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Original Scientific Paper

ADVANCED APPLICATION OF THE JET-GROUTING TECHNIQUE IN BULGARIAN GEOTECHNICAL PRACTICE

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Abstract. *The primary objective of this paper is to showcase the versatile application of jet-grouting as a comprehensive approach for enhancing both structural integrity and soil behavior. This will be achieved by presenting practical examples of its successful implementation within the field of geotechnical engineering in Bulgaria, taking into account the unique local soil conditions. Jet-grouting is a well-acknowledged method for cement soil stabilization, involving the utilization of high-pressure water or cement suspension jets, enveloped in air, to erode and subsequently reconfigure the soil surrounding a borehole. The mechanical properties of the resultant medium are intricately linked to the local soil characteristics and various technical parameters associated with the jet-grouting system, including the number of nozzles, treatment duration, pressure, and fluid composition, among others. Remarkably, the existing design practices in Bulgaria, except for EN 12716:2003, do not offer specific directives or recommendations concerning the execution and quality control of the jet-grouting technique. Consequently, this paper not only aims to advocate best practices for the adoption of jet-grouting in the Bulgarian context but also seeks to elucidate the expected mechanical properties under diverse local soil conditions.*

Key words: *jet-grouting, soil improvement, foundation strengthening, gravity quay wall, soil-mix wall, tailing dam, quality control, monitoring, risk management*

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1. INTRODUCTION

A method for enhancing the mechanical properties of soil and foundation structures to address both structural and geotechnical challenges and to provide innovative design solutions is gaining significant traction in our engineering practice. In recent years, substantial research efforts have been devoted to improving the technological equipment and understanding the relationship between soil parameters, stability, stiffness, and deformation. These endeavors provide insight into what the future holds for construction practices. The approach for assessing the mechanical properties of soil and foundation structures is a crucial element in the geotechnical solutions palette. Surprisingly, large-scale projects that do not incorporate this technology are becoming increasingly rare. The presence of innovative technological solutions and the expanding field of applications offer a broad spectrum of opportunities for the new generation of geotechnical engineers. They must acquire adequate information and practical experience in this field. Traditionally, inquiries about modifying soil parameters' stiffness and deformation are addressed conceptually during the design stage. Geotechnical engineers often defer the technical aspects to specialized contractors and consultants. However, the method for improving mechanical properties of soil and foundation structures is a lesser-known aspect of the project, which can potentially jeopardize the investment. This situation is not typical when technology experiences rapid growth, but currently, research and knowledge expansion in this area are not keeping pace. Fortunately, over the last decades, there has been a surge in scientific articles, books, and educational coursework dedicated to soil improvement. These resources are now easily accessible in today's digital age, even for skeptics of geotechnical engineering. It is essential to recognize that, when correctly applied and managed, technology offers numerous opportunities and helps avoid new problems. Success primarily hinges on knowledge, confidence, and the proper use of technology, which is a universal concern, not limited to geotechnical engineering alone. In an era where the focus of investment projects rests on economic viability through "correct" design decisions, the process becomes multi-layered and complex.

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The study presented herein pertains to the strengthening of soil and foundation structures by creating cylindrical rock-like bodies, suspending them on mechanical soil parameters through the high-pressure injection of cement mortar, a technique known as "jet-grouting." This technology, as described in [1-4], is relatively unknown globally [5] but has gained significant popularity in Bulgaria over the decade. The method boasts a broad range of applications, as exemplified in this study. Some of its versatile uses include foundation reconstruction, tunnel pre-construction, mine design, arches and water dam construction within mines, secant water dam construction, ash wall repairs, and earth pressure protection, among others.

2. THE JET-GROUTING TECHNIQUE

The process known as "jet-grouting" or "cement-soil strengthening" [6] is a pivotal technology within the geotechnical landscape. This method involves the high-pressure injection of a vertical water jet into the soil to create a predetermined pattern, followed by the horizontal injection of a cement solution under high pressure (approximately 400 bar – [7-8]). This process is tailored to match the natural material properties and induces partial erosion, as illustrated in Figure 1.

Notably, this technique allows for the formation of a stone-like structure with compressive strength determined by geological conditions, solution parameters, and execution technology [9]. The insights and data presented in this paper stem from projects executed in Bulgaria and are documented in [10]. During the injection process, a mixture of cement-soil, often referred to as "reflux," can emerge, traveling to the surface through the annular space between the injection cavity and the borehole wall, as depicted in Figure 2.

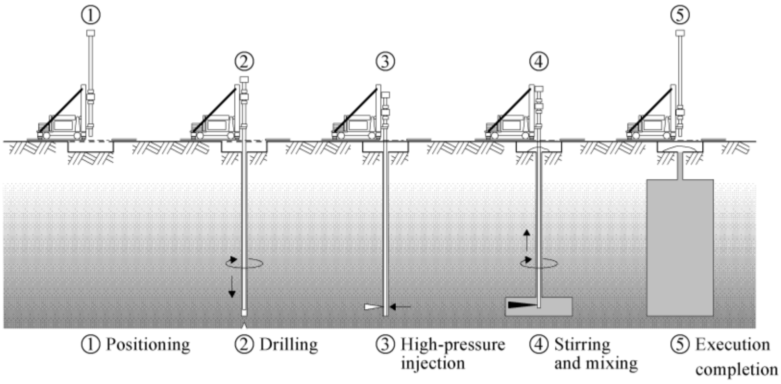


Fig. 1 Technological setup and sequence of execution – from (1) to (5)

