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Testing reinforced soil cushions on the soaked subsidence base

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Abstract. Neogene friable deposits of the Quaternary age, widespread in Mongolia, belong to loess-like subsidence soils, mainly of type I in terms of subsidence, and are of kyrogenic-sublimation origin. As a result of the sublimation process of permafrost ice (the most recent Altai-Tunguska ice age, which covered most of the Euro-Asian region 15-18 thousand years ago) and seasonal deep frozen soils, occurring for many years in deep frozen subsidence soils, the structure is decompacted, as a result of the latter, porosity n=(50÷65)%, porosity coefficient e = (0.70÷0.84), density of dry soil ρd=(1.35÷1.60) ton/m3 or undercompacted, moisture content of sandy loam W=(0.04÷0.06) and loam W=(0.05÷0.08), as a result of repeated freezing and thawing, cracking and grinding of the solid part of the soil occurs, based on this, the content of silty parts is 50-60%. In recent years, experimental and theoretical studies have been actively carried out in many countries of the world to improve traditional soil cushion solutions using geosynthetic materials for horizontal and vertical reinforcement. Currently, in the soil conditions of Mongolia, research work has not been carried out to introduce the method of reinforced soil cushions due to the lack of an appropriate design standard and other regulatory documents. This article discusses the results of stamp field tests to determine the deformation characteristics of highly compacted soil cushions made of crushed stone-sand mixtures and local sandy loam soils with horizontal geosynthetic reinforcements from geogrid and geotextile, modeled in 6 different combinations on pre-soaked subsidence bases.

1 Introduction

For a long time, mankind has used armored soil structures for the construction of various buildings and structures, of which the earliest are the upland buildings of the city of Dur-Kurigatsu and the Great Chinese Wall and others. BC Romans used the method of soil reinforcement for the construction of soil canvases in the city of Rome. Since the beginning of the twentieth century, scientific research has begun in the United States on the use of the

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method of strengthening soil structures with reinforcement from various materials. In the 1960s, French engineer Henri Vidal was the first to propose the use of metal tapes and polymeric materials for the reinforcement of various soil elements and structures [1, 2]. In recent years, in many countries of the world, experimental and theoretical studies of the improvement of traditional solutions of soil cushions for the use of geosynthetic materials for horizontal and vertical reinforcements are being actively carried out. Currently, in the soil conditions of Mongolia, no research work has been performed to introduce the method of reinforced soil cushions due to the lack of the relevant BNbD (Mongolian SNiP) and other regulatory documents [3]. Neogenic loose deposits of the Quaternary age, widespread on the territory of Mongolia, are classified as loess-like subsidence soils, mainly of type I by subsidence [4] and have a cyrogenic sublimation origin, low moisture content and strong fragmentation. Due to these properties they are sometimes classified by indirect signs [5, 6]. To increase their building properties when soaking by the method of applying rational innovative solutions of reinforced soil cushions of shallow and relatively lightly loaded foundations, taking into account the regional peculiarities of the soil and climatic conditions of Mongolia, it is an important construction task [4-6]. Highly compacted reinforced soil cushions can be reliable and simple methods, and from an economic point of view the most acceptable methods that do not require expensive imported machinery and equipment for special construction work [7, 8].

2 Engineering and geological conditions of the test site

In 2020 we carried out field tests of reinforced soil cushions. The test site is located on the territory of the city of Darkhan, where the following types of soils are common:

1. EGE-1: bulk soil with a thickness of 0.3 m;
2. EGE-2: subsiding silty sandy loam (νQ_2), type I in terms of subsidence, with a thickness of 0.3-6.8 m;
3. EGE-3: gravelly loam (a-pQ_2), below 6.8 m. When drilling a well to a depth of 15.0 m, groundwater was not found. The estimated depth of seasonal freezing is 3.20 m.

Table 1. Table of physical and mechanical parameters of soils.

