Experimental justification of the use of synthetic products for strengthening soils of buildings and structures

La justificación experimental del uso de productos sintéticos para el refuerzo de los suelos de edificios y estructuras

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ABSTRACT

Introduction: The purpose of the research of the scientific article is to study the stability of slopes and their reinforced with synthetic materials and the influence of reinforcement elements on the stress and deformation of joint soil massifs. **Materials and Methods**: At article are given: the tests were carried out in the task of the head of the tray with the use of synthetic materials. **Results and Discussion:** The use of technical materials for solving the issues of strengthening slopes and slopes is very relevant today. Synthetic geosynthetics of various production methods are required to perform the following functions in combination: reinforcement - reinforcement with materials of slopes, walls of pits and slopes of embankments, bases as a result of the redistribution of stresses arising in soil materials, and the soil mass under the action of loads from vehicles and its own weight; protection - prevention, exclusion or slowdown of the process of soil erosion, prevention of interpenetration of products of contacting layers; filtration - prevention, exclusion (slowdown), solution of the process of penetration of pound particles into drainages (filter) or their removal (reverse filter); drainage - acceleration, slowing down the arrival, removal of water filtration; waterproofing - reduction or diversion, exclusion of water inflow into the soils of the working layer of the subgrade. **Conclusions**: In tests, synthetic meshes are used to ensure the strength of the edge of the slope at loads of 100 kPa, 200 kPa, 300 kPa: a method for applying the method of strengthening the edge of the slope, with the most compacted base soil and the use of reinforcement elements, is proposed, which leads to an increase in the strength of subsiding soil bases and the edge of the slope during the construction of buildings and structures.

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1. INTRODUCTION

The main purpose of the use of materials is to ensure the reliable functioning of the foundation of buildings and structures, the highway or its individual elements in difficult conditions of construction and operation. The arrangement of additional layers of soil makes it possible to increase the operational reliability and service life of the road structure or its individual elements, the quality of work, simplify the construction technology, reduce construction time, reduce the consumption of traditional road construction products, the volume of earthworks, and the productivity of the road structure [(1) (2)].

Synthetic ready - made geosynthetics are required to perform selectively or in combination with the following functions:

1) reinforcement - reinforcement of structures of slopes and slopes of embankments (including slopes), bases as a result of the redistribution of stresses arising in the soil massif, pavement under the action of loads from vehicles and its own weight;
2) protection - preventing or slowing down the process of soil erosion, preventing mutual understanding of the products of the contacting layers;
3) filtering - preventing (slowing down) the process of penetration of pound particles into drains (filter) or their removal (reverse filter);
4) drainage - acceleration of water drainage;
5) waterproofing is a reduction or exclusion of water inflow into the soils of the working layer of the subgrade.

The most common group of synthetic products is textile, primarily non-woven, as well as woven and other knitted (knitted), woven thread- sewn, bio textiles from non-synthetic raw materials. Woven ready - made geosynthetics include a regular structure, increased strength, high modulus of elasticity, but do not have sufficient water permeability in the plane of the fabric. These ready - made geosynthetics are advisable to use in cases where the layers must perform the functions of reinforcement, protection, but not drainage. There are uniaxial woven (reinforced in one, usually longitudinal, direction) and biaxial, having close values of the mechanical properties of the type in the longitudinal and transverse directions [(3) (4)].

The properties of non-woven textile products, which represent a chaotic weave of short or long fibers in their type of production, depend on the method of reinforcement (fiber bonding). Non- woven textile ready - made geosynthetics are strengthened by mechanical, thermal or chemical means. Mechanically reinforced (needle -punched) non-woven finished geosynthetics are characterized by sufficient strength, high deformability, protective properties, water permeability in the plane of the fabric and in the direction normal to it [(5) (6)].