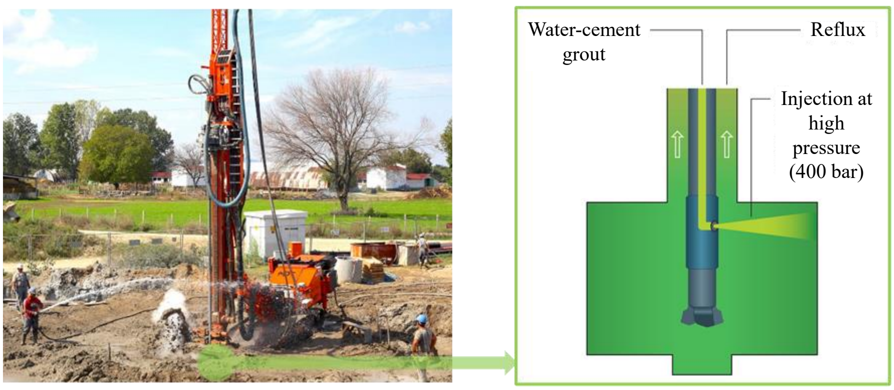


Fig. 2 Set-up of the jet-grouting execution process on site

The "jet-grouting" system comprises monofluid, bifluid, and trifluid variants. In the Bulgarian context, the monofluid variant, which utilizes a water-cement solution and is injected through one or more nozzles, has found the most extensive application. In this configuration, the solution is injected into the borehole and, following subsequent injections, all materials are mixed into a single column [1].

Jet-grouting stands out as a versatile geotechnical solution renowned for its diverse applications across various engineering fields. Its adaptability shines through in foundation construction, where it ensures stable and resilient base support for structures of all sizes and complexities. Additionally, in underground projects, jet-grouting plays a pivotal role in tunneling and mine construction, reinforcing the surrounding soil and enhancing safety. It also finds purpose in environmental projects, aiding in the containment and remediation of contaminated sites. Furthermore, jet-grouting is indispensable in infrastructure projects, offering solutions for repairing and strengthening existing structures, such as bridges and retaining walls. Its capacity to address an array of challenges and its versatility in adapting to different scenarios make jet-grouting a valuable asset in the toolkit of geotechnical engineers, enabling innovative solutions across a wide spectrum of applications – [11].

This paper aims to provide a comprehensive overview of the jet-grouting technique, with a particular focus on its application in Bulgaria. It presents project data and insights, demonstrating how this method interacts with the natural geological conditions.

3. Example 1: Strengthening of an Existing Quay Wall

The first example presents a quay wall located at the port in the city of Burgas – berths 5 and 6. It was built in the first half of the 20th century and is of gravitational type, consisting of four concrete blocks with varying widths and an upper masonry block which serves as a tunnel. Behind the wall, fill consists of crushed rock, clay, and gravel. Over time, significant erosion processes have developed, leading to substantial settlement of the fill behind the quay wall. This has also rendered the space behind the quay wall unsuitable for use. Monofluid jet grouting system has been adopted for this project.

The approach developed and executed in 2019 for strengthening the quay wall consists of:

- Construction of a watertight 2170 m^2 barrier, formed by primary secant "jet-grouting" injection columns (diameter of 1200 mm and spaced at 900 mm intervals), reinforced with HEB100 steel profiles.
- Seismic enhancement of the wall's response involves drilling at an angle through the gravitational blocks and installing 117 tangential secondary "jet-grouting" injection columns (with a diameter of 1200 mm and spaced at 1200 mm intervals), reinforced with 139.7x5 steel pipes. These columns extend below the quay wall's height to offer increased sliding resistance and additional stability by altering the location of the structural system's rotation point.
- ding resistance and additional stability by altering the location of the structural system's rotation point.
- Construction of a reinforced concrete cap beam that combines the primary and secondary set of "jet-grouting" injection columns.

The overall purpose of the secant columns is to ensure deep foundations, whereas the tangential ones are executed for the sake of filling the fill behind the wall by cement grout. The existing situation and the strengthening concept are illustrated in Figure 3.

The purpose of constructing the watertight barrier is twofold: to inject voids in the fill and to compact it (by restructuring soil particles due to the influence of the high-pressure injection jet), as well as to prevent future water infiltration behind the wall. The function of the newly formed deep foundation beneath the foundation base is to enhance seismic response by increasing the bearing capacity for sliding and overturning.

Figure 4 demonstrates the execution, and Figure 5 and Table 1 summarize the results of the mechanical parameter studies of the test injection columns – they were drilled using a triple-tube system, and the collected samples were tested in laboratory conditions.

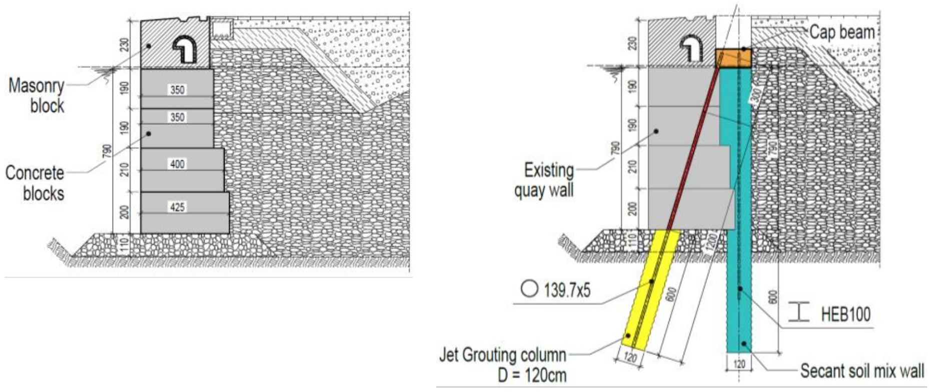


Fig. 3 Existing condition of the quay wall (left) and strengthening concept (right)