No.	Indicator	Designation	Unit	Silty sandy loam	Clay loam
1	Natural moisture	W	fraction of unit	0.042	0.068
2	Natural density	ρ	g/cm^3	1.49	1.88
3	Porosity coefficient	e	fraction of unit	0.73	0.42
4	Moisture degree	S_r	fraction of unit	0.32	0.53
5	Adhesion force	C^I C^{II}	kPa (kg/cm^2)	21 7.6	29
6	Internal friction angle	φ^I φ^{II}	degree	18 13	25
7	Deformation modulus	E_0 E_{sat}	MPa (kg/cm^2)	12.1 (1.21) 4.6 (0.46)	23 (2.3)
8	Design resistance / BNbD 50-01-16	R_0	kPa (kg/cm^2)	280 (2.8)	325 (3.25)

3 Materials and methods

Method of field stamp tests was used. In the test program, the depth of 6 soil cushions is 1.50 m, below which the soil is pre-soaked to simulate a water-saturated weak base. The assignment of geometric dimensions and the design of experimental soil cushions were carried out on the basis of the methodologies [9-11]. The assigned dimensions of soil cushions and reinforcement made of geosynthetic materials are shown in Figure 1.

Fig. 1. Soaking the base of the soil cushion.

After arranging 6 test pits, they were poured with water for 7 days (Fig. 1), the amount of water for soaking each pit is about 10 m3. Design options for reinforced and unreinforced soil cushions are given in Table 2. In the process of preparing soil cushions, soils with a thickness of 20 cm were reinforced and compacted in layers. After compaction of each layer, we determined ρ and W moisture content of compacted soils in the laboratory. Indicators SBR, q_s c, φ were taken by the dynamic compaction meter "PORTABLE BEARING CAPACITY TESTER. MODEL MIS-244-062. (JAPAN). Calculation diagrams of soil cushions are shown in Figure 2, photos of the stamp tests in Figure 3.

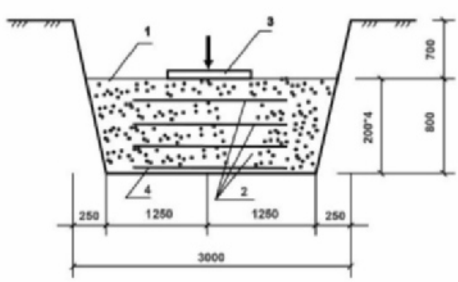

Fig. 2. Design diagram of soil cushions with geosynthetic reinforcements.

Fig. 3. Carrying out stamp tests.

4 Results

The results of the stamp tests are shown in Table 2 and the general curve of the dependence of settlement and pressure is shown in Figure 4.

Table 2. The results of measuring the settlement of the stamp.

No	Options	Construction of soil cushion 3.0x3.0x0.8 (h) m	Pressure, mPa $/S_{pcs}$=2500cm^2/				
			2.5 t 1kg/cm^2	5 t 2kg/cm^2	7.5 t 3kg/cm^2	10 t 4kg/cm^2	Sum ΔS, mm
1	I	Cushion of local sandy loam soils with reinforcement of 1 layer of geotextile, 3 layers of geogrids	3.21	4.82	8.65	16.572	16.582
			$\Delta S = 3.21$	$\Delta S = 1.62$	$\Delta S = 3.83$	$\Delta S = 7.922$	
2	II	Cushion of local sandy loam soils with reinforcement of 4 layers of geotextile	3.86	5.38	10.53	21.75	21.75
			$\Delta S = 3.68$	$\Delta S = 1.70$	$\Delta S = 5.15$	$\Delta S = 11.22$	
3	III	Cushion of a mixture of crushed stone-coarse sands with reinforcement of 1 layer of geotextile, 3 layers of geogrids	2.78	3.62	5.16	13.81	13.81
			$\Delta S = 2.78$	$\Delta S = 0.84$	$\Delta S = 1.54$	$\Delta S = 8.65$	
4	IV	Cushion made of a mixture of crushed stone-coarse sands with reinforcement of 4 layers of geotextile	3.13	5.11	8.49	17.42	17.42
			$\Delta S = 3.13$	$\Delta S = 1.98$	$\Delta S = 3.38$	$\Delta S = 8.93$	
5	V	Cushion made of a mixture of crushed stone-coarse sands without reinforcement	6.21	9.76	19.38	Stamp subsidence	19.38
			$\Delta S = 6.21$	$\Delta S = 3.55$	$\Delta S = 9.62$		
6	VI	Cushion of local sandy loam soils without reinforcement	7.32	11.46	23.71		23.71
			$\Delta S = 7.32$	$\Delta S = 4.14$	$\Delta S = 12.25$		

