UDC 624.1
IRSTI 67.13.21
REVIEW ARTICLE

TECHNOLOGY FOR STRENGTHENING SOIL MATERIALS USING TWO-COMPONENT POLYURETHANE MATERIAL GEOPUR

S.Zh. Jumadilova , V.A. Khomyakov , A.M. Kuanyshbai*

International Educational Corporation, 050043, Almaty, Kazakhstan

Abstract. *Almaty and its environs are located in the foothill zone of the Zailiysky Alatau, where, given the lack of sites with good soils, many buildings and structures have to be built on weak soils, weak clay or subsidence bases. Another problem is construction in seismically active areas, which imposes certain restrictions on the design of foundations and the construction of structures. In such cases, specialized engineering measures are required, whether it is soil replacement, pile foundations or artificial foundations. In construction, there is a wide range of methods for fixing soils: strengthening with piles, vertical reinforcing elements, chemical fixing with solutions that allow you to carry out activities. This article describes the methods and sequence of work when using a two-component polyurethane material GEOPUR. In laboratory and field conditions to increase the bearing capacity of soils. The result of the application of this technology is a triple effect: increased moisture resistance and sealing; stopping or reducing water inflow to underground structures; stabilizing soil cementation - increasing the stability of the foundations of buildings and underground structures; there is a structuring and strengthening of soil, rocks and structures. Due to the introduction of the Geopur® material, soil structuring occurs, and it passes from the class of dispersed to the class of semi-rocky soils, the strength of which is characterized by the uniaxial compressive strength R. Studies have shown that the value of R in depth varies from 1.94MPa at a depth of 0.9m up to 4.57 MPa at a depth of 4.20 m. In accordance with state standard 25100-2011, such material belongs to a variety of soils with low or reduced strength.*

Keywords: *soil fixed, injection method, soil, two component resins.*

***Corresponding author**
Aidana Kuanyshbai, e-mail: a.kuanyshbai@mok.kz

https://doi.org/10.51488/1680-080X/2024.1-05
Received 08 January 2024; Revised 12 February 2024; Accepted 18 March 2024

ӘОЖ 624.1
ҒТАМР 67.13.21
ШОЛУ МАҚАЛАСЫ

GEOPUR ЕКІКОМПОНЕНТТІК ПОЛИУРЕТАНДЫ МАТЕРИАЛДЫ ҚОЛДАНА ОТЫРЫП, ЖЕР МАССИВТЕРІН ҚАТАЙТУ ТЕХНОЛОГИЯСЫ

С.Ж. Джумадилова , В.А. Хомяков , М.А. Қуанышбай*

Халықаралық білім беру корпорациясы, Алматы, 050043, Қазақстан

Аңдатпа. *Алматы және оның айналасы Іле Алатауының тау бөктерінде орналасқан, онда жақсы топырақтары бар учаскелердің тапшылығын ескере отырып, көптеген ғимараттар мен құрылыстарды әлсіз топырақтарда, әлсіз сазды немесе шөгінді негіздерде жүзеге асыру тура келеді. Тағы бір мәселе – іргетастарды жобалау мен құрылыстарды салу кезінде белгілі бір шектеулер қоятын сейсмикалық белсенді аудандарда құрылыс салу. Мұндай жағдайларда топырақты ауыстыру, қадалардың іргетастарын салу немесе жасанды негіз жасау сияқты мамандандырылған инженерлік шаралар қажет. Құрылыста топырақты бекітудің көптеген әдістері бар: қадалармен, тік арматуралық элементтермен нығайту, іс-шараларды жүзеге асыруға мүмкіндік беретін ерітінділермен химиялық бекіту. Бұл мақалада geopur екікомпонентті полиуретанды материалды пайдалану кезінде жұмыстың әдістері мен реттілігі келтірілген. зертханалық және далалық жағдайларда топырақтың көтергіштігін арттыру. Бұл технологияны қолданудың нәтижесі үш есе әсер етеді: ылғалға төзімділікті арттыру және тығыздау; жер асты құрылымдарына су ағынын тоқтату немесе азайту; топырақты тұрақтандыру цементтеу – ғимараттар мен жерасты құрылымдарының негіздерінің тұрақтылығын арттыру; топырақты, жыныстар мен құрылымдарды құрылымдау және нығайту.*