Fig. 4 Executing of the quay wall strengthening measures

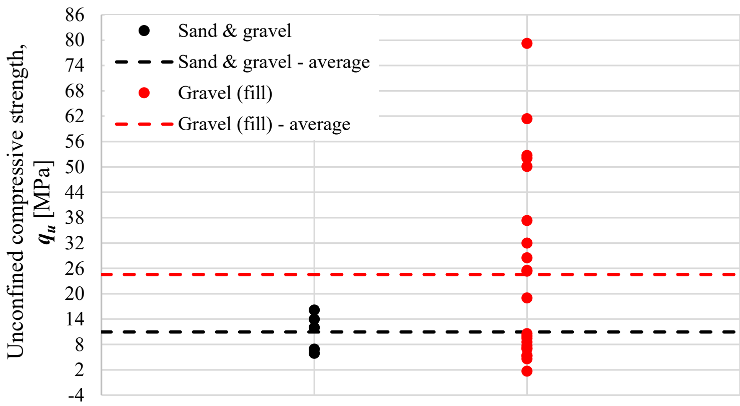
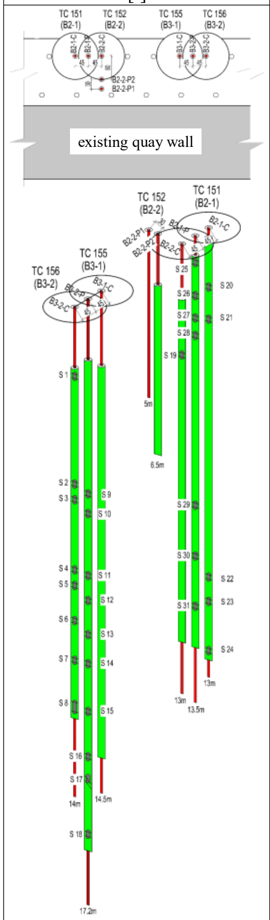


Fig. 5 Summary of results regarding unconfined compressive strength for various kinds of treated soil material: sand-gravel and gravel (fill)

Table 1 Mechanical parameters of test injection "jet-grouting" columns – quay wall

Schematic representation of the test jet-grouting columns	Sample No.	Depth of sample (from the terrain)	Unconfined compressive strength, q_u	Axial strain at fail, $\varepsilon_{u,z}$	Deformation modulus, E_d	Soil type
[-]	[-]	[m]	[MPa]	[%]	[MPa]	[-]
	S20	1.50 ÷ 1.85	5.88	0.370	1589	sand and gravel
	S21	2.40 ÷ 2.80	12.00	0.460	2609	
	S22	10.00 ÷ 10.15	25.30	0.285	8860	gravel (fill)
	S23	10.60 ÷ 10.95	61.40	0.225	27320	
	S24	12.00 ÷ 12.40	5.22	0.400	1305	sandy clay
	S25	0.60 ÷ 0.80	13.96	0.790	1767	sand and gravel
	S26	1.60 ÷ 1.80	16.13	0.460	3507	
	S27	2.20 ÷ 2.47	5.24	0.420	1248	gravel (fill)
	S28	2.70 ÷ 3.00	9.99	0.590	1693	
	S29	7.60 ÷ 7.90	52.10	0.220	23640	
	S30	9.10 ÷ 9.35	50.10	0.224	22390	
	S31	10.56 ÷ 10.80	37.30	0.270	13820	
	S19	2.90 ÷ 3.12	6.90	0.190	3632	sand and gravel
	S1	1.86 ÷ 2.00	32.00	0.253	12640	gravel (fill)
	S2	4.95 ÷ 5.30	5.38	0.750	717	
	S3	5.40 ÷ 5.70	19.00	0.240	7930	
	S4	7.45 ÷ 7.70	25.50	0.247	10320	
	S5	7.93 ÷ 8.10	4.60	0.310	1484	
	S6	8.95 ÷ 9.11	10.53	0.680	1549	
	S7	10.10 ÷ 10.30	9.46	0.580	1631	
	S8	11.33 ÷ 11.75	7.13	0.440	1620	
	S9	5.48 ÷ 5.80	1.67	0.330	506	gravel (fill)
	S10	6.05 ÷ 6.35	52.70	0.287	18360	
	S11	7.85 ÷ 8.10	7.68	0.540	1422	
	S12	8.60 ÷ 8.80	8.53	0.230	3709	
	S13	9.60 ÷ 9.80	79.20	0.200	39540	
	S14	10.40 ÷ 10.65	28.50	0.352	8100	
	S15	11.80 ÷ 12.00	6.95	0.290	2397	
	S16	13.30 ÷ 13.60	1.54	0.120	1283	sandy clay
	S17	13.95 ÷ 14.20	5.66	0.420	1348	stiff clay
	S18	14.50 ÷ 14.80	6.84	0.310	2206	

4. EXAMPLE 2: DEEP EXCAVATION RETAINING SYSTEM

The second example showcasing the jet-grouting monofluid system demonstrates the retaining of a deep excavation through the construction of a soil-cement wall in Burgas city – Figure 6.