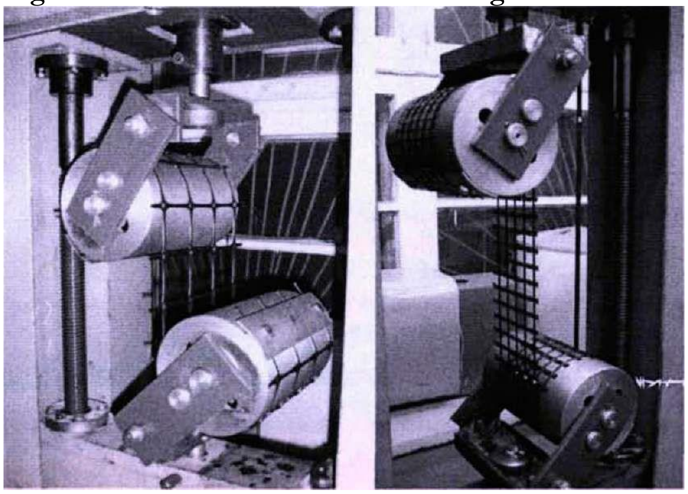
Gabion shells are flat meshes supplied in the form of multilayer blocks assembled at the work site into three-dimensional elements with linear dimensions, as a rule, 2 × 3 ÷ 6 m, 0.4 and 1.0 m thick, divided into sections with linear sizes of 0.5 and 1.0 m. gabion shells are filled at the work site with mineral filler and serve to increase the general and local stability of slopes. Various varieties are included that ensure the incorporation of the gabion into the body of the embankment [(7) (8)].

2. MATERIALS AND METHODS

In Kazakhstan, there are practically no regulatory methods for determining the properties of synthetic products used for construction. Hence, to determine the physical and mechanical properties of the type, the following European, American and domestic regulatory and methodological documents were taken as a basis: ISO 10319: 1993 (E). Geotextiles-Wide-width tension test ; ASTM D 4595. Standard Test Method for Tensile Propertiesof Geotextiles by the Wide-Width Strip Method [(9)]; ISO 10321:1992(E). Geotextiles-Tensile test for joints/seams by wide-width method [(10)]; DIN EN ISO 3146.Plastics Determination of melting behavior (melting temperature or melting range) of semi-crystalline polymers by capillary tube and polarizing-microscope methods RI Test Method GG1. Geogrid Rib Tensile Strength; GRI Test Method GG2.Geogrid Junction Strength; GRI Specification GG6. Grip Types for Use in the Wide Width Testing of Geotextiles and Geogrids; GRI Standard Practice GG4(a). Determination of the Long-Tern Design Strength of Stiff Geogrids; R RK 218-78-2009.

Determination of tensile strength of synthetic products. The essence of the method is to determine the load required for the destruction of the sample in tension (Figure 1) with the determination of the corresponding ultimate strains. When developing this methodology, the international standard ISO 10319 was taken as a basis.

Figure 1. Determination of tensile strength



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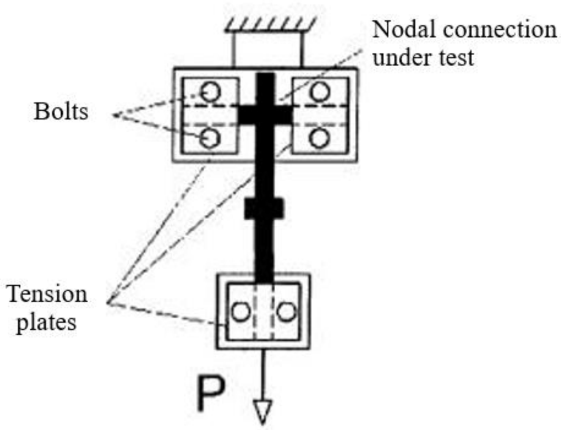
The main feature of these tests was the use of special volute clamps that do not damage the section. The procedure for preparing and conducting the test. For testing, samples are cut out with a width of 180-220 mm, depending on the type of product and the size of the cells. In this case, the number of longitudinal ribs must be at least five [11]. The length of the samples is from 1000 to 2000 mm. Different length requirements are explained by the fact that in order to ensure reliable fixation in the clamps located on the drums, samples from different products require different lengths of samples (for example, for a polypropylene grid, one incomplete turn around the drum is required (Figure 1), and for fixing fiberglass requires at least two turns). When used instead of drums, vise-type clamps often break at the clamps.