Түйін сөздер: *топырақты бекіту, инъекциялық әдіс, топырақ, екікомпоненттік шайырлар.*

***Автор-корреспондент**
Айдана Куанышбай, e-mail: a.kuanyshbai@mok.kz

https://doi.org/10.51488/1680-080X/2024.1-05
Алынды 08 қаңтар 2024; Қайта қаралды 12 ақпан 2024; Қабылданды 18 наурыз 2024

УДК 624.1
МРНТИ 67.13.21
ОБЗОРНАЯ СТАТЬЯ

ТЕХНОЛОГИЯ УПРОЧНЕНИЯ ГРУНТОВЫХ МАССИВОВ С ИСПОЛЬЗОВАНИЕМ ДВУХКОМПОНЕНТНОГО ПОЛИУРЕТАНОВОГО МАТЕРИАЛА GEOPUR

С.Ж. Джумадилова , В.А. Хомяков , М.А. Куанышбай*

Международная образовательная корпорация, Алматы, 050043, Казахстан

Аннтотация. *Алматы и его окрестности располагаются в предгорной зоне Заилийского Алатау, где с учетом дефицита участков с хорошими грунтами многие здания и сооружения приходится реализовывать на слабых грунтах, слабых глинистых или просадочных основаниях. Еще одной проблемой является строительство в сейсмоактивных районах, что накладывает определенные ограничения при проектировании фундаментов и строительстве сооружений. В таких случаях требуется проведение специализированных инженерных мероприятий, будь то замена грунта, устройство свайных фундаментов или выполнение искусственного основания. В строительстве существует широкий спектр методов закрепления грунтов: упрочнение сваями, вертикальными армирующими элементами, химическое закрепление растворами, которые позволяют осуществлять мероприятия. В данной статье приводятся методики и последовательность выполнения работ при использовании двухкомпонентного полиуретанового материала GEOPUR. в лабораторных и полевых условиях по повышению несущей способности грунтов. Результатом применения данной технологии является тройной эффект: повышение влагостойкости и герметизация; остановка или уменьшение водопритока в подземные сооружения; стабилизирующая цементация грунта – повышение устойчивости оснований зданий и подземных сооружений; происходит структурирование и укрепление грунта, породы и конструкций.*

Ключевые слова: *закрепление грунта, инъекционный метод, грунт, двухкомпонентные смолы.*

***Автор-корреспондент**
Айдана Куанышбай, e-mail: a.kuanyshbai@mok.kz

https://doi.org/10.51488/1680-080X/2024.1-05
Поступило 08 января 2024; Пересмотрено 12 февраля 2024; Принято 18 марта 2024

ACKNOWLEDGEMENTS/SOURCE OF FUNDING

The study was conducted using private sources of funding.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

According to the survey, the territory is located on a gently sloping plain, an elongated strip along the northern slope of the Zailiysky Alatau ridge. The accumulative type of relief is widespread within the entire metro line. In geomorphological terms, the section from the Moskva station to the Kalkaman station is located within the piedmont plume formed as a result of the confluence of the alluvial fans of the Bolshaya Almatinka and Kargalinka mountain rivers. The surface is flat, with a slope from the mountains to the plain. The surface is complicated by the river valleys of the Kargalinka and B. Almatinka rivers. The valley of the Kargalinka River is poorly expressed. Floodplain areas are poorly traced. The left bank of the river is steep, the right bank is gentle. The depth of the river incision is 1.50-3.0 m. The sides are composed of loam, the bottom of the river is pebbly. The valley of the B. Almatinka river with a cutting depth of -5-6m. The sides are steep, from the surface to a depth of 2.60 m they are composed of loams, deeper - boulder and pebble soils with sandy loamy, loamy and sandy aggregates. The banks of the river are lined with reinforced concrete slabs (**Toma &Al-Hadidi, 2022**).