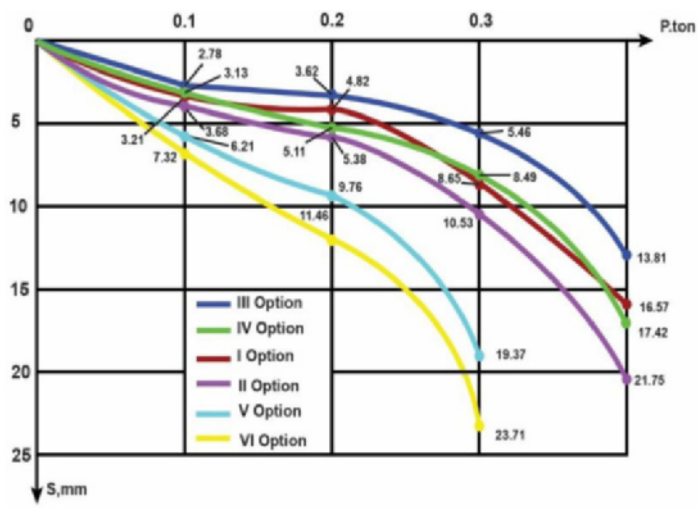

Fig. 4. General curves of dependence S = f(P) for options of highly compacted soil cushions.

Comparative graphs of the settlement of stamp tests by types of reinforcement and material of cushions are shown in Figures 5-8.

The deformation modulus E of highly compacted soil cushions from a mixture of crushed stone-coarse sands and local sandy loam soils with reinforcement from geogrids and geotextile, without reinforcement on soaked weak subsidence soils of the base was determined by the method of field stamping tests A = 2500 cm2. The numerical values of E are calculated using the Schlecher formula for a round die and in accordance with the standard method (MNS 2489: 1986) and are shown in Table 3.

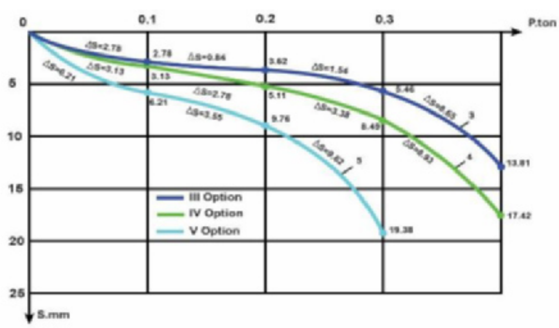

Fig. 5. Comparison of the curves S = f(P) of soil cushions from a mixture of crushed stone-coarse sands according to options III, IV, V.

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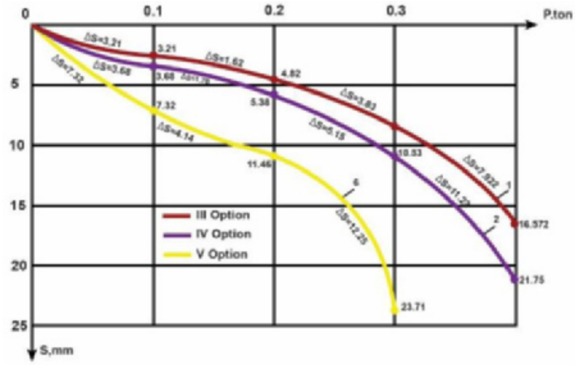

Fig. 6. Comparison of curves S = f(P) of soil cushions from a mixture of local loamy soils according to options I, II, VI.