The equipment used must provide a complete diagram of the deformation of the samples with an error in measuring the load and elongation of not more than 1% of the measured value. The tests are carried out at a product temperature of 20+\-2°C. Tensile strength at a constant lowering speed of the lower drum 2 mm/min. To pre-tension the sample, a pre-force of 2N is created. The initial distance between the axes of the drums is at least 400 mm. The synthetic product is tested along the longitudinal and transverse ribs, at least 5 samples are tested for each of the directions [12].

Determination of the strength of nodal joints. The essence of the method is to determine the load required to destroy the nodal connection. The force (load) required to pull the threads out of the knot was taken as the breaking load. When developing this technique, the standard of the Institute of Synthetics GRI Test was taken as a basis method GG 2. Geogrid Junction strength. The procedure for preparing and conducting the test. For testing, samples are cut out in the shape of the letter T with a length of longitudinal threads of 250 mm, transverse -140 mm. The samples are fixed in clamps and tested according to the design scheme. (Figure 2).

Figure 2. Scheme of testing the strength of the nodal connection



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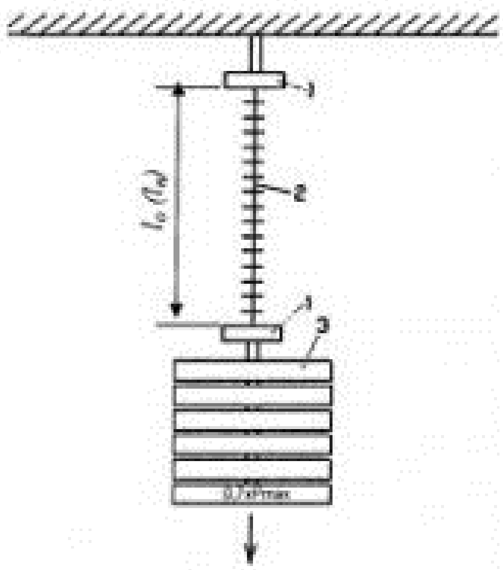
The tests were carried out at a product temperature of 20°+/-2°C. The strength of the nodal connection of the grid was determined on a tensile testing machine MP-5 at a constant lowering speed of the lower clamp of 20+/-2 mm/min. The number of tested samples was taken depending on the value of the coefficient of variation kv.

- *Heat resistance rating.* The essence of the method is to determine the change in strength after exposure to high temperature (160°C). When developing this technique, GOST 29104.14-91 was adopted as a basis. The procedure for preparing and conducting the test. For testing, samples are cut out 1000-2000 mm long and 180-220 mm wide. The samples are placed in sand poured into one or more metal trays and heated to a temperature of 160±2°C. Pallets with sand and mesh samples are placed in a thermal chamber with the above temperature and kept for 30 minutes. After the specified time has elapsed, the pallets are removed from the heat chamber and cooled to a temperature of 20±2°C, after which mesh samples are removed from the cooled sand and the tensile strength is determined by method B1. The number of tested samples is taken at least 5 pcs.
- *Definition of tensile creep type properties.* The essence of the method is to determine the ability of a synthetic product to withstand long-term action of constant loads.

The procedure for preparing and conducting the test. For testing, mesh samples are cut out with a width of one rib and a length of at least 1.5 m (Figure 3).

Figure 3. Scheme of testing for long-term strength



Source: compiled by authors.

The samples are fixed in clamps (1), a compression load equal to 2N is applied to them, and the initial length of the sample L 0 mm is measured. Then, a constant load (3) is suspended from the lower clamp, the value of which is set equal to 0.7 of the breaking load Pmax per one rib. Tests are carried out at room temperature (18-23°C), in a dark room. The duration of the test is 15 days. Measurements of the length of the samples are performed daily. The number of tested samples is taken at least 5 pcs.

