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REVIEW ARTICLE

INJECTION OF TWO-COMPONENT GEOPUR RESIN FOR STRENGTHENING SANDY SOILS

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Abstract. *The article explores the use of GEOPUR, a two-component polyurethane resin, for strengthening sandy soils. It highlights the process of soil stabilization through high-pressure grouting, which improves water resistance, stabilizes soil structures, and enhances anchoring strength. The research investigates the application of this resin in consolidating weak, loose soils and its effect on their physical and mechanical properties. Laboratory experiments were conducted on sand samples to simulate real-world conditions, testing the resin's effectiveness in improving soil density, compressive strength, and overall stability. The study analyzes how the resin's expansion within the soil structure impacts soil behavior, concluding that the GEOPUR resin significantly enhances the soil's load-bearing capacity. Various parameters, such as the volume of injected resin, consolidation efficiency, and the strength-density relationship, are evaluated to provide practical recommendations for soil stabilization using this innovative material. The findings demonstrate the resin's potential in geotechnical applications, particularly in situations where traditional stabilization methods are not feasible or efficient. The article concludes with suggestions for optimizing the resin injection process to maximize its effectiveness in both laboratory and field conditions, making it a promising solution for future ground improvement projects.*

Keywords: *resins, polyurethane, injection, sand, resin fixation, sandy soils.*

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ҚҰМ ТОПЫРАҚТАРДЫ НЫҒАЙТУҒА АРНАЛҒАН ЕКІ КОМПОНЕНТТІ GEOPUR ШАЙЫРЫ ИНЪЕКЦИЯСЫ

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Аңдатпа. *Мақалада құмды топырақты нығайту үшін GEOPUR екі компонентті полиуретанды шайырын қолдану зерттеледі. Бұл мақалада топырақты тұрақтандыру процесі жоғары қысымды цементациялау арқылы жүзеге асатыны, суға төзімділікті жақсартатыны, топырақ құрылымын тұрақтандыратыны және бекіту күшін арттыратыны атап өтіледі. Зерттеу осы шайырды әлсіз және бос топырақты бекітуге қолдануды және оның физикалық және механикалық қасиеттеріне әсерін қарастырады. Шайырдың топырақ тығыздығын, сығылу беріктігін және жалпы тұрақтылығын арттырудағы тиімділігін тексеру үшін зертханалық эксперименттер нақты жағдайларды модельдеу арқылы құм үлгілерінде жүргізілді. Зерттеуде шайырдың топырақ құрылымында кеңеюі топырақ сипаттамасына әсері талданады және GEOPUR шайыры топырақтың жүк көтергіш қабілетін айтарлықтай арттыруы туралы қорытынды жасалады. Инъекцияланған шайырдың көлемі, консолидация тиімділігі және беріктік пен тығыздық арасындағы қатынас сияқты әртүрлі параметрлер топырақты тұрақтандырудың практикалық көрсеткіштерін ұсыну үшін бағаланады. Зерттеу нәтижелері шайырдың дәстүрлі тұрақтандыру әдістері тиімсіз немесе мүмкін болмайтын жағдайлардағы геотехникалық мәселелердің әлеуетін көрсетеді. Мақалада жоғары тиімділікті зертханалық және далалық жағдайларда шайыр инъекциясы процесін оңтайландыру бойынша ұсыныстар келтірілген. Аталған әдіс топырақтарды жақсартудағы болашақ жобалар үшін перспективті шешім болып табылады.*

Түйін сөздер: *шайырлар, полиуретан, инъекция, құм, шайыр бекіту, құмды топырақ.*

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ОБЗОРНАЯ СТАТЬЯ

ИНЪЕЦИРОВАНИЕ ДВУХКОМПОНЕНТНОЙ СМОЛОЙ GEOPUR ПРИ УКРЕПЛЕНИИ ПЕСЧАННЫХ ГРУНТОВ

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Аннотация. *В статье рассматривается использование двухкомпонентной полиуретановой смолы GEOPUR для укрепления песчаных грунтов. Особое внимание уделяется процессу стабилизации грунта посредством высоконапорного цементационного нагнетания, которое улучшает водонепроницаемость, стабилизирует структуру грунта и повышает прочность анкеровки. Исследование изучает применение этой смолы для консолидации слабых и рыхлых грунтов и ее влияние на их физические и механические свойства. Лабораторные эксперименты проводились на образцах песка, чтобы смоделировать реальные условия, и проверялась эффективность смолы в повышении плотности грунта, его прочности на сжатие и общей стабильности. В исследовании анализируется, как расширение смолы в структуре грунта влияет на его поведение, и делается вывод, что смола GEOPUR значительно увеличивает несущую способность грунта. Оцениваются различные параметры, такие как объем инъектируемой смолы, эффективность консолидации и взаимосвязь между прочностью и плотностью, чтобы дать практические рекомендации по стабилизации грунта с использованием этого инновационного материала. Полученные результаты демонстрируют потенциал применения смолы в геотехнических задачах, особенно в случаях, когда традиционные методы стабилизации грунта не являются эффективными или целесообразными. В статье даются предложения по оптимизации процесса инъекции смолы для максимальной эффективности как в лабораторных, так и в полевых условиях, что делает этот метод перспективным решением для будущих проектов по улучшению грунтов.*