The plan dimensions of the excavation are 32 m by 47 m, with a depth of 11.50 m. The retaining structure (soil-mix wall) covers a total area of 3000 m^2 and is formed by reinforced (every second element with HEA280 profile) secant (spaced at 500 mm intervals) injection columns with a diameter of 700 mm and a length of 17.00 m – at their upper end, they are connected by a reinforced concrete beam. The retaining soil-mix wall is supported by three rows of self-drilling anchors, equipped with a water ingress prevention system during wall penetration, followed by an additional operation – injection immediately behind the soil-mix wall upon completion. The concept for retaining the deep excavation is illustrated in Figure 7 through a plan and section.

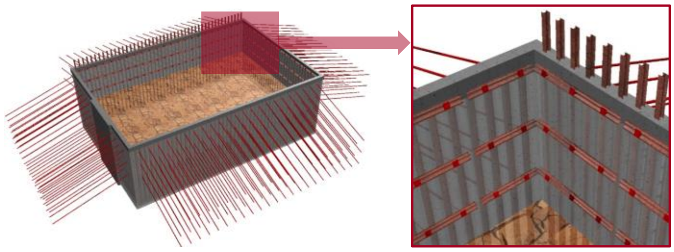


Fig. 6 3D visualization of the excavation retained by a soil-mix wall

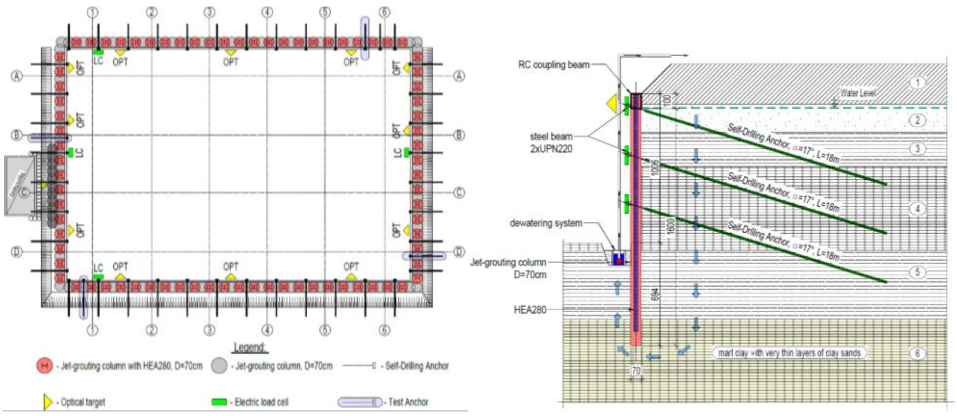


Fig. 7 Plan view (left) and typical section (right) of the excavation

The project was completed in 2021 as demonstrated in Figure 8.

Fig. 8 Excavation execution process

Some of the challenges related to the project execution were associated with the high level of groundwater, located approximately 2.90 m below ground level, as well as the presence of an existing breakwater on the construction site. The diameter and compressive strength of the injection columns were confirmed through triple tube core drilling and lab sample testing – [4]. The results are summarized in Figure 9 and Table 2 – they indicate the change of unconfined compression strength depending on the soil.

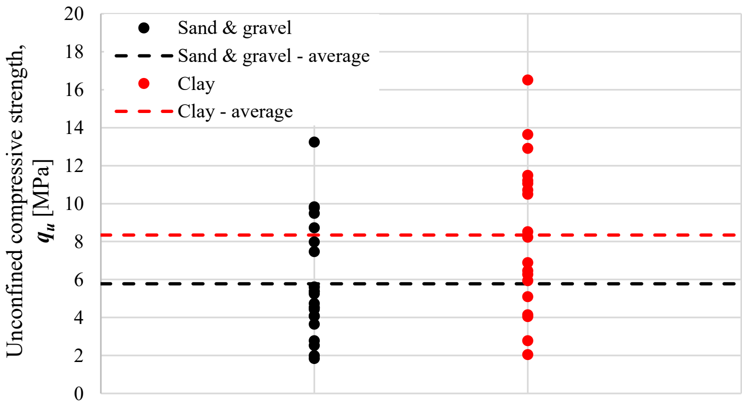
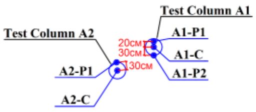
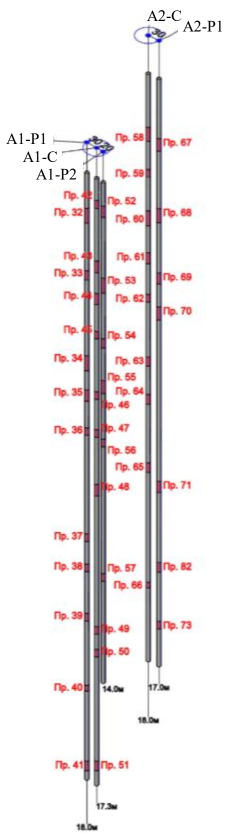


Fig. 9 Summary of results regarding unconfined compressive strength for various kinds of treated soil material: sand-gravel and clay

Table 2 Mechanical parameters of test injection "jet-grouting" columns – retaining wall