2 CLASSIFICATION OF GEOPUR MATERIAL

GEOPUR® TECHNOLOGIES products are based on high-pressure grouting technique using GEOPUR two-component polyurethane material manufactured by company GME Consult. The use of GEOPUR technology allows filling voids and cracks in the rock by injection of polyurethane resin, as well as reducing the porosity of macroporous soils by filling pores with cementing material to increase the strength of the anchor fastening in the construction of retaining walls and the operation of anchors in the stabilization of landslides and to increase the efficiency of the base in the construction of micropiled foundations for buildings, structures and machines

GEOPUR is a cementing material. Application possibilities of GEOPUR material tend to be applied in various fields: underground structures, tunneling; geological and technical works; civil engineering.

The materials of the GEOPUR® injection system include polyurethane resins that differ in the level of foaming, which increases in sequence from types 082/1000, 082/600, 082/360, 082/290, 082/180, 082/90, 230, 240. Not includes fluorinated and chlorinated hydrocarbons and halogens. Composition of GEOPUR®:component A honey-colored liquid (all types); it is a composition of polyepepoliol, catalyst, admixture, flame retardant, foam strengthening and water. Component B dark yellow-brown liquid (all types); a mixture of polycyclic oligomers emanating from its performance. Always after mixing the two main components in the calculated ratio, an exothermic process of polyurethane resins occurs. The level of foaming of the reaction product determines the mechanical properties. In all systems, it is possible to move the start of the curing and foaming reaction by 360 seconds. Material is typically delivered with foaming onset in two minutes (**Weng et al., 2019**).

Table 1

Laboratory research program (author's material)

Soil type	The state of the fixed type of soil	Component composition		Defined parameters				Note
				Physical		Mechanical		
		A	B	Density, t/m^3	Note	Compressive strength, MPa	Modulus of deformation MPa	
loam	solid	1	1,1	+		+	+	
	soft plastic	1	1,1	+		+	+	
	fluid	1	1,1	+		+	+	

* the number of tested samples is not less than 6 pieces

3 METHODOLOGY FOR CONDUCTING LABORATORY RESEARCH

For laboratory studies, samples of loam of different soil conditions were prepared according to the test program. To prepare the samples, a cylinder made of a high-strength plastic pipe with dimensions from 35 cm to 50 cm in height and a diameter of 20 cm to 40 cm was used. The end walls of the pipes were monolithic with reinforced mortar grade M100. A hole was drilled in the pipe wall and the R8 “packer” device was installed to inject the mixture component according to the test program. View the **figure 1-2.**

Figure 1 – Sample preparation for laboratory testing (author’s material)

For injection, an injection pump of the applicable types is installed, including injection accessories. The device allows you to dose individual components in a ratio of 1:1, in the case of the Geour brand 082/90 system, which was pumped into the sample under pressure by means of a pump until complete failure (**Pu et al., 2021**). A failure was taken to be the state when the mixture bled out through the gaps in the end faces of the cover, or back through the packer. After the injection, the samples were kept for 24 hours, for the formation of foam and fixing with the soil. The next step was to remove the samples from the cylinders and separate the fixed mass from the non-fixed mass. To determine the volume of fixed soil, special measurements were carried out, the calculation of mass and volume. Next, rectangular or round specimens up to 10 cm high were cut out of the hardened mass, which were tested on by hydraulic test press MATEST with a capacity of 2000 kN according to the loading scheme with a statically increasing load (**Awwad & Nurakov, 2020**).