Ключевые слова: *смолы, полиуретан, инъекция, песок, закрепление смолизацией, песчанные грунты.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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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

The stabilization of sandy soils is a major problem in geotechnical engineering, especially in construction projects where soil consolidation and strength are key to ensuring the stability of the foundation. Traditional methods of soil stabilization, although effective, often face problems related to cost, efficiency and environmental impact. In response to these challenges, the use of innovative materials such as two-component polyurethane resins has become a promising solution to improve the physical and mechanical properties of weak soils.

GEPUR Technologies offers a two-component polyurethane resin system designed for injection under high pressure into soils in order to increase their bearing capacity and water resistance. This method has gained popularity due to its ability to penetrate loose soils and fill voids, which leads to an improvement in the structure of the soil and an increase in its stability. When resin is injected into sandy soils, voids and cracks are filled, thereby increasing the overall density and strength of the soil, providing a reliable solution for stabilizing the foundation.

This article discusses the use of GEOPUR resin to stabilize sandy soils, with an emphasis on its effectiveness in improving soil properties such as density, compressive strength and water resistance. Laboratory tests conducted on sand samples demonstrate the resin's ability to improve soil performance under difficult conditions. The study also provides practical recommendations for optimizing the resin injection process, making it a valuable tool for future soil improvement projects.

2 LITERATURE REVIEW

The utilization of polyurethane expanding resins for foundation stabilization and soil improvement has gained significant attention in recent years due to its efficiency and non-invasiveness. Apuani et al. (2015) introduced a method of strengthening settled foundations by injecting polyurethane expanding resins. They combined traditional geotechnical tests with a noninvasive geophysical technique, Electrical Resistivity Tomography (ERT), which provides accurate 3D images of the soil before, during, and after the injection process. This technique enables real-time monitoring of soil consolidation and ensures the effectiveness of the injection process. Similarly, Fischanger et al. (2015) investigated the potential of ERT in evaluating improvements in the mechanical properties of treated sands, specifically those prone to liquefaction. Their study demonstrated the value of ERT in monitoring soil compaction and consolidation by analyzing resistivity changes. **(Apuani et al., 2015), (Fischanger et al., 2015)**.

The use of polyurethane resin has also been explored in the context of the pultrusion process for injecting thermoset resin. Sandberg et al. (2021) analyzed non-isothermal flow during the pultrusion process and found that heating configurations and convective flows led to unique phase transitions not previously described in literature. This suggests that the behavior of polyurethane resin under different conditions can vary significantly, affecting its mechanical properties **(Sandberg et al., 2021)**.

Sabri and Shashkin (2020) conducted laboratory experiments to examine the mechanical properties of polyurethane resin, particularly how its density, influenced by expansion during the injection process, affects stabilization efficiency. The study showed a direct relationship between the resin's density and its strength, highlighting the importance of understanding the resin's behavior during expansion **(Sabri & Shashkin, 2020)**.

Recent studies have also investigated the long-term performance and practical applications of polyurethane injections in foundation repair. Dominijanni et al. (2022) presented case studies demonstrating the effectiveness of resin injections in improving soil stiffness and shear strength. Their findings emphasized the importance of estimating horizontal stress and volumetric strain changes near injection sites. Furthermore, the research by Miranda et al. (2023) on closed-cell expansive polyurethane resin in sand masses revealed that this material behaves like soft rock with high shear strength, making it a promising tool for ground improvement **(Dominijanni et al., 2022; Miranda et al., 2023)**.

Dirgėlienė and Kordušas (2024) reviewed the properties, applications, and limitations of polyurethane resin injection for soil stabilization, noting its efficiency in preventing settlement and enhancing load-bearing capacity. However, they also highlighted challenges such as achieving uniform resin distribution and accurately estimating injection parameters. Despite these challenges, the use of polyurethane resins continues to grow, offering a reliable solution for foundation stabilization and structural reinforcement in geotechnical engineering **(Dirgėlienė & Kordušas, 2024)**.