Schematic representation of the test jet-grouting columns	Sample No.	Depth of sample (from the terrain)	Unconfined compressive strength, q_u	Axial strain at fail, $\varepsilon_{u,z}$	Deformation modulus, E_d	Soil type
[-]	[-]	[m]	[MPa]	[%]	[MPa]	[-]
Plan view:  **Section:** 	32	1.70 ÷ 2.10	5.24	0.41	1278	sand and gravel
	33	3.35 ÷ 3.60	9.48	0.58	1634	
	34	5.60 ÷ 6.00	4.51	0.67	673	
	35	6.50 ÷ 6.80	1.99	0.33	603	
	36	7.50 ÷ 7.70	1.84	0.29	634	
	37	10.30 ÷ 10.50	11.21	0.82	1367	clay
	38	11.10 ÷ 11.30	4.04	0.54	748	
	39	12.40 ÷ 12.60	5.09	0.66	771	
	40	14.30 ÷ 14.45	8.52	0.63	1352	
	41	16.30 ÷ 16.55	6.46	0.98	659	
	42	1.35 ÷ 1.55	4.74	0.65	741	sand and gravel
	43	2.95 ÷ 3.25	4.43	0.63	703	
	44	3.80 ÷ 4.10	4.07	0.69	590	
	45	4.80 ÷ 5.00	7.47	0.47	1589	
	46	6.40 ÷ 6.60	2.77	1.02	272	
	47	7.40 ÷ 7.60	2.53	0.88	288	
	48	8.85 ÷ 9.15	8.23	0.51	1614	clay
	49	12.60 ÷ 12.80	2.78	0.94	296	
	50	13.20 ÷ 13.40	5.94	0.65	914	
	51	16.15 ÷ 16.40	13.63	0.71	2920	
	52	1.40 ÷ 1.70	8.72	0.79	1104	sand and gravel
	53	3.30 ÷ 3.70	4.52	0.74	611	
	54	4.90 ÷ 5.10	5.35	0.68	787	
	55	6.00 ÷ 6.35	5.61	0.59	951	
	56	7.55 ÷ 7.75	4.07	0.41	993	
	57	11.10 ÷ 11.30	10.71	0.55	1945	clay
	58	2.40 ÷ 2.75	5.38	0.67	803	sand and gravel
	59	3.50 ÷ 3.70	3.65	0.63	579	
	60	4.60 ÷ 5.00	7.98	0.77	1036	
	61	5.70 ÷ 6.00	9.83	0.79	1244	
	62	6.80 ÷ 7.00	10.49	0.61	1720	clay
	63	8.45 ÷ 8.70	11.49	0.58	1981	
	64	9.45 ÷ 9.70	6.89	0.43	1602	
	65	11.25 ÷ 11.50	6.27	0.84	746	
	66	14.40 ÷ 14.55	4.14	1.04	398	
	67	2.55 ÷ 2.90	5.60	0.94	596	sand and gravel
	68	4.40 ÷ 4.80	9.77	0.48	2035	
	69	6.10 ÷ 6.40	13.23	0.50	2646	
	70	7.00 ÷ 7.35	12.90	0.74	1743	clay
	71	11.60 ÷ 11.90	11.06	0.52	2127	
	72	13.75 ÷ 14.00	16.51	0.48	3440	
	73	15.30 ÷ 15.50	2.05	0.69	297	

5. Example 3: Mat Strengthening and Improving the Soil-Foundation-Superstructure Response

The third example illustrates the practice of strengthening the "soil-foundation-superstructure" system. The considered building structure (Fig. 10) is reinforced concrete (columns, beams, and slabs for vertical load-bearing and walls for seismic resistance) and was designed in 2007 – [12]. According to the original design, the building has 14 floors and 5 underground levels. The construction began in 2008 and was interrupted in 2010. Only the underground levels were completed over a period of 2 years. Due to changes in investment intentions, it was decided to add 4 additional floors to the building and change its function from offices to residential units. A strengthening design was developed for this purpose. Figure 11 shows the adopted strengthening concept.

Fig. 10 Existing condition and 3D view of the superstructure

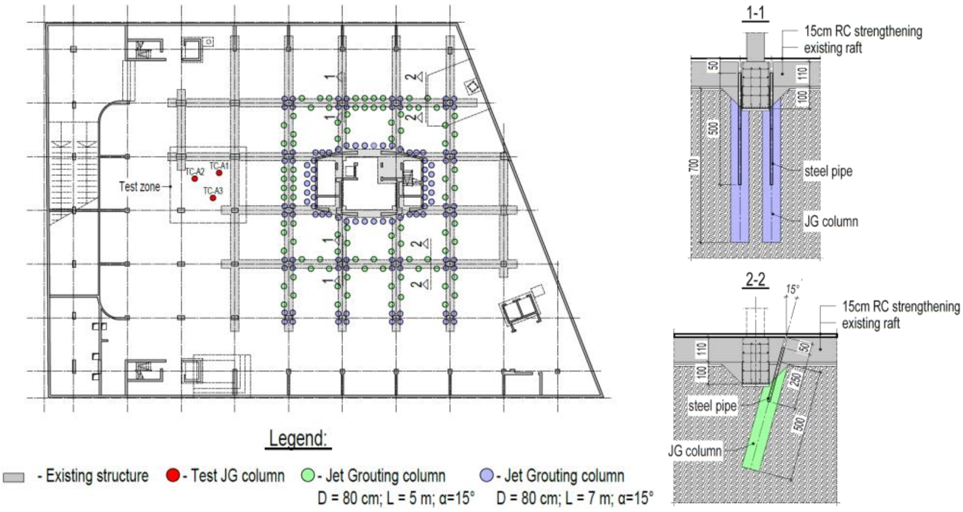


Fig. 11 Strengthening concept for the “soil-foundation-superstructure” system

The foundation structure of the existing part of the building is a mat. In order to reduce settlements due to the additional load from the building's extension and to increase the bearing capacity considered in the calculations, it was decided to execute injection columns using the "jet-grouting" monofluid system as a comprehensive measure to improve mechanical parameters of soil and strengthen the existing foundation structure – [13-14]. The geometrical characteristics of the existing condition (clear height in the basement of 2.80 m) dictated the chosen solution as the only viable option as shown on Figure 12.