Figure 2 – An example of fixing loam with a two-component resin in the laboratory (author’s material)

4 FIELD TEST METHODOLOGY

Field studies were carried out on the territory of the construction site "Metrostroyproekt". Soil injection during the construction of underground structures is used to overcome areas of incoherent water-saturated and disturbed rocky soils, eliminate water inflows into underground workings and structures, install pit fencing, protective screens (curtains), strengthen the bases and foundations of buildings and other structures located in the zone of influence of construction. For field research, using a Permon VKS 80 pneumatic drill with a reverse, 2 screw anchors with a diameter of 32 mm were drilled into the ground to a depth of 3.5 meters at a distance of 2 from the axis. At each end of the anchor before drilling, diamond core bits with a diameter of 38 mm were installed (**Lukpanov et al., 2019**). After reaching a depth of 3.5 meters, mounting foam was poured around the anchor for sealing and metal plates were installed.A coupling with a mixer and a gun for injecting a two-component resin are installed on the upper end of the anchor. The two component resin is injected using a portable Graco Reactor E-10hp system. The Reactor E-10hp is a 1:1.1 mixing ratio electrically powered portable dispenser. Two-component resin after mixing is injected with a special gun (**Tao et al., 2023**). Fluid is supplied to the Reactor E-10hp by gravity and comes from the 22.7 L (6 gal) supply tanks installed on the unit.3 anchors were injected in the field. Anchors 1 and 2 were installed in loam to a depth of 4.2m. Anchor 3 is installed in gravel soil to a depth of 3.5 m. Obviously, the application of one or another method of soil stabilization will depend on the porosity of the base, or on its filtration coefficient (**Zhussupbekov et al., 2018**).

Figure 3 – An example of fixing loam in the field (Ankers 1 and 2)
(author's material)

Data on the consumption of two-component resin for each anchor:

Anchor No. 1 - the amount of injected two-component resin is 62 kg. Pumping time is 38 min. The volume of hardened soil is 0.98 m3, the consumption percentage is 63.27 kg/m3. (Date of injection 02.09.2021, date of removal of the anchor 05.09.2021)

Anchor No. 2 - the amount of injected two-component resin is 65 kg. Pumping time is 38 min. The volume of hardened soil is 0.82 m3, the consumption percentage is 79.27 kg/m3. (Date of injection 02.09.2021, date of removal of the anchor 05.09.2021)

Anchor No. 3 - the amount of injected two-component resin is 82 kg. Pumping time 40 min. The volume of hardened soil (a mixture of loam and gravel soil) is 0.703 m3. The consumption percentage for gravel soil was 116.65 kg/m3. (injection date 12.24.2021, anchor removal date 01.17.2022). View the **Figures 3-5 and Tables 3-4.**

The more often the piles are made, the greater the degree of compaction the base soil receives (**Liu et al., 2019**).

Table 3
Density determination from field tests (author's material)