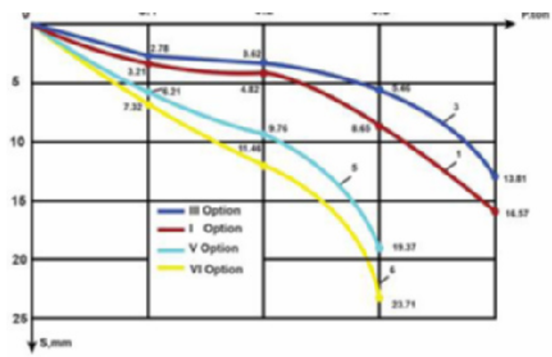

Fig. 7. Comparison of curves S = f(P) of soil cushions with reinforcement of geogrids according to options III, I, V, VI.

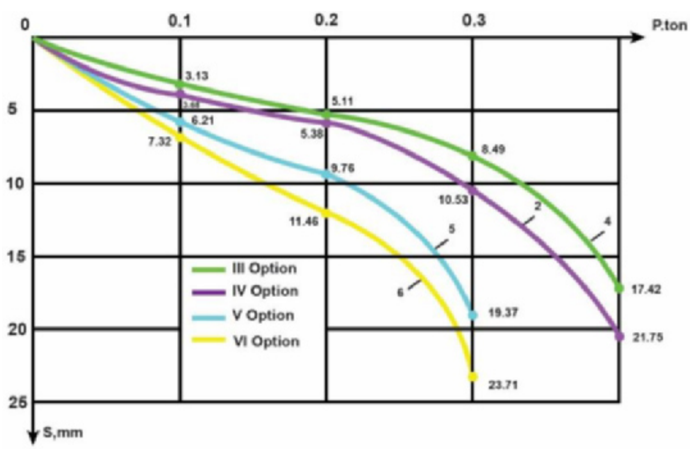

Fig. 8. Comparison of the S = f(P) curves of soil cushions with geotextile reinforcement according to options II, IV, V, VI.

Table 3. Table of generalized results of stamp tests for determination of E and other tests.

No	Options	Stamp tests	Results of tests with a dynamic densimeter				Tests with cutting rings		
		E, MPa	CBR	q_c	c	φ	ρ	W	S_r
A. Ground cushions from local sandy loam soils									
1	Option **VI**: without reinforcement	9.32	15.9	1252.3	92.2	27.4	1.98	0.144	0.65
2	Option **II**: reinforcement with 4 layers of geotextile	12.35	22.84	1989.2	122.7	31.9	2.09	0.132	0.60
3	Option **I**: reinforcement with 1 layer of geotextile, 3 layers of geogrids	14.71	23.3	1826.5	124.9	32.2	2.03	0.136	0.61
B. Ground cushions from a mixture of crushed stone-coarse sand									
1	Option **V**: without reinforcement	11.31	22.6	1759.4	121	31.7	2.06	0.146	0.66
2	Option **IV**: reinforcement with 4 layers of geotextile	15.28	26.1	1990.6	134.2	33.5	2.08	0.146	0.66
3	Option **III**: reinforcement with 1 layer of geotextile, 3 layers of geogrids	33.27	26.2	2047.2	137.4	33.9	1.97	0.140	0.63
C. Geogrid Reinforced Soil Cushions									
1	Option **VI**: without reinforcement with local sandy loam soils	9.32	15.9	1252.3	92.2	27.4	1.98	0.144	0.65
2	Option **V**: without reinforcement with a mixture of crushed stone-coarse sands	11.31	22.6	1759.4	121	31.7	2.06	0.146	0.66
3	Option **I**: reinforcement with 1 layer of geotextile, 3 layers of geogrids from local sandy loam soils	14.71	23.3	1826.5	124.9	32.2	2.03	0.136	0.61
4	Option **III**: reinforcement with 1 layer of geotextile, 3 layers of geogrids from a mixture of crushed stone-coarse sand	33.27	26.2	2047.2	137.4	33.9	1.97	0.140	0.63
D. Geotextile Reinforced Soil Cushions									
1	Option **VI**: without reinforcement from local sandy loam soils	9.32	15.9	1252.3	92.2	27.4	1.98	0.144	0.65
2	Option **V**: without reinforcement from a mixture of crushed stone-coarse sands	11.31	22.6	1759.4	121	31.7	2.06	0.146	0.66
3	Option **II**: reinforcement with 4 layers of geotextile from local sandy loam soils	12.35	22.84	1989.2	122.7	31.9	2.09	0.132	0.60
4	Option **IV**: reinforced with 4 layers of geotextile from a mixture of crushed stone-coarse sands	15.28	26.1	1990.6	134.2	33.5	2.08	0.146	0.66

