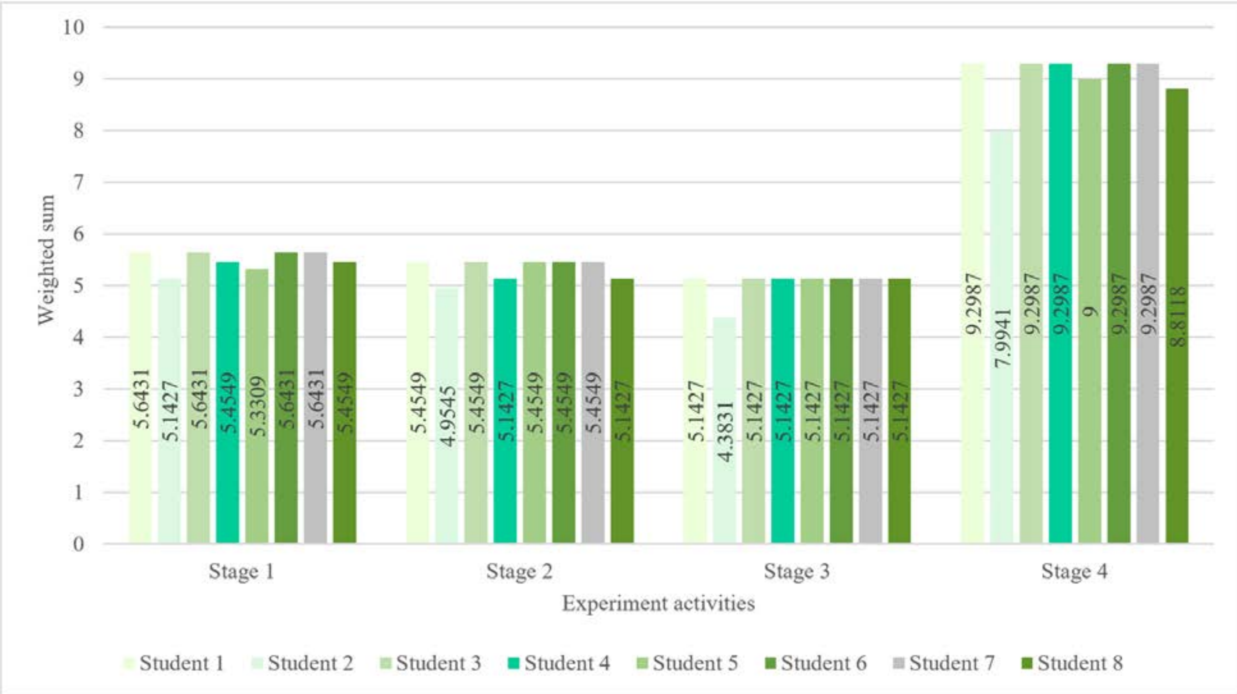


Figure 5: Analysis of postgraduate student performance - comparison.

CONCLUSIONS

This experiment outlined in this article contributes to the formation of practical skills in postgraduate students. The experiment requires the knowledge of basic laws of soil mechanics, characteristics of soil properties and methods of their determination, methods of strength assessment and stability of soil masses. It was determined that the geotextile-reinforced quasi-soil gives less spike-like collapsing under soaking than quasi-soil without geotextile during the investigation. It decidedly points out that reinforcement of quasi-collapsing soil by geomaterials; namely, geotextile, allows for increasing the bearing capacity of soil and improving its deformation properties. The coefficient of subsidence of reinforced and unreinforced soil varies in a small range because the used geotextile is inferior to other geotextile material in its mechanical properties.

The analysis showed that the postgraduate students coped well with the experiment, but it was noticeable that one student (postgraduate student 2) had more difficulties at the third and final stage than other students. However, upon completion of the experiment, that student received satisfactory results partly due to the support of other postgraduate students and the lecturer. The multi-criteria analysis showed that postgraduate student 2 needed to tighten their knowledge of computer literacy and skills of working with equipment. Moreover, postgraduate student 2 and also student 8 needed to develop skills for independent activity. For this reason, a plan was created for an express course to improve theoretical knowledge and practical skills for postgraduate students.

This article represents one example of postgraduate students' training in experimental research. The presented analysis allowed for a detailed approach to each student's abilities and their development at different stages of the experiment. The skills practice in the university laboratory contributed to the postgraduate students' experience necessary for their professional practice in engineering. More specifically, the acquired skills will allow the graduates to correctly determine the collapsing soil's properties and decide on the most suitable technological solution for strengthening the soil base.

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