Group No.	No.	Sample No.	Sampling depth, m	Height, cm	Width, cm	Length, cm	Weight, kg	Density, p (kg/m³)	Average density, kg/m³
1	**1**	П-С-1,1	0,9	11	7	8,4	0,836	1292,51	1287,97
	2	П-С-1,2	0,9	10,7	7,6	8,8	0,908	1268,83	
	3	П-С-1,3	0,9	9	7,5	8,2	0,732	1322,49	
	4	П-С-1,5	0,9	9,6	8,3	9,3	1,104	1489,83	
	5	П-С-1,6	0,9	10,6	10,3	7,7	1,064	1265,63	
	6	П-С-1,7	0,9	13,5	10	10,1	1,728	1267,32	
2	**1**	П-С-2,1	1,85	12,8	8,5	9,1	1,48	1494,82	1356,50
	2	П-С-2,2	1,85	12	7,5	7,3	0,96	1461,18	
	3	П-С-2,4	1,85	9	7,2	8,3	0,684	1271,75	
	4	П-С-2,5	1,85	13,5	6,5	9,3	1,006	1232,72	
	5	П-С-2,6	1,85	10,7	5,5	9,3	0,636	1162,05	
	6	П-С-2,8	1,85	7,3	6,8	7,2	0,542	1516,47	
3	**1**	П-С-3,1	2,1	10,7	7,7	9,3	1,042	1359,91	1487,52
	2	П-С-3,2	2,1	11,7	8,4	9,3	1,408	1540,47	
	3	П-С-3,4	2,1	11,4	5,8	11,5	1,214	1596,57	
	4	П-С-3,5	2,1	10	6,6	9,8	0,928	1434,75	
	5	П-С-4,1	2,3	10,6	5,4	8,2	0,722	1538,23	
	6	П-С-4,2	2,3	9,9	8,8	8,3	0,998	1380,17	
	7	П-С-4,3	2,3	10,9	6,1	7,7	0,8	1562,58	
4	**1**	П-С-5,1	3	12,2	5	6,1	0,564	1515,72	1455,94
	2	П-С-5,3	3	12,1	5,9	6,3	0,554	1231,77	
	3	П-С-5,6	3	12,6	6,2	10,5	1,26	1536,09	
	4	П-С-5,7	3	12,6	5,1	9,4	0,858	1420,42	
	5	П-С-5,8	3	8,5	6,4	7,7	0,616	1470,58	
	6	П-С-5,9	3	11	9	7,7	1,19	1561,06	
5	**1**	П-С-6,1	3,4	9,1	7	9	0,808	1409,38	1363,0
	2	П-С-6,2	3,4	9,9	7,4	8,3	0,688	1131,47	
	3	П-С-6,3	3,4	8,1	6,9	7,7	0,636	1477,85	
	4	П-С-6,4	3,4	9,3	6,1	9	0,682	1335,76	
	5	П-С-6,5	3,4	12,5	8	7,9	1,156	1463,29	
	6	П-С-6,6	3,4	10,8	7,6	10,3	1,15	1360,26	
6	**1**	П-С-7,1	4,2	16	10,6	9,8	2,672	1607,62	1479,13
	2	П-С-7,2	4,2	12,6	10	10,5	1,912	1445,20	
	3	П-С-7,3	4,2	13,7	7,6	8,8	1,324	1445,01	
	4	П-С-7,4	4,2	14,5	8,2	8,6	1,442	1410,21	
	5	П-С-7,5	4,2	15	11,1	11,7	2,882	1479,42	
	6	П-С-7,6	4,2	8,8	8,3	8,8	0,956	1487,35	

Table 4
Rresults of laboratory studies of hardening of massifs with GEOPUR material (author's material)

Soil type	Sample number	Soil condition	Density (t/m³)	Humidity (W)	Initial volume (m³)	Volume of injection (kg)	Volume of hard-ened soil (m³)	Consumption percentage (kg/m³)
loam	L-C-1	natural	1,751	0,22	0,06	0,06	0,000165	363,64
	L-C-2	natural	1,728	0,16	0,06	0,31	0,00322	96,27
	L-C-3	natural	1,716	0,20	0,05	0,09	0,000351	256,41
	L-C-4	natural	1,743	0,17	0,06	0,253	0,00266	95,11
	L-C-5	wet		0,273	0,04	0,117	0,0002	585,00