- *Damage assessment of synthetic products.* The essence of the test method is to simulate under laboratory conditions the effects of sealing equipment, leading to damage to the ribs of the fibers.
- *Evaluation of strength after exposure to freeze-thaw cycles.* The essence of the method is to determine the change in strength after exposure to cyclic freezing and thawing. The procedure for preparing and conducting the test. For testing, samples are cut out 1000-2000 mm long and 180-220 mm wide. Samples are placed on the bottom of one or more baths. Distilled water is poured into the bath so that the water level above the samples is not lower than 15 mm. The bath with samples is placed in a freezer, in which the temperature is set to minus 15 ± 2°C and kept under these conditions until the water is completely frozen, but not less than 8 hours. After that, the bath with samples is removed from the freezer and the samples are completely thawed until there is no ice in the bath at room temperature (18-23°C). If necessary, adjust the water level in the bath and repeat the freezing process. Thus, samples are subjected to 25 or 50 freeze and thaw cycles [13]. After completion of the required number of cycles, the samples are removed from the bath,

dried in air for at least a day, and the ultimate tensile strength is determined according to the procedure. The number of tested samples is taken at least 5 pcs.
Investigated Synthetic Products. Grids and flat gratings based on glass fiber and polymer were used for the experiments (all names and brands used for research have been changed to avoid advertising of any manufacturer). Some physical and mechanical indicators of the used ones are given in the table one (Table 1).

Table 1. Physical and mechanical properties of fibers.

Product and conditional mesh brand		Characteristics	
		Tensile strength (longitudinal/transverse), kN/m	Elongation at break, %
Polymer mesh	POLY 20	20/20	≤10
Fiberglass mesh	ST 50	50/50	≤4
	ST 100	100/100	

Source: compiled by authors.

3. RESULTS AND DISCUSSION

The experimental part of the article presents an analysis of the analytical justification for studying the nature of the reinforcing properties of a synthetic product and the joint work of a soil base reinforced with vertical elements. A design technique for strengthening subsiding soil foundations with reinforcing elements is presented [(14)]. (Tulendiev et al., 2019). Results of determination of the tensile strength of synthetic products (Table 2).

Table 2. Test results “ST 50” at a temperature of 20°C.

No	Name indicator	Service obzn.	Unit rev.	Wed value	Sample number					
					1	2	3	4	5	6
1	Breaking load	P m ah	kN	5.86	5.20	6.75	5.20	5.30	5.30	6.75
2	Sample Width	b_sp	M	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3	Tensile strength	Rp	kN/m	59	52	68	52	53	53	68
4	Total Relative Deformation	$£\_max$	%	1.4	1.3	1.6	1.3	1.3	1.3	1.6
5	Conditional indicator of deformability	Em ah	kN/m	4100	4000	4218	4000	4077	4077	4219

Source: compiled by authors.

During the tests, it was found that the presence of a textile layer does not affect the strength characteristics and the results, respectively, will be identical to the test results without it, hence the need for additional tests was not (Table 3).

Table 3. Test results ST 100 at 20 °C.

No	Name indicator	Service . ref .	Unit rev.	Wed value	Sample number					
					1	2	3	4	5	6
1	Breaking load	P m ah	kN	10.9	11.2	9.50	9.50	11.2	11.7	12.2
2	Sample Width	b_sp	M	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3	Tensile strength	Rp	kN/m	109	113	95	95	113	118	123
4	Total Relative Deformation	$£\_max$	%	1.4	1.3	1.4	1.3	1.3	1.4	1.4
5	Conditional indicator of deformability	Em ah	kN/m	8090	8654	6786	7308	8654	8393	8750

Source: compiled by authors.

As can be seen from the test results, fiberglass based products include both greater strength and less deformability, which is more desirable when using these products as a reinforcing layer (Table 2-5).

Table 4. Test results "Poly 20" at a temperature of 20°C.

No	Name of indicator	Service ref .	Unit rev.	Wed value	Sample number					
					1	2	3	4	5	6
1	Breaking load	P m ah	kN	2.86	2.70	2.75	2.85	3.00	3.10	2.75
2	Sample Width	b_sp	M	0.140	0.140	0.140	0.140	0.140	0.140	0.140
3	Tensile strength	Rp	kN/m	20.4	19.3	19.6	20.4	21.4	22.1	19.6
4	General relative deformation	$£\_max$	%	5.0	5.2	5.1	4.7	5.4	4.8	4.9
5	Conditional indicator of deformability	Em ah	kN/m	407	372	383	433	395	458	403

Source: compiled by authors.

