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Effectiveness of reinforcement on soil subsidence

Abstract. The application of methods of improvement of ground bases in subsidence areas is an urgent issue today. This is evidenced by the continuing difficulties with the operation of transport structures. This study presents experimental studies of soil reinforcement. An important factor is to determine the properties of the soil, so the paper presents the results of laboratory tests. The angle of internal friction and the deformation increases to a greater extent when the reinforcing element is embedded in the ground, which will increase the bearing capacity of the foundations and reduce the deformability and settlement of the soil mass. The use of a reinforcing element in the ground not only makes it possible to improve the physical and mechanical properties of the soil but also gives an economic effect. It allows you to reduce the cost of the volume of earthworks. The results obtained in this study have considerable potential for eliminating problems arising from the construction of structures in subsidence areas.
Keywords: soil, geosynthetics, subsidence, reinforcement, properties.

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1. Introduction

When planning new construction complexes, it is necessary to consider the complex engineering and geological conditions of collapsible soils [1]. Before erecting structures in such areas, it is necessary to apply various methods to increase the soil's bearing capacity and stability [2]. The bearing capacity of such soils is low, so before making foundations on them, applying different soil stabilization methods is necessary [3]. Three groups of methods are used for the improvement of soil bases: constructive methods of base improvement; compaction of soil bases; and consolidation of soil bases [4-5]. Indirect methods [6] of determining collapsibility are used at the earliest stages of the investigation of loess soils in the territory under study to determine the propensity of soils to collapse. Based on their assessment of the choice of methods of further research of soils and justification of appointments of field and laboratory tests, the approximate evaluation of the volume of work. But unlike direct methods, they don't allow for estimating the numerical collapsibility value of loess soils. And one of the methods for improving soil base is applying geosynthetics.

Geosynthetics is a common classification terminology for all kinds of synthetic materials used in various construction branches, including road construction [7]. This term includes geotextiles, geogrids, geonets, geomembranes, and geocomposites.

Using geosynthetics opens new opportunities to solve various problems in the design and construction of roads and the most complex engineering structures. First, polymeric fabric helps evenly distribute the weight load on the whole area of the object. In addition, the material prevents liquid and moisture from penetrating the road base, thus saving it from destruction and erosion. Also, a multilayer construction of a road object constructed with geosynthetic materials is less subject to mechanical damages - potholes, holes, cracks, and ruts [8].

Geonets are filament meshes made of glass fiber to reinforce asphalt concrete pavements and weak subgrade soil. Using geonets increases the operational reliability and service life of road structures, improves work conditions and quality, simplifies construction technology, reduces construction time, reduces the consumption of traditional road-building materials, and uses local soil [9]. Geonet is used to construct and reconstruct highways and temporary roads on weak substrates to strengthen slopes and inclines.

The main advantages of geotextiles are good extensibility and excellent water-transmissibility, while their high strength and deformation resistance make it possible to initially reduce the roadbed's thickness. All the above advantages in the characteristics and properties of geotextiles influenced the choice of this material as a study material and its application in the structural and technological solution.

2. Methods and materials

2.1 Laboratory determination characteristics of soil

2.1.1 Determining particle size distribution (grain) composition using a sieve method

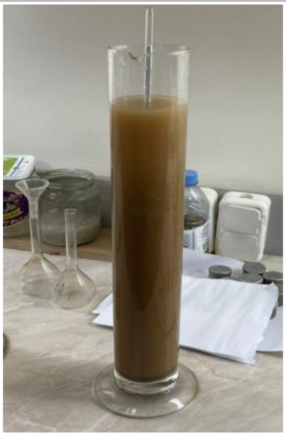
To determine the granulometric (grain) composition of soils by sieve method, the following apparatus and equipment were used: sieves with the size of holes 10; 5; 2; 1; 0,5; 0,25; 0,1 mm; laboratory scales; technical scales with a relative error of weighing of not more than 0.1%; porcelain mortar; pestle with a rubber tip; porcelain cup; rubber bulb; brush. The average sample of soil g_1 was selected by quarting and then weighed on the scales. The sieves were mounted by the column and placed on the pallet to increase the size of the holes. The selected sample was transferred to the top sieve of the first set (diameter of holes from 10 to 0,5 mm), closed with a lid, and sieved with light lateral blows with the palms of his hands until the soil was completely sorted. Soil fractions lingering on the sieves were poured, starting from the upper sieve into a mortar, then were additionally grinded with a pestle with a rubber tip, again sieved on the same sieves.