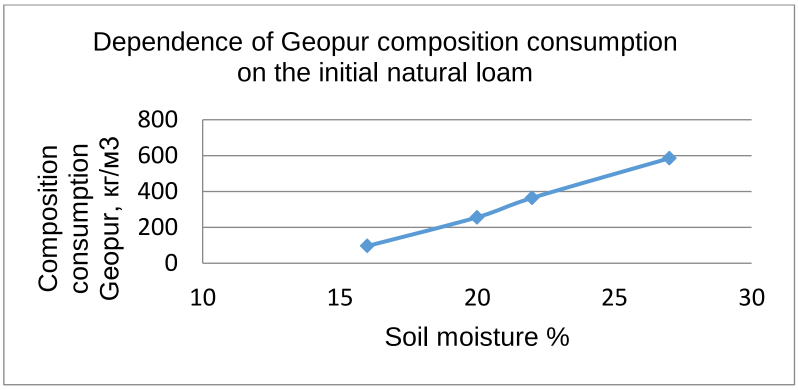

Figure 4 – Dependence of Geopur composition consumption on the initial natural loam (author's material)

5 DETERMINATION OF UNIAXIAL COMPRESSIVE STRENGTH

The loading of a clay soil sample is carried out at a given rate of increment of the relative vertical deformation of the sample, choosing it depending on the expected strength of the soil Rc. so that the test time is 2 – 15 min, which usually corresponds to a rate of 0.5% – 2% per 1 min. A lower speed is chosen for samples with smaller deformations during destruction. The vertical deformations of the sample were measured with an error of 0.01 mm for clay soils and recorded during loading at no less than 10 stress values before failure. The test was carried out until the destruction of the sample, i.e., until the maximum value of the vertical load was reached. In the case of testing a clay soil sample in the absence of visible signs of destruction, the test was terminated at a relative vertical deformation of the sample e = 15% (**Ulitsky et al., 2017**).

To determine the modulus of deformation and the modulus of elasticity of the soil, the test was not brought to the destruction of the sample, stopping it at a stress of 50% – 60% of the value of Rc. If necessary, the sample was unloaded in the same sequence as the loading (**Chen et al., 2022**).

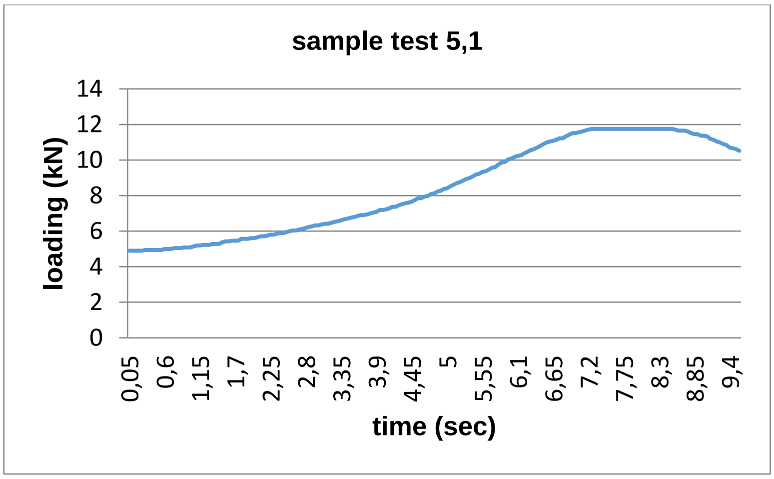

Figure 5 – Resulting sample test schedule (author's material)

To determine the modulus of deformation and the modulus of elasticity of the soil, the test was not brought to the destruction of the sample, stopping it at a stress of 50% - 60% of the value of Rc. If necessary, the sample was unloaded in the same sequence as the loading (**Khomyakov et al., 2020**).

Table 5
Determination of strength by field tests (author's material)