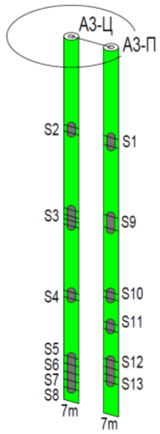
Fig. 12 Execution of the strengthening measures

The adopted arrangement of 206 injection columns with a diameter of 800 mm is shown in Figure 11. The execution sequence consists of six main stages as follows:

- Drilling holes in the existing foundation mat. Execution of jet-grouting columns (length of 7.0 m and 5.0 m) by injecting a water-cement grout at high-pressure.
- Installing steel pipes (114.3x8, length of 5.0 m and 2.5 m) in order to transmit loads from the foundation mat to the injection columns and to increase their load-carrying capacity.
- Grouting the gap between the steel pipes and the foundation mat.
- Installing reinforcement bars in the steel pipes, providing a connection to the foundation mat.
- Filling the steel pipes with grout and strengthening the foundation mat by executing a 15 cm RC jacket on its upper surface.

The strengthening was carried out in 2019 and the execution is shown in Figure 12. Table 3 summarizes the results from the test field (triple-tube core drilling and laboratory testing of samples subjected to uniaxial compression).

Table 3 Mechanical parameters of test injection "jet-grouting" columns – mat strengthening

Schematic representation of the test jet-grouting columns	Sample No.	Depth of sample (from the terrain)	Unconfined compressive strength, q_u	Axial strain at fail, $\varepsilon_{u,z}$	Deformation modulus, E_o	Soil type
[-]	[-]	[m]	[MPa]	[%]	[MPa]	[-]
	S1	0.80 ÷ 1.00	3.272 ± 0.164	0.37 ± 0.04	885	Pliocene clay, N_2
	S2	0.84 ÷ 1.00	4.992 ± 0.250	0.95 ± 0.09	525	
	S3	2.76 ÷ 2.90	4.577 ± 0.229	0.37 ± 0.04	508	
	S4	4.80 ÷ 4.94	8.093 ± 0.405	0.47 ± 0.05	1722	
	S5	6.00 ÷ 6.23	7.332 ± 0.367	0.49 ± 0.05	1496	
	S6	6.23 ÷ 6.40	4.665 ± 0.233	0.96 ± 0.10	486	
	S7	6.40 ÷ 6.53	6.038 ± 0.302	0.48 ± 0.05	1258	
	S8	6.53 ÷ 6.71	6.100 ± 0.305	0.62 ± 0.06	984	
	S9	2.60 ÷ 2.88	4.985 ± 0.249	0.76 ± 0.08	656	
	S10	4.50 ÷ 4.63	6.259 ± 0.313	0.94 ± 0.09	665	
	S11	5.20 ÷ 5.36	5.837 ± 0.294	0.73 ± 0.07	800	
	S12	5.60 ÷ 5.76	6.874 ± 0.344	0.86 ± 0.09	799	
	S13	5.86 ÷ 6.00	5.790 ± 0.290	0.77 ± 0.08	752	

6. EXAMPLE 4: RETROFIT OF THE FOUNDATIONS OF A DAMAGED CATHEDRAL

The fourth example presents the jet-grouting monofluid system as a modern approach to solving engineering problems in emergency situations. Specifically, it examines one of the measures to strengthen and restore the damaged "St. Cyril and St. Methodius" cathedral in Burgas city, originally built in 1907. The church suffered significant damage due to uneven settling caused by nearby excavation work in 2013. Therefore, in 2016, it was reinforced in a way that allows it to withstand both gravitational loading and seismic forces.

The measures for strengthening and saving the church included the following: injecting cracks with a shrinkage-compensated and low-volume expansion grout, applying carbon-fiber-reinforced polymers (CFRP) in vulnerable areas (vaults and domes), pre-stressing the structure in a closed-loop at several levels, installing ties, and strengthening the foundations using the jet-grouting technique – the focus of this paper. This type of soil-foundation strengthening system was chosen due to the deteriorated soil conditions beneath the church's foundations as a result of the incident. Another reason for this choice was the desire to avoid compromising the ground anchors of a nearby structure and the existing emergency measures taken immediately after the incident. The reinforcement of the foundations and soil consisted of the following:

Execution of 209 inclined reinforced (with HEA140 steel profile) injection “jet-grouting” columns with a diameter of 1100 mm.

Construction of a combining reinforced concrete beam at the upper end of the injection columns. The concept is shown in Figure 13, and the execution process is demonstrated in Figure 14.