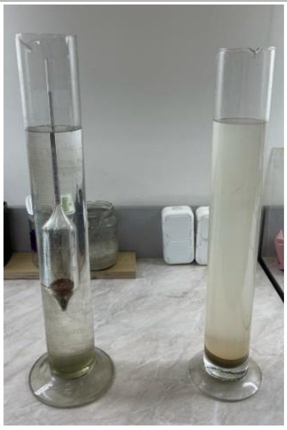
The completeness of the sieving of soil fractions was checked by shaking each sieve over a sheet of paper. Each fraction of the soil trapped on the sieves was weighed separately (df). The soil loss during sieving was allocated to the fractions in proportion to their mass.

2.1.2 Determination of granulometric (grain) composition of soils by the areometric method

To determine the granulometric composition of the grounds were applied the following instruments, equipment, materials, and reagents: areometer with a scale of 0.995 - 1 - 1.030 and the division price of 0.001; a set of sieves with a pallet; sieves with the size of holes 10; 5; 2; 1.0; 0.5; 0.25; 0.1 mm; scales; mortar and pestle made of porcelain; pestle with a rubber tip; porcelain cup; a desiccator with a silica gel indicator; drying cabinet; conical flat-bottomed flask with a capacity of 500 cm3; funnels of about 4 and 14 cm in diameter; measuring cylinder with a capacity of 1 l and a diameter of (60 ± 2) mm, a thermometer with an accuracy of 0.5°C.

Without splashing out and foaming, the suspension has been shaken with a stirrer for 1 minute until sediments are completely stirred from the bottom of the cylinder. The time of areometer reading was determined after the end of suspension shaking. Then for 10-12 seconds before measuring the density of the suspension, the areometer was carefully lowered into it, which should float freely without touching the walls and the bottom of the cylinder, and the reading was taken by the areometer R. The duration of areometer reading was not more than 10 s (Figure 1).





a) start testing **b) end of the test**

Figure 1. The measurement of slurry density

The temperature of the suspension was controlled by temperature measurement with an error of up to 0.5°C during the first 5 min (before the experiment) and then after each measure of the density of the suspension with an areometer. If the temperature differed from 20°C, a temperature correction was added to the areometer readings. The data obtained by the areometer method are shown in Table 1.

Table 1. Obtained data in determining the grain composition of the soil

Time, min	Areometer	t, °C
1	10.04	23
30	9.98	23
180	9.98	23

Then was calculated the percentage of soil fractions larger than 10; 10-5; 5-2; 2-1 mm and the mass of the dry average soil sample. To determine the moisture content of the soil by drying to constant weight, the following equipment was used: a drying cabinet; laboratory scales; metal or glass beakers.

Samples of soil for moisture determination were selected from 15-50 g, then placed in a pre-dried, weighed numbered beaker and sealed tightly with a lid. When sampling from a disturbed specimen, the soil was thoroughly mixed to ensure that the moisture was evenly distributed throughout the specimen. The soil sample in the buster was weighed. The open buster was placed in a heated desiccator. The soil was dried to a constant weight at (105±2)°C. After each drying, the closed bust was cooled to room temperature and weighed. The sample was dried until the difference in mass of the soil with the box at the next two weightings did not exceed 0.02 g.

2.1.3 Determination of the upper limit of plasticity - liquid limit by the balancing cone method

The liquid limit was defined as the moisture content of the paste prepared from the studied soil, at which the balancing cone is immersed under the action of its own mass for 5 seconds to a depth of 10 mm. Equipment used: drying cupboard; laboratory scales; metal boxes; Vasiliev's balancing cone with a cylindrical cup; metal box 7-8 cm in diameter; spatula; mortar with the pestle; sieve with a 1 mm hole; fine grater; petroleum jelly.

To determine the liquid limit, disturbed specimens were selected for which preservation of natural moisture is required. When tested using an air-dry soil sample, it was ground in a porcelain mortar, not allowing the soil particles to be crushed and at the same time removing vegetation residues larger than 1 mm. It was sifted through a 1 mm mesh sieve. Soil passed through the sieve, moistened with distilled water to a thick paste, stirred with a spatula, and kept in a sealed glass jar.

The prepared primer paste was thoroughly mixed with a spatula and placed in a cylindrical cup in small portions densely (without air cavities). The surface of the paste was smoothed with a trowel flush with the edges of the cup. A balancing cone lubricated with a thin layer of vaseline was brought to the surface of the ground paste so that its tip touched the paste. The cone is then gently released, allowing it to sink into the paste under its own weight. Immersion of the cone in the paste for 5 s to a depth of 10 mm shows that the soil has moisture corresponding to the yield boundary (Figure 2).