Group No.	No.	Sample No.	Depth of sampling (m)	Maximum load, F (kN)	Tensile strength, Rc (MPa)	Average tensile strength (MPa)
1	1	П-С-1,1	0,9	14,316	2,435	
	2	П-С-1,2	0,9	16,932	2,532	
	3	П-С-1,3	0,9	12,842	2,088	
	4	П-С-1,5	0,9	10,273	1,331	1,946
	5	П-С-1,6	0,9	10,511	1,325	
	6	П-С-1,7	0,9	19,834	1,964	
2	1	П-С-2,1	1,85	43,377	5,608	
	2	П-С-2,2	1,85	27,253	4,978	
	3	П-С-2,4	1,85	12,699	2,125	
	4	П-С-2,5	1,85	20,119	3,328	3,966
	5	П-С-2,6	1,85	16,076	3,143	
	6	П-С-2,8	1,85	22,592	4,614	
3	1	П-С-3,1	2,1	24,352	3,401	
	2	П-С-3,2	2,1	27,967	3,580	
	3	П-С-3,4	2,1	32,771	4,913	4,969
	4	П-С-3,5	2,1	21,356	3,302	
	5	П-С-4,1	2,3	32,961	7,444	
	6	П-С-4,2	2,3	52,889	7,241	
	7	П-С-4,3	2,3	23,02	4,901	
4	1	П-С-5,1	3	11,367	3,727	
	2	П-С-5,3	3	9,703	2,610	
	3	П-С-5,6	3	28,728	4,413	
	4	П-С-5,7	3	15,505	3,234	3,475
	5	П-С-5,8	3	24,352	4,942	
	6	П-С-5,9	3	13,317	1,922	
5	1	П-С-6,1	3,4	10,559	1,676	
	2	П-С-6,2	3,4	8,514	1,386	
	3	П-С-6,3	3,4	11,177	2,104	2,134
	4	П-С-6,4	3,4	7,372	1,343	
	5	П-С-6,5	3,4	20,832	3,296	
	6	П-С-6,6	3,4	23,496	3,002	
6	1	П-С-7,1	4,2	48,038	4,624	
	2	П-С-7,2	4,2	43,139	4,108	
	3	П-С-7,3	4,2	43,329	6,479	4,567
	4	П-С-7,4	4,2	19,548	2,772	
	5	П-С-7,5	4,2	78,478	6,043	
	6	П-С-7,6	4,2	24,637	3,373	

6 CONCLUSIONS

The average density of the hardened soil as a whole has changed in the direction of decrease. According to Kazakh Geotechnical Research Institute surveys, the natural density of loams was 1.64-1.67 t/m3. After the introduction of Geopur® materials, the density changes and is 1.28t/m3 from a depth of 0.9 to 1.48t/m3 at a depth of 4.20m. The decrease in density occurs as a result of decompaction of the soil during foaming with Geopur® material.

Due to the introduction of the Geopur® material, soil structuring occurs, and it passes from the class of dispersed to the class of semi-rocky soils, the strength of which is characterized by the uniaxial compressive strength R. Studies have shown that the value of R in depth varies from 1.94MPa at a depth of 0.9m up to 4.57 MPa at a depth of 4.20 m. In accordance with state standard 25100-2011, such material belongs to a variety of soils with low or reduced strength.

The effectiveness of applying the hardening method using Geopur® material should be confirmed by verification calculations of accepted structural models using the physical and mechanical properties of the hardened soil obtained as a result of these studies.

When hardening is carried out according to the technology using the two-component polyurethane material GEOPUR®, with an appropriate calculation justification, the bearing capacity and operational reliability of soil massifs will be ensured.