The results of testing products based on fiberglass under the conditional name “ST 50” and “ST 100” at a temperature of -20°C did not differ from the results of tests at a temperature of 20°C (see Tables 5 and 6).

Table 5. Test results for Poly 20 at -20°C

No	Name indicator	Service ref.	Unit rev.	Wed value	Sample number					
					1	2	3	4	5	6
1	Breaking load	P m ah	kN	2.51	2.40	2.48	2.51	2.51	2.64	2.48
2	Sample Width	b_sp	M	0.14	0.14	0.14	0.14	0.14	0.14	0.14
3	Tensile strength	Rp	kN/m	17.9	17.2	17.7	17.9	17.9	18.8	17.7
4	Total Relative Deformation	$£\_max$	%	3.5	3.6	3.5	3.2	3.2	3.3	3.4
5	Conditional indicator of deformability	Em ah	kN/m	519	480	500	552	552	564	526

Source: compiled by authors.

The results of tests of Poly 20 products at a temperature of 20°C (Table 6) showed how, compared with the test results at a temperature of 20°C (table 4), a decrease in strength by 12% and deformability by 30% is observed.
The tests were carried out on synthetic products "ST 50", “ST 100” and “Poly 20”.

Table 6. The amount of loss of strength

No	Product name		Loss of strength, % of the original after 50 freeze and thaw cycles
1	“ST 100”	longitudinal strands	15
		cross strands	14
2	“ST 50”	longitudinal strands	16
		cross strands	15
3	“Poly 20”	longitudinal strands	26
		cross strands	28

Source: compiled by authors.

A significant difference in the degree of damage made on the basis of fiberglass and polymer is explained by the peculiarities of the properties of raw materials and production technology.
In the laboratory of soil mechanics, an analysis was made of the effect of vertical reinforcement on the deformability of the foundation base. The effect of strengthening the foundation soils with additional elements of fibers, which are used instead of bulk structures of retaining walls, was studied.
Accounting for double reinforcement (joint operation of the pile model and the grid), presumably, should have resulted in savings in materials and labor intensity (Table 7).

Table 7. Test program

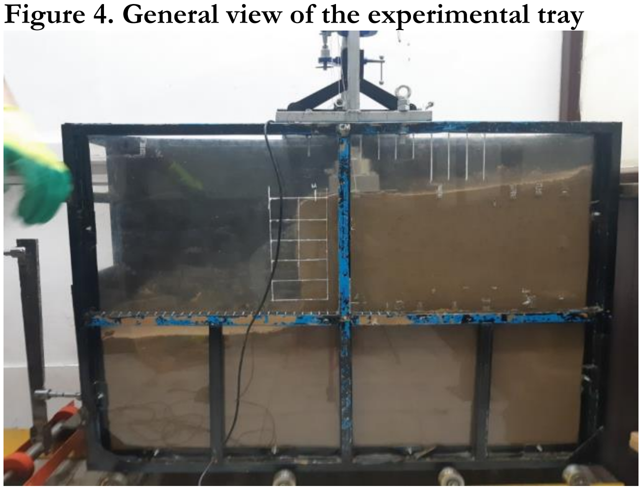
No	Soil type and structure, sampling site	Depth selection, m .	Granules -metric compound, Ø in mm	The value of the vertical pressure P, kPa.	Shift amplitude
1	2	3	4	5	6
1	Mixture: sand, high viscosity motor oil (hereinafter referred to as aggregate)	4	0.1÷1	25 50 75 100 150 200 300	0.1

Source: compiled by authors.

The purpose of our experiment is to simulate the behavior of the soil during the development of deep pits, to study the effect of aggregate size on the stability of the pit, and to identify the functional dependence of slope stability on the size of inclusions in the composition of the soil that forms the slope of the pit. Stamp tests were carried out (stamp size 200 x 350 mm) in a bulk metal tray. A stepwise increasing axial vertical load in the range of 25–300 kPa was transferred to the foundation model. Several series of experiments were carried out. The soil was laid in layers and the metal was compacted

For the experiment, a tray made of metal, chipboard and organic glass was used. The tray is a rectangle with its type of production. Length 1200mm, width 230mm and height 1000mm. The front wall of the tray is transparent plexiglass, the back and side walls are made of metal sheet. The structure reinforcement frame is made of a metal square 50mm by 30mm. and connected by a weld. Figure 4 shows a general view of the experimental tray.