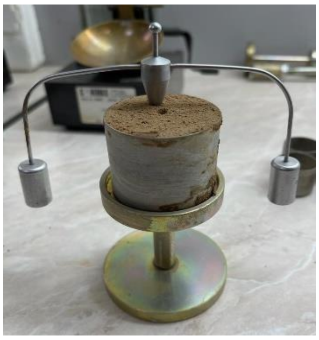


Figure 2. Dipping the cone into the paste

After reaching the fluidity limit, samples of 15-30 g were taken from the past to determine the moisture content in accordance with the requirements.

2.1.4 Determination of the lower limit of plasticity - plastic limit

The plastic limit (plasticity) should be defined as the humidity of the paste prepared from the studied soil, at which the paste rolled out in a roll with a diameter of 3 mm begins to break up into pieces of 3-10 mm. Equipment used: drying cabinet; laboratory scales; metal boxes; vasiliev's balancing cone with a cylindrical cup; porcelain or metal cup 7-8 cm in diameter; spatula, mortar with the pestle; sieve with a 1 mm hole according to the current normative documentation; fine grater; vaseline. To determine the plastic limit, disturbed specimens were used, for which the preservation of natural moisture is required.

The prepared primer paste was thoroughly mixed, and then a small piece was taken and rolled out with the palm of the hand on a glass or plastic plate until the bundle of about 3 mm in diameter was formed (Figure 3).

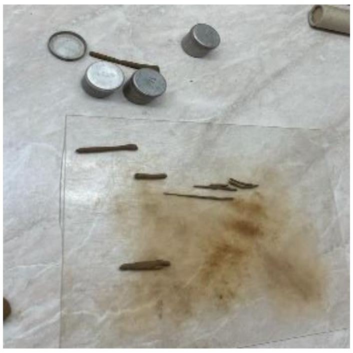


Figure 3. Rolling out harnesses

Rolling continued until the bundle disintegrated along transverse cracks into 3-10 mm long pieces. The pieces of the disintegrating bundle were collected in boxes covered with lids. When the weight of soil in the beakers reached 10-15 g, the moisture content was determined.

Results of determining the lower limit of plasticity number are represented in Table 2.

Table 2. Results of determining the lower limit of plasticity number

No. of box	m, g	m1, g	m0, g	wL, %	wL_{aver}, %	IP=WL- WP, %
8	5.4	13.8	12.7	15.06	15.1	7.9
504	5.1	13.0	11.9	16.18		
17	5.5	14.0	14.0	14.12		

2.2 Experimental tests of quasi-collapsing soils performed in a uniaxial compression apparatus

The tests were conducted with the odometer. In turn, the conducted research consisted of two parts: a study of quasi-collapsing soil [10] and an investigation of collapsing soil reinforced with geotextile. The second part was conducted to determine the effect of quasi-soil reinforcement by geotextile on collapsing. For this purpose, a nonwoven geotextile was selected (Figure 4).

The load was applied one kilogram 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 from watch-type indicators (WTIs).

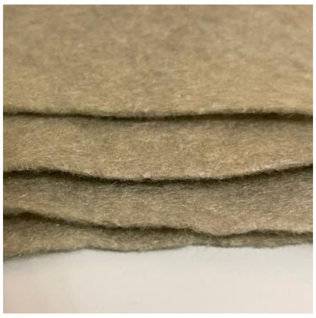


Figure 4. Non-woven geotextile

3. Results and Discussion

The results of soil grain composition by sieve method are presented in Table 3.

Table 3. Results of determining the grain size distribution of soil [11]

No. of sieves	m_{sieve}, g	$m_{sieve+soil}$, g	m_{soil}, %	sieved soil, g
500	849.5	943.6	94.1	12.54
250	781.0	979.5	198.5	26.5
100	810.1	1256.4	446.4	59.52
50	803.5	813	9.5	1.27
>50	781.3	782.8	1.5	0.2

The percentage content of each fraction of the soil are: coarse fraction - 1-0.25-66.6%; medium fraction - 0.25-0.05-66.1%; small fraction - 0.05-0.002-66.1%. The results of determining the moisture content of the soil are presented in Table 4.

Table 4. Results of determining the moisture content of soil by drying to constant weight

No. of box	m, g	m_1, g	m_0, g	w, %	w_{cp}, %
8	5.4	18.9	16.8	18.4	18.24
19	5.2	19.0	17.7	10.4	
12	5.2	18.3	16.4	17	
5	5.4	20.1	16.9	27.8	
504	5.1	15.8	14.2	17.6	

The results of determining the upper limit of plasticity are shown in Table 5.

Table 5. Results of determining the upper limit of plasticity

No. of box	m, g	m_1, g	m_0, g	w_L, %	w_{Laver}, %
19	5.2	20.2	17.4	22.95	23%
12	5.2	19.8	17.0	23.73	
5	5.4	17.4	15.2	22.45	

Results of determining the lower limit of plasticity number are represented in Table 6.

