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REINFORCEMENT OF BASES WITH DISPERSED REINFORCEMENT FROM PLASTIC WASTE

The article presents the results of laboratory tests with a stamp of sandy soils of different densities, reinforced with a different percentage of the total volume with fiber made by cutting strips from plastic bottles. The aim of the work is to obtain the values of the modulus of deformation of the soil, the reinforcement of which is carried out with plastic fiber. Also in this article, a comparison was made of non-reinforced soil with reinforced. The presented results of laboratory studies show the effectiveness of the use of fiber made from plastic waste, which in the future will significantly save on the device of artificial sand bases, as well as improve environmental performance.

В статье приведены результаты лабораторных испытаний штампом песчаных грунтов разной плотности, армированных с разным процентом от общего объема фиброй, изготовленной путём нарезки полосок из пластиковых бутылок. Целью работы является получение величин модуля деформации грунта, армирование которого осуществлено пластиковой фиброй. Произведено сравнение неармированного грунта с армированным. Представленные результаты лабораторных исследований показывают эффективность применения фибры, изготовленной из отходов пластика, что в будущем позволит существенно экономить на устройстве искусственных песчаных оснований, а также улучшить экологические показатели окружающей среды.

Keywords: *dispersed reinforcement, plastic waste, replacement of the base, reinforcement of the base, strength of the bases, reinforcing elements, stamp tests, anthropogenic load*

Ключевые слова: *дисперсное армирование, отходы пластика, замена основания, усиление основания, прочность оснований, армирующие элементы, штамповые испытания, антропогенная нагрузка*

At the beginning of the twentieth century, paper consumption increased drastically with the rapid growth of industrialization. Paper began to be used not only in industries but also in other applications, including food packaging in stores. For several decades, paper was an essential resource, and by the mid-1950s, deforestation reached a critical scale and the planet was on the brink of an environmental disaster for the first time. In parallel with the growth in paper consumption, the chemical industry also developed, which by that time had accumulated experience in the synthesis of polyethylene. Numerous studies have shown the absolute harmlessness of polyethylene in humans. Moreover, as it seemed, a relatively cheap way to save forests was revealed, and the paper used for food packaging was replaced by polyethylene. Over the years, packaging materials have been constantly modernized, and polyethylene has been partially replaced by plastics with similar properties. Simplicity, low cost, and high performance have made plastic the most produced packaging for food in the world. According to statistics, one million plastic bottles are produced every minute in the world, not only for packaging food but also for packaging various nonfood (technical) liquids. Today, most countries in the world are not ready to process or dispose this volume of plastic in an environmentally friendly manner, which has led to contamination of large land areas as well as the world's oceans. Approximately 15 million tons of plastic annually contaminate rivers, lakes, seas, and oceans, adversely affecting the flora and fauna. In connection with this problem, an urgent question arises about the applicability of plastic waste, with minimal processing, in other production sectors.

In construction, plastic waste can be used as thin strips for dispersed reinforcement of artificial foundations, which partially replace the thickness of weak natural soils with low physical and mechanical characteristics, or when filling areas to raise the relief to design elevations [1, 2]. Notably, reinforcement of artificial foundations in Russia has been implemented for more than 30 years, and geotextiles or geogrids produced specifically for these purposes are used in most cases, for e.g., rolled materials or flat frames [3, 4]. As such, no attempts to produce dispersed reinforcement of soils were noted; accordingly, a series of experiments were performed in this regard.

These experiments were conducted in a laboratory soil tray with a cross-sectional pipe having an internal diameter of 410 mm, with a lever system attached to the upper edge for performing stamp tests (Fig. 1). The soil subjected to reinforcement was fine, low-moisture sand. Polyethylene terephthalate strips of 5.0 × 70.0 mm in size, obtained by cutting bottles of food liquids, were used as reinforcing elements. The soil layer thickness was taken as 300 mm. Two series of experiments were performed. Series 1 and 2 were conducted on soil with a density of 1.73 g/cm^3 and 1.82 g/cm^3, respectively [5]. In each series, four experiments were performed, as a result of which stamp tests of soils were conducted. In the first three experiments, soil was tested with fiber reinforcement percentages of 10%, 20%, and 30% of the original volume (Fig. 2). Fourth experiment was performed on a soil layer without reinforcement.