5 Discussions

The deformation moduli of highly compacted soil cushions with horizontal reinforcements with geosynthetic materials and without reinforcement from local sandy loam soils and a mixture of crushed stone-coarse sands with a moisture content W_{opt} increase in comparison with the deformation moduli of local sandy loam soils of the experimental site, with a natural moisture content of E = 12.1 MPa and after soaking E = 3.6 MPa:

a) *E of cushions of option VI from part A of Table 3* without reinforcement from local sandy loam soils, on the base soil with moisture W_{sat} is 1.15 times less than *E* of the local base soil at *W* and 2.59 times higher than *E* of the local base soil at W_{sat}.

E of *option I* cushions (with reinforcement), is 1.22 times higher than *E* of the base soil with natural moisture and 4.09 times higher than the base soil with water saturation.

E of the cushion of *option II* (with reinforcement) is 1.03 times higher than *E* of the base soil with natural moisture and 3.43 times higher than the base soil with water saturation.

b) *E cushions of option V from part B of Table 3* without reinforcement from a mixture of crushed stone-coarse sands on the base soil with moisture W_{sat} is 1.07 times less or approximately equal to *E* of the local base soil at *W* and 3.14 times higher than E of the local base soil at W_{sat}.

The cushions of *option III* (with reinforcement) are 2.94 times higher than *E* of cushions of option V;

The cushions of *option IV* (with reinforcement) are 2.17 times higher than the *E* of cushions of option V;

c) *Cushions of option VI from Part B of Table 3* are 1.21 times less than *E* of the cushions of option V, 1.58 times less than *E* of option I, and 3.57 times less than *E* of option III.

d) *E of option VI from part D of Table 3* is 1.21 times less than *E* of option V, 1.33 times less than *E* of option II, and 1.65 times less than *E* of option IV.

6 Conclusions

1. Modulus of deformation of soil cushions from local sandy loam soils and a mixture of crushed stone-coarse sands with or without reinforcement from geogrids and geofabrics on a pre-soaked base, as compared to the base soil with natural moisture or water-saturated state according to options increases by 1.03-4.09 times.

2. Only the modulus of deformation of the cushion of option VI from local sandy loam soils is 1.15 times less than the modulus of deformation of the natural base soil with moisture W. Hence, it can be concluded that due to the high layer-by-layer compaction of local sandy loam soils, it is possible to create relatively stable soil cushions during technogenic soaking compared to a natural sandy loam basement of a shallow and lightly loaded foundation of buildings and structures. The test results show that, with reinforcement, they give better results.

3. The use of local sandy loam soils for highly compacted soil cushions with and without geosynthetics reinforcement can reduce the estimated cost of the foundation by eliminating numerous costs. In addition, in terms of protecting the surrounding nature, it is extremely good modern innovative green technology, since there is no need to develop a rubble and sand quarry.

4. According to the test results, it was found that the numerical values of the deformation and strength characteristics of soil cushions, depending on the moisture regime of the soil of the base of the cushions, the type of soil materials of the cushion and geosynthetic materials for reinforcing soil cushions, can be further improved.

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