Table 6. Results of determining the lower limit of plasticity number

No. of box	m, g	m_1, g	m_0, g	w_L, %	w_{Laver}, %	$I_P=W_L-W_P$, %
8	5.4	13.8	12.7	15.06	15.1	7.9
504	5.1	13.0	11.9	16.18		
17	5.5	14.0	14.0	14.12		

Change of quasi-soil coefficient of relative collapsing when changing the percentage ratio of components (soil - quicklime) with and without geotextile reinforcement presented in Table 7 [12].

Table 7. Results of coefficient of relative collapsing

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%	$\varepsilon_{sl} = 0.04 > 0.01$	$\varepsilon_{sl} = 0.0315 > 0.01$

4. Conclusion

When designing structures on collapsing soils, the possibility of increasing their moisture content due to soaking the soil from external sources (rainwater, meltwater) from above should be considered. It is necessary to provide a set of measures, including the elimination of collapsible properties (water protection and structural measures).

It is necessary to apply to the pavement «capping layer» structure in areas where the groundwater level is close to the bottom of the embankment for a more rigid resistance to loads from the above structure. It also reduces the chance of differential settlement in the slab by supporting it more homogeneously than an unimproved subgrade. It is also much easier to compact a subbase on a capping layer than on saturated clay, meaning that by installing a capping layer, delays in constructing the subbase due to wet weather can be reduced.

In this investigation has been laboratory proven that reinforcement of the collapsing soil with geomaterials, namely geotextiles, increases the bearing capacity of the soil and improves its deformation properties. The coefficient of relative collapsing for samples with a ratio (soil 60% - 40% lime) is ε_{sl}=0.03>0.01 (not reinforced with geotextile), ε_{sl} =0.021>0.01 (reinforced with geotextile), for samples with a ratio (soil 50% - 50% lime) is ε_{sl} =0. 035>0.01 (not reinforced with geotextile), ε_{sl}=0.03>0.01 (reinforced with geotextile), for samples with the ratio (soil 40% - 60% lime) equal to ε_{sl}=0.04>0.01 (not reinforced with geotextile), ε_{sl}=0.031>0.01 (reinforced with geotextile).

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Топырақтың шөгуі кезіндегі арматураның тиімділігі

Андатпа. Шөгінді аумақтарда топырақ негіздерін жақсарту әдістерін қолдану бүгінгі таңда өзекті мәселе болып табылады. Бұған көлік құрылыстарын пайдаланудағы қиындықтар дәлел бола алады. Бұл жұмыста топырақты нығайту бойынша эксперименттік зерттеулер ұсынылған. Топырақтың қасиеттерін анықтау маңызды фактор болып табылады, сондықтан жұмыста зертханалық зерттеулердің нәтижелері келтірілген. Ішкі үйкеліс бұрышы мен деформация арматуралық элемент жерге енген кезде жоғарылайды, бұл іргетастың көтергіштігін арттырады және жер массасының деформациясы мен шөгуін азайтады. Топырақта арматуралық элементті қолдану топырақтың физика-механикалық қасиеттерін жақсартуға мүмкіндік беріп қана қоймай, экономикалық әсер береді. Бұл жер жұмыстарының құнын төмендетуге мүмкіндік береді. Осы зерттеуде алынған нәтижелер шөгінді аумақтарда құрылыстар салу кезінде туындайтын проблемаларды жою үшін айтарлықтай әлеуетке ие.

Түйін сөздер: топырақ, геосинтетика, шөгу, арматура, қасиеттері.

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Эффективность армирования на просадочность грунта

Аннотация. Применение методов улучшения грунтовых оснований на просадочных территориях является актуальной проблемой на сегодняшний день. Об этом свидетельствуют сохраняющиеся трудности с эксплуатацией транспортных сооружений. В данной работе представлены экспериментальные исследования по укреплению грунтов. Важным фактором является определение свойств грунта, поэтому в работе представлены результаты лабораторных исследований. Угол внутреннего трения и деформация увеличиваются в большей степени, когда армирующий элемент внедряется в грунт, что увеличит несущую способность фундамента и уменьшит деформируемость и оседание грунтового массива. Использование армирующего элемента в грунте не только позволяет улучшить физико-механические свойства грунта, но и дает экономический эффект. Это позволяет снизить стоимость объема земляных работ. Результаты, полученные в данном исследовании, имеют значительный потенциал для устранения проблем, возникающих при строительстве сооружений на просадочных территориях.

Ключевые слова: грунт, геосинтетика, просадка, армирование, свойства.

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