Pressure on the experimental soil was transmitted in steps by a round metal stamp with an area of 60 cm^2 by placing weights of 3 kg on a vertical suspension of the lever system, creating a pressure of 0.01 MPa under the stamp [6]. Each subsequent load stage was performed after the complete attenuation of the sediment from the previous stage. The increase in load continued until the increase in soil deformation from the newly applied load exceeded the deformation level from the previous stage by more than five times. The magnitude of soil deformation was recorded using a dial indicator (deflectometer) with a division value of 0.01 mm.

The results of the experiments and the plotted graphs of the dependence of stamp settlement on load are presented in Tables 1–8 and Figs. 3–10.

Fig. 1. General view of laboratory installation for stamp testing of soils

Fig. 2. Process of mixing soil with polyethylene terephthalate strips

Series 1 experiments, soil density: 1.73 g/cm³.

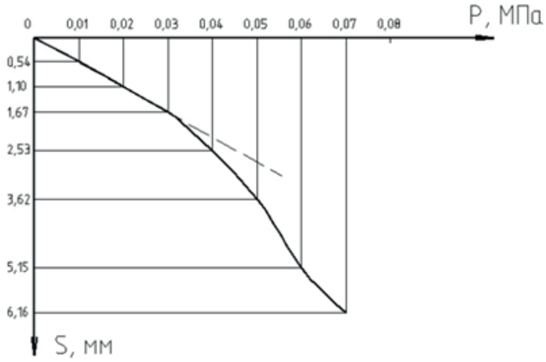

Fig. 3. Graph of dependence of stamp settlement on load when testing soil without reinforcement

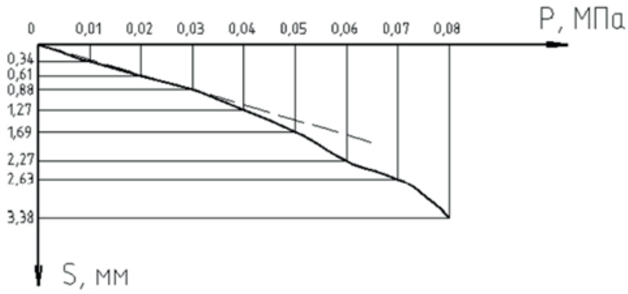

Fig. 4. Graph of dependence of stamp settlement on load when testing soil with 10% reinforcement

Table 1

Stamp Tests of Soil without Reinforcement

Soil reinforcement percentage, %	Load on the stamp N, кг		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$, kg	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
0	N_1 = 6.0	42.0	P_1 = 0.01	0.07	0.54	0.54	6.16
	N_2 = 6.0		P_2 = 0.01		1.10	0.56	
	N_3 = 6.0		P_3 = 0.01		1.67	0.57	
	N_4 = 6.0		P_4 = 0.01		2.53	0.86	
	N_5 = 6.0		P_5 = 0.01		3.62	1.09	
	N_6 = 6.0		P_6 = 0.01		5.15	1.53	
	N_7 = 6.0		P_7 = 0.01		6.16	1.01	

Table 2

Stamp Tests. Percentage of Soil Reinforcement 10 %

Soil reinforcement percentage, %	Load on the stamp N, kg		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$, kg	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
10	N_1 = 6.0	48.0	P_1 = 0.01	0.08	0.34	0.34	3.38
	N_2 = 6.0		P_2 = 0.01		0.61	0.27	
	N_3 = 6.0		P_3 = 0.01		0.88	0.27	
	N_4 = 6.0		P_4 = 0.01		1.27	0.39	
	N_5 = 6.0		P_5 = 0.01		1.69	0.42	
	N_6 = 6.0		P_6 = 0.01		2.27	0.58	
	N_7 = 6.0		P_7 = 0.01		2.63	0.36	
	N_8 = 6.0		P_8 = 0.01		3.38	0.75	