3 MATERIALS AND METHODS

GEOPUR technologies products are based on the high-pressure grouting technique with the two-component GEOPUR polyurethane material from GME.

The result of this technology is a triple effect: (1) improving water resistance and sealing - stopping or reducing water inflow into underground structures; (2) stabilizing soil grouting - increasing the stability of the foundations of buildings and underground structures; (3) soil, rocks and structures are structured and strengthened.

Application of GEOPUR technology allows to fill voids and cracks in the rock by injection of polyurethane resin, as well as to reduce the porosity of macroporous soils by filling the pores with cementitious material **(Golovanov, 2013)**.

The application possibilities of GEOPUR material tend to be used in various fields:
Underground construction and tunneling involve activities such as filling depressions and voids, protecting structures when crossing fault zones, stabilizing loose material in open-pit mines, securing cavities during tunneling, improving the mechanical properties of rock masses, sealing and preventing water inflow, anchoring ground and rock, and strengthening overburden rock. Self-tapping micropiles and anchors are used for insertion into the soil.

Cementitious self-tapping micro-piles and anchors are made by drilling into threaded reinforced steel rods and then cemented with a polyurethane or cement mixture. Micro-piles are installed in the ground, on rock, and in building structures.

The main element of the anchor / micro-pile is an adjustable steel anchor (IBO type anchor rod) with thread (4). The units include: hexagonal nuts (1), washer under the anchor rod with even load distribution (2), couplings (3), cross drill head (5), clamping and adjustable couplings (6). Part of the system is also an adapter for connection to the rod by drilling equipment **(Sabri & Shashkin, 2020)**. The grouting system adapter is used for connection to the grouting equipment.

The anchor rods can be adjusted by means of couplings to the desired length up to a maximum of 15 m. The anchors are manufactured as temporary or stationary anchors **(Sabri & Shashkin, 2020)**.

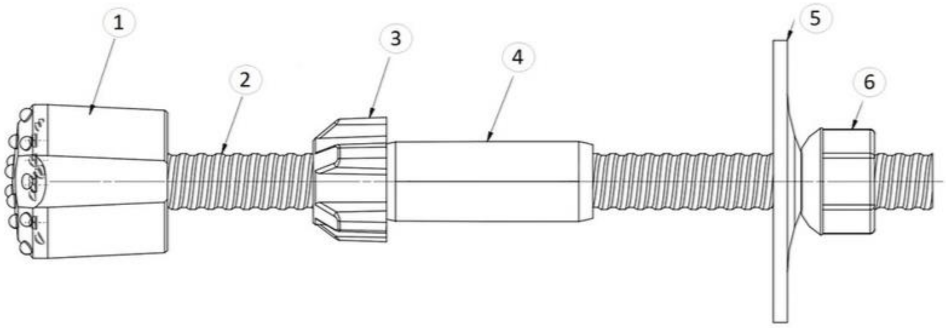

Figure 1 – Schematic diagram of the anchor **(Ground anchors, 2023)**

As shown in **Figure 1**, the IBO anchor rod has three functions: first, it functions as a drill pipe to achieve the required depth; secondly, it acts as a channel for the injection of cement through its hollow core; and thirdly, after the cement hardens, it acts as an anchor or micropile. **Table 1** shows the technical specifications of the anchor rods that are in use. The following types of anchor rods are currently in use.

Table 1
Technical characteristics of anchor rods

Type anchor / micropile	R25	R32N	R32S	R38	R51	R76
Outer / inner diameter, mm	25 / 14	32 / 18,5	32 / 15	38 / 12	51 /12	76 / 12
Maximum load, kN	200	280	360	500	550	1600
Weight, kg/m	2,3	3,4	4,2	6,0	7,0	8,4
Dimensions of the coupling sleeve, mm: width / length	35 / 150	40 / 160	40 / 160	50 / 220	63 / 200	95 / 220

Self-tapping anchors and micropiles offer several advantages, including suitability for use in difficult geological conditions (e.g., shifting sands, water-bearing sands and gravel), as well as in confined spaces (under technological installations, on ceilings, and in narrow areas), high mobility of technology, and the ability to apply full load on the anchors or micropiles within 1 hour to 1 day after the completion of cementing work when using cement mortar with polyurethane **(Sabri et al., 2021)**.

3.1 METHODOLOGY OF LABORATORY TESTS

Table 2
Program of laboratory tests

Type of soil	Condition or the soil type to be consolidated	Component composition		Defined parameters			
				Physical		Mechanical	
		A	B	Density, t/m^3	Prim	Compressive strength, MPa	Modulus of deformati on pressure, MPa
Sand	Medium coarse	1	1,7	+		+	+

Note: the number of tested samples is not less than 6 pcs.