Figure 4. General view of the experimental tray



Source: compiled by authors.

In tests, synthetic meshes are used to ensure the strength of the edge of the slope at loads of 100 kPa, 200 kPa, 300 kPa. Based on the above criteria, a product with a mesh of 1 * 1mm was selected. The soil product is sand of medium size (0.5-1 mm), compacted from a density of 2.26 g/cm3 to a density of 4.76 g/cm3. The tests were carried out in a tray (Figure 4).

Figure 5. Prepared tray with soil for experiments

Source: compiled by authors.

To measure the vertical deformation of the stamp under load, a deflection meter is provided. The deflection meter is designed to record the displacement of individual points of structures when loading a stamp with static loads, the division value is 0.01 mm. The deflectometer was attached to the frame of the experimental stand using clamps, strictly above the stamp. The deformation was fixed with the help of a thread, on one side fixed to the stamp, on the other - to the plumb line, the thread, under the weight of the plumb line, was pressed against the leading roller of the deflection meter. When the stamp was upset, the thread, creating a torque, changed the position of the drive roller, which was reflected on the dial of the deflection meter.

As can be seen in Figure 5, the tray is divided in the middle by a partition. In the right part of the tray, the investigated composition of the soil will be laid with a given density, number and fineness of the aggregate. On the right side of the tray is a void, representing the excavation space as its type of production. The vertical load on the edge of the slope was transferred by a jack through stamp, size 200x350 mm. The load value was recorded by a DIN-1 dynamometer. The load was applied in steps of 25–100 kN. The maximum pressure on the sole of the stamp was up to 300 kPa. The soil model was placed in the tray in layers, each layer was compacted with a manual rammer, 3 strokes along one track. After each compaction of 50 mm model soil, gypsum powder was placed on the front side of the experimental tray to visually inspect soil deformations under load.

Loading is set vertically, with a gradual increase from 100 kPa, 200 kPa, 300 kPa with a frequency of 15 minutes. This test showed how, when reinforced with synthetic products, the deformations of the base were insignificant and no destruction occurred. From which it follows, as strengthening the edge of the slope, with the most compacted base soil and application, gives us the opportunity to strengthen the edge of the slope during the construction of buildings and structures. Further, the task was to use additional vertical reinforcement with the application of seismic load to provide a stronger foundation.

$$Кс = \tau/\sigma, \quad (1)$$

In this case, the shear coefficient Kc becomes a function of normal stresses σ, which, as experience shows, have a very significant effect on it.

Stamp dimensions 20*20 cm; Stamp area F=0.2*0.2=0.04м²;

Shear stress is determined by the formula:

$$\frac{N}{F} = \tau, \quad (2)$$

Next, we determine the load on the stamp. We accept a minimum of 100 kg, a maximum of 1200 kg. N= τ*F=25*0.04=1Kh=100kg. The model was tested with a stepwise increasing load in the following sequence: 25 kPa, 50 kPa, 75 kPa, 100 kPa, 150 kPa, 200 kPa, 300 kPa. The maximum draft of 78.86 mm was achieved at 300 kPa.

Table 8. Test 1 - No Gain

No	Indications of the deflection meter 1	Indications of the deflection meter 2	Draft S1f	Draft S2f
0	55.68	40.89	0	0
25	56.0	40.46	0.32	0.43
50	56.01	40.28	0.33	0.61
75	56.45	39.52	0.77	1.37
100	57.73	38.45	2.05	2.44
150	59.81	36.6	4.13	4.29
200	62.48	34.42	6.8	6.47
250	65.52	34.15	9.84	6.74
300	78.86	33.14	23.18	7.75

Source: compiled by authors.

Tests No 1 (Table 8) - without reinforcement of the base and test No 2 (Table 9) - with reinforcement with vertical metal piles (for example, metal spokes with a thickness of 4 mm). According to the results of the test, we determine the draft of the stamp.