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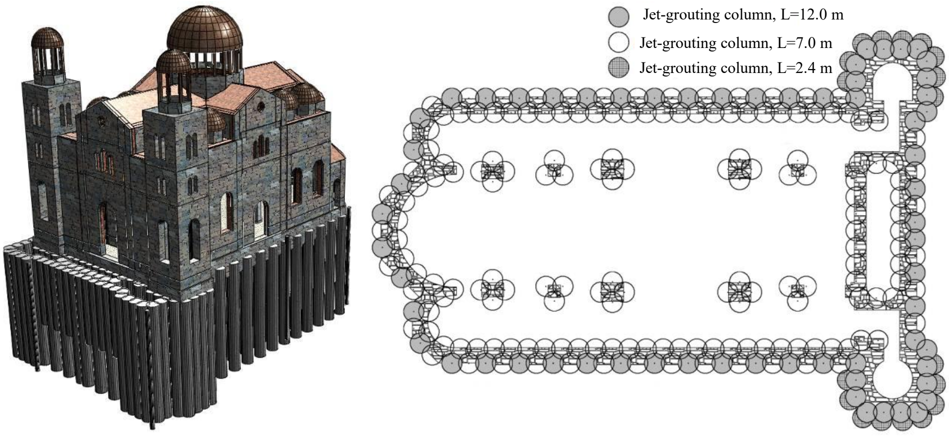

Fig. 13 Soil-foundation strengthening concept for rescuing the damaged cathedral

Fig. 14 Execution process – rescuing the “St. Cyril and St. Methodius” cathedral

7. Example 5: Strengthening of Defected Piles

The fifth example from practice presents the foundation structure of an ammonia tank in the city of Devnya. It consists of two reinforced concrete slabs with a thickness of 60 cm each and vertical structural elements (columns) between them. According to the geological report, the soil conditions at the construction site are specific, characterized by consolidation processes due to the self-weight of the soil medium (the over-consolidation ratio, OCR, has values lower than 1.0). Therefore, in order to ensure reliable load transfer from the tank to the soil, a solution with deep foundation (cast-in-place piles with a diameter of 880 mm and length of 28.95 m) is adopted. The length of the piles is chosen so that a relatively stiff soil layer (marl clay) in the stratigraphy is reached, ensuring sufficient bearing capacity of the system. Thus, the designed piles are of end-bearing type. Due to anticipated consolidation settlements over time in the soil layers, the friction along the piles' surface is considered negative, acting as additional load on the piles. After the execution of all piles in 2020, geophysical investigations (pile echo tests – PET) and sampling were carried out, revealing defects (lack of integrity) in all piles. This necessitated measures to strengthen them. The planned approach involves drilling through the center of all piles using a hydraulic hammer and injecting grout from below at high pressure (monofluid system) – Figure 15.

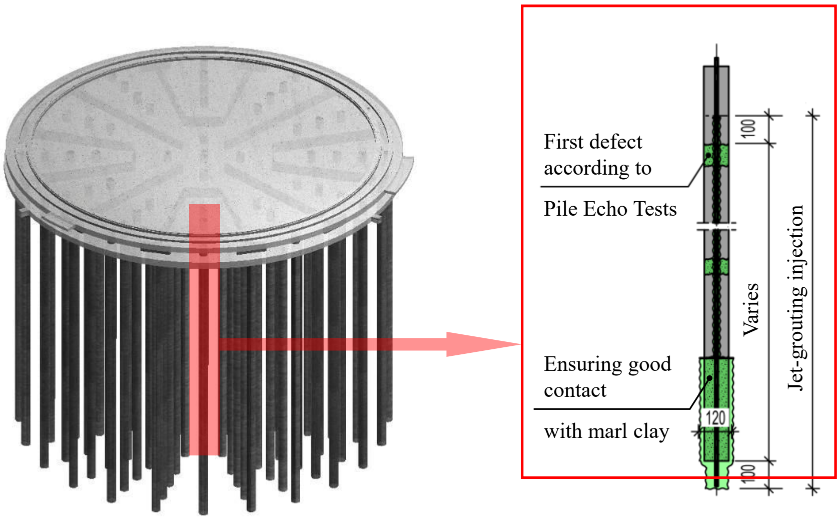

Fig. 15 Concept for strengthening of defected piles

The goal is to ensure the integrity of the piles, allowing the transmission of forces along their entire length to the top and from there to the underlying ground (marl clay), as well as to restore the support conditions of the foundation structure (rigid points). The adopted strengthening method is based on jet-grouting technology and was implemented in 2021 – Figure 16.

After strengthening, samples were taken from the strengthened elements, which were subsequently tested in the laboratory. The achieved uniaxial compressive strength is summarized in Table 4.

Fig. 16 Execution process –strengthening of piles by the jet grouting technique

Table 4 Mechanical parameters of piles strengthened by the jet grouting technique