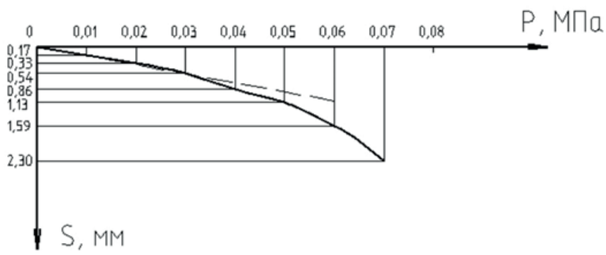

Fig. 5. Graph of dependence of stamp settlement on load when testing soil with 20% reinforcement

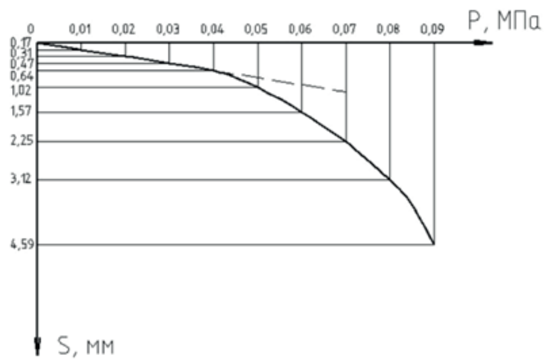

Fig. 6. Graph of dependence of stamp settlement on load when testing soil with 30% reinforcement

Table 3

Stamp Tests. Percentage of Soil Reinforcement 20 %

Soil reinforcement percentage, %	Load on the stamp N, kg		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
20	N_1 = 6.0	42.0	P_1 = 0.01	0.07	0.17	0.17	2.30
	N_2 = 6.0		P_2 = 0.01		0.33	0.16	
	N_3 = 6.0		P_3 = 0.01		0.54	0.21	
	N_4 = 6.0		P_4 = 0.01		0.86	0.32	
	N_5 = 6.0		P_5 = 0.01		1.13	0.27	
	N_6 = 6.0		P_6 = 0.01		1.59	0.46	
	N_7 = 6.0		P_7 = 0.01		2.30	0.71	

Table 4

Stamp Tests. Percentage of Soil Reinforcement 30 %

Soil reinforcement percentage, %	Load on the stamp N, kg		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$, kg	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
30	N_1 = 6.0	54.0	P_1 = 0.01	0.09	0.17	0.17	4.59
	N_2 = 6.0		P_2 = 0.01		0.31	0.14	
	N_3 = 6.0		P_3 = 0.01		0.47	0.16	
	N_4 = 6.0		P_4 = 0.01		0.64	0.17	
	N_5 = 6.0		P_5 = 0.01		1.02	0.38	
	N_6 = 6.0		P_6 = 0.01		1.57	0.55	
	N_7 = 6.0		P_7 = 0.01		2.25	0.68	
	N_8 = 6.0		P_8 = 0.01		3.14	0.89	
	N_9 = 6.0		P_9 = 0.01		4.59	1.45	

Series 2 experiments, soil density: 1.82 g/cm³.

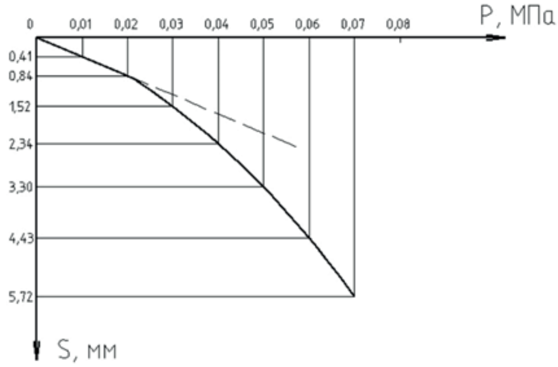

Fig. 7. Graph of dependence of stamp settlement on load when testing soil without reinforcement