REFERENCES

1. **Weng, Meng-Chia - Liu, Yong - Lee, Jeffrey - Awwad, Talal - Gruzin, Vladimir - Kim, Vladimir** (2019) Sustainable Reconstruction in Conditions of Dense Urban Development: 13-23.https://link.springer.com/chapter/10.1007/978-3-319-95750-0_2
2. **Khomyakov V.,Yemenov Y, Zhamek N., (**2020) Methods of restoration of deformed retaining walls in seismic conditions16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering,.1-12. https://www.elibrary.ru/item.asp?id=43281652
3. **Zhussupbekov A, Zhunisov T, Issina A, Awwad T.** (2013) Geotechnical and structural investigations of historical monuments of Kazakhstan. In Proceedings of Second International Symposium on Geotechnical Engineering for the Preservation of Monuments and Historic Sites, Naples, Italy (pp. 779-784 https://www.researchgate.net/publication/260615494_ Geotechnical_and_structural_ investigations_ of_historical_monuments_of_Kazakhstan
4. **Toma, N.M., Al-Hadidi, M.T.**(2022). The effect of soaking and wetting on the properties of the gypsum soil treated with polyurethane. Association of Arab Universities Journal of Engineering Sciences. https://jaaru.org/index.php/auisseng/article/view/615
5. **Ulitsky, V., Shashkin, A., Shashkin, K., Lisyuk, M., Awwad, T.** (2017). Numerical simulation of new construction projects and existing buildings and structures taking into account their deformation scheme. In ICSMGE 2017-19th International Conference on Soil Mechanics and Geotechnical Engineering, 2061-2064. http://surl.li/sbcmh
6. **Lukpanov, R.E., Awwad, T., Orazova, D.K., Tsigulyov, D.V.** (2019). Geotechnical Research and Design of Wind Power Plant. Sustainable Civil Infrastructures. 220-7. https://link.springer.com/chapter/10.1007/978-3-030-01920-4_19
7. **Pu, S., Duan, W., Zhu, Z., Wang, W., Zhang, C., Li, N., Jiang, P., Wu, Z.** (2022). Environmental behavior and engineering performance of self-developed silico-aluminophosphate geopolymer binder stabilized lead contaminated soil. Journal of Cleaner Production.. hhttps://doi.org/10.1016/j.jclepro.2022.134808
8. **Liu, J., Chen, Z., Zeng, Z., Kanungo, D.P., Bu, F., Bai, Y., Qi, C., Qian, W.** (2020). Influence of polyurethane polymer on the strength and mechanical behavior of sand-root composite. Fibers and polymers, 21, 829-39. https://doi.org/10.1007/s12221-020-9331-z
9. **Al-Atroush, M.E., Sebaey, T.A.** (2021). Stabilization of expansive soil using hydrophobic polyurethane foam: A review. Transportation Geotechnics. Mar 1;27:100494 https://doi.org/10.1016/j.trgeo.2020.100494
10. **Tao, R., Li, H., Liu, Z., Zhang, X., Wang, M., Shen, W., Qu, M., Mei, Y. (**2023). The adsorbent preparation of FeOOH@ PU for effective chromium (VI) removal. Environmental Science and Pollution Research. 33-69. https://doi.org/10.1007/s11356-022-24569-2
11. **Chen, R., Cai, G., Dong, X., Pu, S., Dai, X., Duan, W.** (2022). Green utilization of modified biomass by-product rice husk ash: A novel eco-friendly binder for stabilizing waste clay as road material. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2022.134303
12. **Awwad, T., Donia, M.** (2016). The efficiency of using a seismic base isolation system for a 2D concrete frame founded upon improved soft soil with rigid inclusions. Earthquake Engineering and Engineering Vibration. 49-60. https://doi.org/10.1007/s11803-016-0304-6
13. **Awwad, T., Meziab, A.** (2020). Influence of natural pozzolana & lime additives on improvement of clayey soil (CBR) to be useable in embankment of road works, 457-475, https://www. researchgate.net/publication/345247376_Influence_of_Natural_Pozzolana_Lime_Additives_ on_Improvement_of_Clayey_Soil_CBR_to_be_Useable_in_Embankment_of_Road_Works
14. **Awwad, T., Nurakov, S.** (2020). The Determination of Soil Cutting Force Applied with Bucketless Bottom Rotor with Account of Speed and Runout, 476-486, https://doi.org/10.1007/978-981-15-0450-1_50
15. **Awwad, T., Kodsi, S., Oda, K., Inui, T.** (2019). A study of the influence of surcharge loading on clay soil settlements using viscous modelling. Viskoz modelleme kullanilan kil zemini http://surl.li/scylr