Pile No.	Sample No.	Depth of sample (from the terrain)	Unconfined compressive strength, q_u	Pile No.	Sample No.	Depth of sample (from the terrain)	Unconfined compressive strength, q_u	Pile No.	Sample No.	Depth of sample (from the terrain)	Unconfined compressive strength, q_u
[-]	[-]	[m]	[MPa]	[-]	[-]	[m]	[MPa]	[-]	[-]	[m]	[MPa]
P36	48	3.00 ÷ 3.23	52.6	P48	8	3.10 ÷ 3.44	53.3	P69	-		
	49	5.00 ÷ 5.40	54.9		9	5.12 ÷ 5.50	27.9				
	50	7.00 ÷ 7.32	45.6		10	7.17 ÷ 7.53	50.6				
	51	9.00 ÷ 9.38	50.7		11	9.00 ÷ 9.42	48.6				
	52	10.00 ÷ 10.38	56.5		-						
	53	11.07 ÷ 11.37	57.5		12	11.00 ÷ 11.36	57.1				
	54	12.00 ÷ 12.37	53.1		-						
	55	13.09 ÷ 13.43	47.2		13	13.00 ÷ 13.47	45.3				
	56	14.13 ÷ 14.50	56.5		-						
	57	15.00 ÷ 15.35	56.0		14	15.21 ÷ 15.52	48.5				
	58	16.08 ÷ 16.38	41.5		-						
	59	17.00 ÷ 17.38	45.8		15	17.16 ÷ 17.53	51.2		70	17.14 ÷ 17.45	70.7
	60	18.06 ÷ 18.30	56.5		-				-		
	61	19.00 ÷ 19.24	43.7		16	19.00 ÷ 19.40	48.7		71	19.16 ÷ 19.44	54.0
	62	20.00 ÷ 20.41	59.4		17	20.05 ÷ 20.52	47.6		72	20.11 ÷ 20.37	53.3
	63	21.00 ÷ 21.23	61.8		18	21.00 ÷ 21.47	43.8		73	21.16 ÷ 21.39	37.0
	64	22.00 ÷ 22.37	51.6		19	22.00 ÷ 22.43	37.0		74	22.16 ÷ 22.50	62.7
	65	23.00 ÷ 23.36	40.0		20	23.10 ÷ 23.47	30.5		75	23.00 ÷ 23.38	41.8
	66	24.00 ÷ 24.23	33.4		21	24.00 ÷ 24.36	33.8		76	24.16 ÷ 24.54	32.5
	67	25.00 ÷ 25.38	46.3		22	25.00 ÷ 25.47	34.9		77	25.00 ÷ 25.41	35.8
	68	26.00 ÷ 26.32	30.7		23	26.08 ÷ 26.50	41.5		78	26.00 ÷ 26.36	64.7
	69	27.00 ÷ 27.31	37.5		24	27.09 ÷ 27.36	39.6		79	27.00 ÷ 27.36	66.5
	-				25	28.00 ÷ 28.45	25.7		80	28.00 ÷ 26.30	30.2
					26	29.15 ÷ 29.28	8.9		81	29.00 ÷ 29.26	47.1

8. CONCLUSION

The presented examples in this paper demonstrate the versatile application of jet-grouting as an effective and comprehensive method for enhancing both structural integrity and soil behavior in geotechnical engineering projects in Bulgaria. These practical cases showcase the adaptability of jet-grouting to various geotechnical challenges and local soil conditions. Jet-grouting, involving the high-pressure injection of water-cement solutions to reshape and stabilize soil, has proven to be a valuable technique in Bulgaria, addressing a range of engineering needs. Despite the absence of specific national guidelines, this paper advocates best practices and provides insights into the mechanical properties of jet-grouted soil-cement elements under diverse soil conditions. In a rapidly evolving field of geotechnical engineering, where innovation is key to addressing complex challenges, jet-grouting offers a versatile tool. It has found application in foundation strengthening, retaining wall construction, seismic enhancement, and environmental remediation, among other areas. The examples presented here demonstrate its effectiveness in achieving structural stability and soil improvement. As the field of soil reinforcement continues to expand, it is essential for geotechnical engineers to acquire knowledge and practical experience in this domain. With the availability of resources and information, including research articles, books, and educational materials, the new generation of geotechnical engineers can harness the potential of technologies like jet-grouting to provide innovative and reliable solutions to a wide range of geotechnical problems.

In conclusion, the success of jet-grouting in Bulgaria serves as a testament to its adaptability and effectiveness in addressing geotechnical challenges. By adhering to best practices and continually expanding our understanding of this technique, we can harness its full potential in geotechnical engineering, ensuring the stability and resilience of structures and the improvement of soil conditions in various applications.

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NAPREDNA PRIMENA TEHNIKE "MLAZNOG INJEKTIRANJA" U BUGARSKOJ GEOTEHNIČKOJ PRAKSI

Osnovni cilj ovog rada je da predstavi raznovrsnu primenu tehnike mlaznog injektiranja kao kompleksnog pristupa za poboljšanje strukturne celovitosti i ponašanja zemljišta. Ovo će biti postignuto predstavljanjem praktičnih primera njegove uspešne primene u oblasti geotehničkog inženjerstva u Bugarskoj, uzimajući u obzir jedinstvene lokalne uslove zemljišta. Mlazno injektiranje je dobro priznat metod stabilizacije cementnih zemljišta, uključujući korišćenje mlaznih tečnosti pod visokim pritiskom sa vodom ili cementnom suspenzijom, u okruženju vazduha, kako bi se erodiralo i posledično rekonfigurisalo zemljište u okolini bušotine. Mehaničke osobine rezultirajućeg sredstva su složeno povezane sa lokalnim karakteristikama zemljišta i različitim tehničkim parametrima povezanim sa sistemom mlaznog injektiranja, uključujući broj dizni, trajanje tretmana, pritisak i sastav tečnosti, između ostalog. Zapaža se da postojeći praktični projekti u Bugarskoj, osim za EN 12716:2003, ne nude specifična uputstva ili preporuke u vezi sa izvođenjem i kontrolom kvaliteta tehnike mlaznog injektiranja. Stoga, cilj ovog rada nije samo da propagira najbolje prakse za usvajanje mlaznog injektiranja u bugarskom kontekstu, već takođe da rasvetli očekivane mehaničke osobine u raznolikim lokalnim uslovima zemljišta.

Ključne reči: *mlazno injektiranje,, konsolidacija zemljišta, jačanje fundamenta, obalni zid, zid sa smešanim zemljištem, brana za otpad, kontrola kvaliteta, nadgledanje, upravljanje rizicima*