For laboratory tests, samples of sandy type of soil were prepared according to the test program **Table 2**. A cylinder made of high-strength plastic pipe with dimensions of height from 35cm to 50cm and diameter of 20cm-40cm was used for sample preparation, below is a picture.

Figure 2 – Sandy sample in cylindrical shape (author's material).

The method of laboratory research was as follows: the pipe was filled with a type of soil of given moisture and density **(Usmanov, 2014)**. The end walls of the pipe were grouted with reinforced mortar of M100 grade. A hole was drilled in the pipe wall and a *"packer" R8* device was installed for injection of the mixture component according to the test program. By means of a special plunger-type pump and equipment that allows dosing individual components in the volume ratio of 1:1.1 two-component polyurethane resin (Geopur brand 082/90) under pressure by means of the pump was injected into the specimen until complete failure **(Fischanger, 2015)**. Failure was defined as the state when the mixture escaped through the gaps in the end faces of the cover or back through the packer **(Kondratov, 2005)**.

GEOPUR material can be applied in various geological and technical works, including the stabilization of slopes, embankments, and surface mines, anchoring supporting walls, constructing underground barriers with low permeability, stabilizing unconsolidated soil, sealing temperature joints, designing micro-pile foundations, and stabilizing landslides.

GEOPUR, a cementitious material, offers a wide range of applications in civil engineering, including strengthening foundation soil (even below the water table), ensuring the stability of structures threatened by mining or construction activities, reinforcing brick or stone masonry, restoring thermal insulation, sealing utility inlet openings, caulking, stopping water inflow, constructing building foundations, sealing and anchoring construction pit walls (including under the water table), improving soil conditions before construction, and installing micro-piles in soils with low bearing capacity

GEOPUR polyurethane material consists of components A and B: (1) Composition of component A - the color of liquid honey; a mixture of simple polyether polyol, accelerating additives, flammability-reducing admixtures, foam stabilizers and water; (2) Composition of component B is a dark brown to yellow colored liquid (all species); polymethylene polyphenylene isocyanates, defenylmethane-4, 4, 4-diisocyanate, diphensthetamine-4, 4-diisocyanate (MDI) and a mixture of polycyclic oligomers depending on function.

After mixing the two basic components in this ratio, the polyurethane resin is formed by an exothermic reaction.

After injection, the specimens were allowed to stand for 24 hours, for foam formation and consolidation with the soil. The next step was to remove the samples from the cylinders and separate the consolidated mass from the unconfined mass **(Figure 2, 3)**. Special measurements, mass and volume calculations were carried out to determine the volumes of the consolidated soil **(Apuani et al., 2015)**.

Figure 3 – Example of sand consolidation with two-component resin in laboratory conditions (author's material).

Then from the hardened mass samples of rectangular or circular shape up to 10 cm high are cut out, which were tested on a hydraulic test press C055 with a capacity of 2000 kN MATEST company on the scheme of loading statically increasing load **(Figure 4)**.

Designed for testing cylindrical specimens up to 160 mm in diameter and 320 mm in height, as well as concrete cubes with sides of 150 and 100 mm.

a) b)

Figure 4 – Tests of sand specimens: a) at the moment of testing and b) after testing them in compression (author's material).

4 RESULTS AND DISCUSSION

Below there are two tables in which the samples were divided into 3 groups for further testing. **Table 3** shows parameters such as soil condition, density, initial volume, injection volume, consolidated soil volume and flow rate.

Table 3
Results of hardening of arrays with GEOPUR resin (laboratory tests)

Soil type	№ sample	Ground condition	p-dinsity, t/m³	Initial volume, m³	Injection volume, кg	Volume of hardened soil, m³	Percentage of consumption кg/m³
Sand	L-P-1	compacted	1,798	0,06	1	0,01	100,00
	L-P-2	compacted	1,721	0,05	0,47	0,0042	111,90
	L-P-3	loose	1,59	0,06	0,417	0,0052	80,19

Table 4 shows the geometric parameters, maximum compressive load on the press, tensile strength, stability and flow rate.