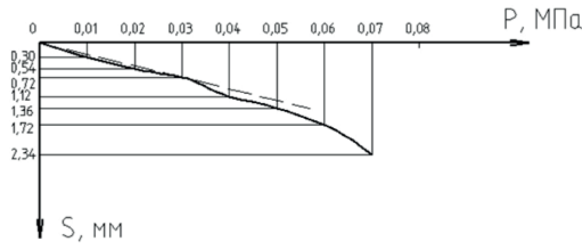

Fig. 8. Graph of dependence of stamp settlement on load when testing soil with 10% reinforcement

Table 5

Stamp Tests of Soil without Reinforcement

Soil reinforcement percentage, %	Load on the stamp N, kg		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$, kg	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
0	$N_1 = 6.0$	42.0	$P_1 = 0.01$	0.07	0.41	0.41	5.72
	$N_2 = 6.0$		$P_2 = 0.01$		0.84	0.43	
	$N_3 = 6.0$		$P_3 = 0.01$		1.52	0.68	
	$N_4 = 6.0$		$P_4 = 0.01$		2.34	0.82	
	$N_5 = 6.0$		$P_5 = 0.01$		3.30	0.96	
	$N_6 = 6.0$		$P_6 = 0.01$		4.43	1.13	
	$N_7 = 6.0$		$P_7 = 0.01$		5.72	1.29	

Table 6

Stamp Tests. Percentage of Soil Reinforcement 10 %

Soil reinforcement percentage, %	Load on the stamp N, kg		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$, kg	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
10	$N_1 = 6.0$	42.0	$P_1 = 0.01$	0.07	0.30	0.30	2.34
	$N_2 = 6.0$		$P_2 = 0.01$		0.54	0.24	
	$N_3 = 6.0$		$P_3 = 0.01$		0.72	0.18	
	$N_4 = 6.0$		$P_4 = 0.01$		1.12	0.40	
	$N_5 = 6.0$		$P_5 = 0.01$		1.36	0.24	
	$N_6 = 6.0$		$P_6 = 0.01$		1.72	0.36	
	$N_7 = 6.0$		$P_7 = 0.01$		2.34	0.62	

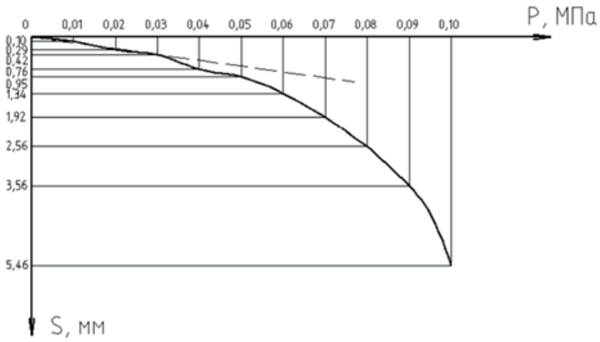

Fig. 9. Graph of dependence of stamp settlement on load when testing soil with 20% reinforcement

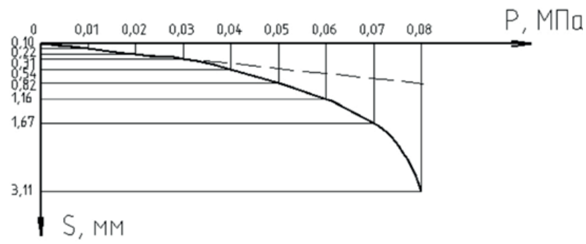

Fig. 10. Graph of dependence of stamp settlement on load when testing soil with 30% reinforcement

Table 7

Stamp Tests. Percentage of Soil Reinforcement 20 %

Soil reinforcement percentage, %	Load on the stamp N, kg		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$, kg	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
20	$N_1 = 6.0$	60.0	$P_1 = 0.01$	0.10	0.10	0.10	5.46
	$N_2 = 6.0$		$P_2 = 0.01$		0.29	0.19	
	$N_3 = 6.0$		$P_3 = 0.01$		0.42	0.13	
	$N_4 = 6.0$		$P_4 = 0.01$		0.76	0.34	
	$N_5 = 6.0$		$P_5 = 0.01$		0.95	0.19	
	$N_6 = 6.0$		$P_6 = 0.01$		1.34	0.39	
	$N_7 = 6.0$		$P_7 = 0.01$		1.92	0.58	
	$N_8 = 6.0$		$P_8 = 0.01$		2.56	0.64	
	$N_9 = 6.0$		$P_9 = 0.01$		3.56	1.0	
	$N_{10} = 6.0$		$P_{10} = 0.01$		5.46	1.90	