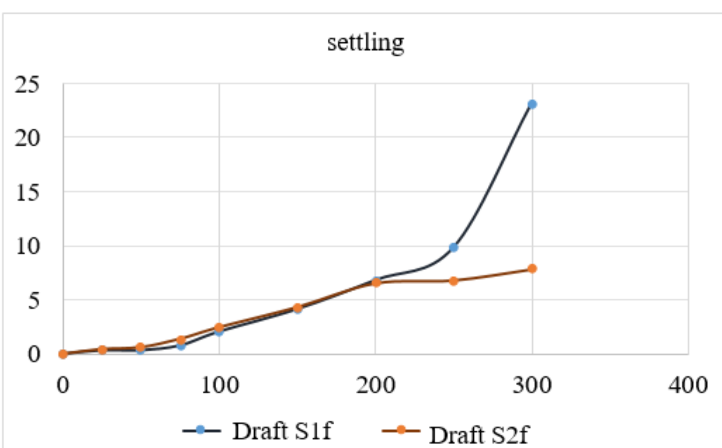
Table 9. Test 2 with reinforcement with metal spokes

No	Indications of the deflection meter 1	Indications of the deflection meter 2	Draft S1f	Draft S2f
0	71.13	30.40	0	0
25	73.15	29.10	2.02	1.3
50	74.47	27.90	1.32	1.2
75	75.63	26.80	1.16	1.1
100	76.55	25.83	0.92	0.97
150	78.23	24.37	1.68	1.46
200	79.90	24.15	1.67	0.22
250	81.70	24.15	1.8	0
300	83.88	24.15	2.18	0

Source: compiled by authors.

A visual comparison of the experimental tests of the foundation soil, reinforced separately with meshes and additionally with vertical reinforcements, is shown below in Figures 6 and 7.

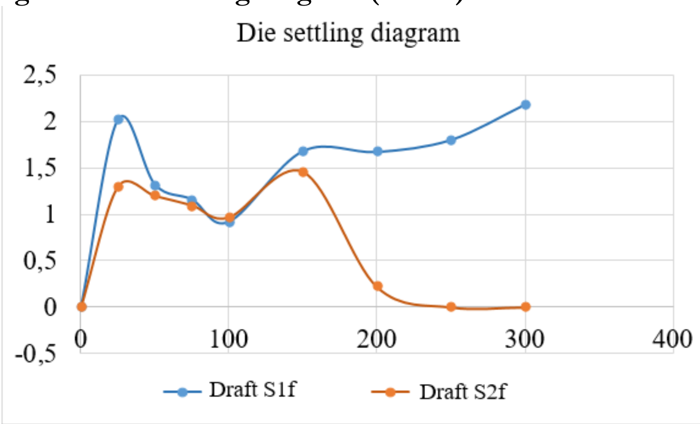
Figure 6. Diagram of die settling (Test 1)



Source: compiled by authors.

A visual comparison of the experimental tests of the foundation soil, reinforced separately with meshes and additionally with vertical reinforcements, is shown below in Figures 7.

Figure 7. Die settling diagram (Test 2)



4. CONCLUSIONS

1. All tests were carried out in accordance with the requirements of SP RK 5.01 102 2013 “Foundation of Buildings and Structures”.
2. The paper analyzes the method an of strengthening weak foundations, where soil reinforcement materials are synthetic geosynthetics used as soil reinforcing elements, the use of which leads to an increase in the bearing capacity of the soil.
3. The joint work of foundation soils is a factor in increasing the bearing capacity of the foundations of buildings and structures, they are arranged in the soil and contribute to an increase in the mechanical properties of the foundation.
4. The test results showed that the use of gratings leads to an increase in the strength properties of the type of foundation soils, which maximally excludes an increase in the settlement of the foundation of the designed building and structure.
5. Model tests in the tray showed that the use of base reinforcement materials allows increasing the bearing capacity of the base by 1.5-2 times under static load.
6. The use of a grid reduces the ability of the foundation soils to develop shear (lateral) deformations and, accordingly, reduce the foundation settlement.

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