Table 4
Compression test results of sand samples

Sample designation	Height, cm	Width, cm	Length, cm	Weight,kg	Maximum load, F (kN)	Tensile strength, Rc, (MPa)	Density, p (kg/m^3)	Note
L-P-1,6	8,9	5	6	0,548	120,476	40,159	2052,43	group 1
L-P-1,3	8	6	8	0,76	152,818	31,837	1979,16	
L-P-3,6	9,2	5,3	5,5	0,516	78,668	26,987	1924,08	
L-P-1,4	8,5	7,2	7,2	0,934	133,698	25,791	2119,64	
L-P-3,2	9	5	6,15	0,566	74,15	24,114	2045,16	
L-P-3,1	9,6	5,3	5,8	0,548	60,547	19,696	1856,97	group 2
L-P-3,4	8,2	5	6,3	0,542	56,226	17,850	2098,33	
L-P-1,1	9,2	6,1	7	0,874	75,675	17,722	2224,82	
L-P-1,5	10	6,6	9	1,306	104,78	17,640	2198,65	
L-P-3,7	10	6,3	7,1	0,766	72,105	16,120	1712,49	
L-P-3,3	9,1	5,6	6	0,502	53,793	16,010	1641,81	
L-P-2,2	10	6,7	9,3	1,024	49,275	7,908	1643,39	group 3
L-P-2,1	8,8	8,7	8,7	1,216	49,227	6,504	1825,62	
L-P-3,5	9,7	6	7,6	0,614	26,825	5,883	1388,13	
L-P-1,2	9,7	6	6	0,75	17,36	4,822	2147,76	
L-P-2,4	10,1	5,3	5,5	0,45	13,42	4,604	1528,45	
L-P-2,3	10	6	5,5	0,37	14,364	4,353	1121,21	

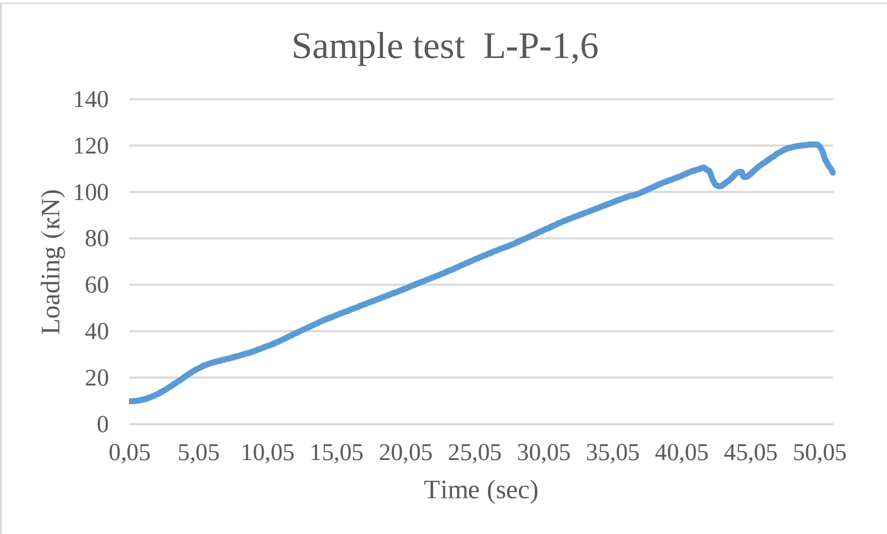

Figure 5 – Results of strengthening arrays with GEOPUR resin

As can be seen in **Figure 5**, the load gradually increases from 0 to approximately 80 kN during the first 10 seconds. This indicates that the material is undergoing a uniform loading phase, which is likely indicative of elastic properties where the sample deforms along a line in response to an applied load. From about 10 to 35 seconds, the load continues to increase, but more slowly. Between approximately 35 and 45 seconds the load peaks at around 135 kN. After the peak (about 45 seconds), the load decreases slightly, indicating potential failure or damage to the material. This means that the sample has exceeded its tensile strength and is beginning to fail.

5 CONCLUSIONS

1. The use of resin in weak loose soils significantly improves the dynamic properties of the soil. Application of resin technology is effective for consolidation of weak loose soils.

2. The samples were divided into 3 groups; 1 compacted sand (p=1.798 t/m^3), 2 compacted sand (p=1.721 t/m^3), 3 group loose sand (p=1.59 t/m^3). Group 1 and 2 compacted sand, group 3 with loose sand. In 1 sample 1 kg of resin was injected, in 2 0.47 kg, in 3 0.417 kg. The volume of hardened soil amounted to 0.01 m^3 in group 1, 0.0042 m^3 in group 2, 0.0052 in group 3.

3. During the test on the hydraulic press MATEST C055 were obtained values of the tensile strength of each sample. The average value of tensile strength in the compacted samples of group 1 29.78 MPa, in the second group 17.51 MPa, in group 3 with loose sand 5.68 MPa

4. Based on the test results, it can be concluded that the use of polyurethane resin in weak loose soils will improve the bearing capacity of the soil.

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