Table 8

Stamp Tests. Percentage of Soil Reinforcement 30 %

Soil reinforcement percentage, %	Load on the stamp N, kg		Stamp pressure on the ground P, MPa		Indicator readings h_i, mm	Stamp settlement S, mm	
	stage N_i, kg	total load $\sum N_i$, kg	stage P_i, MPa	total pressure $\sum P_i$, MPa		per stage S_i, mm	total $\sum S_i$, mm
30	$N_1 = 6.0$	48.0	$P_1 = 0.01$	0.08	0.10	0.10	3.11
	$N_2 = 6.0$		$P_2 = 0.01$		0.22	0.12	
	$N_3 = 6.0$		$P_3 = 0.01$		0.31	0.09	
	$N_4 = 6.0$		$P_4 = 0.01$		0.54	0.23	
	$N_5 = 6.0$		$P_5 = 0.01$		0.82	0.28	
	$N_6 = 6.0$		$P_6 = 0.01$		1.16	0.34	
	$N_7 = 6.0$		$P_7 = 0.01$		1.67	0.51	
	$N_8 = 6.0$		$P_8 = 0.01$		3.11	1.44	

On the basis of the results of the stamp tests (soil density: 1, 73 g/cm³), the deformation modulus was calculated for each variant of soil reinforcement:

$$E_0 = (1-\nu^2)\cdot K_p \cdot K_1 \cdot D\frac{\Delta p}{\Delta S} = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{1{,}67} = 0{,}111\ \text{MPa}.$$

$$E_{10} = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{0{,}88} = 0{,}211\ \text{MPa}.$$

$$E_{20} = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{0{,}54} = 0{,}344\ \text{MPa}.$$

$$E_{30} = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{0{,}64} = 0{,}386\ \text{MPa}.$$

On the basis of the results of the stamp tests (soil density: 1, 82 g/cm³), the deformation modulus was calculated for each variant of soil reinforcement:

$$E_0 = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{0{,}84} = 0{,}147\ \text{MPa}.$$

$$E_{10} = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{0{,}72} = 0{,}258\ \text{MPa}.$$

$$E_{20} = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{0{,}42} = 0{,}441\ \text{MPa}.$$

$$E_{30} = (1-0{,}3^2)\cdot 1\cdot 0{,}79\cdot 8{,}6\frac{0{,}03}{0{,}31} = 0{,}598\ \text{MPa}.$$

The results of laboratory studies show that reinforcing sandy soil with fiber made from plastic waste substantially increases strength indicators such as the deformation modulus. Notably, the higher the percentage of soil reinforcement, the higher the overall deformation modulus. Thus, for soil with a density of 1.73 g/cm³ and reinforcements of 10, 20 and 30 %, the deformation modulus increases by 1.90, 3.10, and 3.47 times, respectively. For soil with a density of 1.82 g/cm³ and reinforcements of 10, 20 and 30 %, the deformation modulus increases by 1.75, 3.0, and 4.06 times, respectively. The higher deformation modulus of soil with a density of 1.82 g/cm³ can be explained by the much smaller pore volume of this soil; accordingly, its deformability is lower. Food plastic waste does not corrode, has a long decomposition process in soil, and resists most chemical compounds. The use of plastic waste to strengthen the base will reduce the anthropogenic load on the environment and reduce the cost of processing or disposal of food packaging. Notably, cutting strips (fiber) from bottles is not a very expensive operation, which reduces the cost of constructing artificial foundations. Currently, we can draw preliminary conclusions that plastic waste can be used as reinforcement for artificial foundations, but further research in this field is required.

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