ТЕХНОЛОГІЯ БУДІВЕЛЬНОГО ВИРОБНИЦТВА

УДК 624.1 DOI 10.31649/2311-1429-2019-2-87-95

V. E. Gubashova[1]

EXPERIENCE OF CARRYING OUT OF GROUND-CEMENT ELEMENTS ON THE JET GROUTING TECHNOLOGY IN SLAGS OF A BLAST-FURNACE PROCESS

1JV Osnova-Solsif LCC, Kiev, Ukraine

The article describes the first experience in Ukraine in the implementation of ground-cement columns in the blast furnace slags.

In accordance with the project to reinforce the soil base during the reconstruction of the place with a canopy in the station for the production of air separation products with the installation of VRU-1400 in the city of Enakievo, experimental work was performed on the territory of the plant to confirm the correctness of the selected technological parameters of Jet Grouting in the actual engineering-geological conditions of the construction site and control of the geometric and strength parameters of cement columns.

Two test ground-cement columns were completed, visual and instrumental examination of the jet columns was performed (confirmation of the cylindrical shape, continuity of the shaft of the excavated part of the jet column, measurement of the actual diameter), the cores were drilled from the body of the jet column in the horizontal direction and the material was tested for compressive strength, as well as core sampling in the vertical direction for the entire length of the jet column, testing of soil-cement material.

Based on the results of the visual examination, the cylindrical shape of the jet grouting elements was confirmed and the actual diameters were measured, which amounted to 610 ... 640 mm that is more than the required for the project - 600 mm.

The selected vertical core confirms the design length of the jet column, the continuity of the body of the jet column and the absence of gaps in the treatment processing with a high-pressure jet of cement solution.

According to the results of laboratory tests of cement-slag cylinders selected from horizontal cores, the strength of the material ranged from 4.76 to 7.68 MPa for 24 days of age and 7.96 MPa for 28 days. According to the results of testing cylinders made of vertical core, the minimum strength of cement-slag material was 7.3 MPa, the maximum - 11.2 MPa. The obtained results of the compressive strength of soil-cement material exceed the design strength equal to 2.5 MPa.

As a result of the test work on the construction site of the VRU-1400, the correctness of the technical solution for the selection of Jet Grouting technology for reinforcement the foundation base in difficult engineering and geological conditions, namely blast furnace slags, was confirmed.

Key words: Jet Grouting technology, jet-grouted column, blast furnace slags, ground-cement material.

Introduction

Reinforcement of the foundations of existing buildings is not rarity in the modern construction world. The reasons for the implementation can be both reconstruction and differential settlement, which arose due to imperfect communications or the construction of a new building next to an existing one, etc.

Construction technologies provide a wide range of methods for reinforcement the soil foundation: placing under new foundations, cement injection, chemical injection, etc. [1,2,3]. A design engineer, faced with the problem of developing a reinforcement project, can choose any of the existing technologies depending on the engineering and geological conditions, the construction of the building, the ability to perform work and the availability of underground utilities.

Reinforcement of the soil base of new foundations is a rare occurrence, because in process of designing, not only calculations of the strength of structures and foundations should be performed, but also possible precipitation should be calculated, as well as all possible factors of negative influence should be taken into account.

The reason for the work on reinforcement the soil base during the reconstruction of the place with a canopy in the station for the production of air separation products with the installation of VRU-1400 in the city of Enakievo was the discrepancy between the engineering and geological conditions of the construction site and previously performed surveys. When additional engineering and geological surveys at the stage of developing detailed documentation for the foundations of the structures of the plant for the production of air separation products with the installation of VRU-1400 were carried out, it was found that unconsolidated zones of various thicknesses at various depths are present in the blast furnace slags.

Jet Grouting technology was chosen to perform the soil reinforcement of existing foundations for the air separation product plant.

Jet Grouting technology is based on the high-velocity injection of one or more fluids (grout, air, water) into the subsoil. The fluids are injected through small-diameter nozzles placed on a pipe that, in its usual application, is first drilled into the soil and is then raised towards the ground surface during jetting [4].

Advantages of Jet Grouting technology [5]:

- a wide range of soil conditions for applying jet grouting technology;
- the ability to work in flooded soils;
- high speed of work;
- the ability to work in tight working space;
- low levels of dynamic loads;
- implementation of jet-grouted columns to a given depth of various configurations with the control of their parameters, both geometric and strength.

A feature of the application of Jet Grouting technology at this construction site was blast furnace slags. In Ukraine, this was the first experience in the implementation of jet-grouted elements in such engineering-geological conditions.

The project was developed to reinforcement the foundation with ground-cement piles (jet columns) with a diameter of 600 mm, a depth of 10 m, made using the jet-grouting method to improve the construction properties of soils. At the same time, the required compressive strength of the material of ground-cement jet columns by design documentation is set at a level of not less than 2.5 MPa.

In accordance with the test program of jet-grouted columns at the construction site of VRU-1400, two test jet columns with a length of 10 m were performed to control the quality of the completed jet columns of the JV Osnova-Solsif. Characteristics of soil on the construction site are represented in the Table 1.

The test jet columns were designed to confirm the correctness of the selected technological parameters of Jet Grouting in the actual engineering and geological conditions of the construction site and to control the receipt of the required geometric and strength parameters.

Table 1

Characteristics of soils

№	*Name of indicators of properties of soils*	*Units*	*IGE 1*	*IGE 2*	*IGE 4*	*IGE 5*	*IGE 6*	*IGE 7*	*IGE 8*
1	Unit weight, γ" natural state saturated state	kN/m^3	18,55 20,55	20,02	20,01	19,58	19,85	20,92	24,55
2	Specific cohesion, c" saturated state	MPa	0,002	-	0,028	0,020	0,036	0,027	-
3	Internal friction angle, φ" saturated state	deg	36	-	16	15	13	18	-
4	Deformation modulus, E natural state saturated state	MPa	14,9 14,2	-	20,0	14,0	24,0	19,0	-

Groundwater is found at depths of 2.3 m ... 4.8 m from the surface of the earth (absolute marks - 169.80 m ... 172.20 m) in sediments of the soils of Layer 1 (blast furnace slags) and are waters of technogenic origin. Territory is assessed as flooded.

Due to the particularity of the engineering and geological structure of the site, the presence of zones with varying degrees of compaction and increased porosity in blast furnace slags, in fact, the output of the spoil to the soil surface was recorded in a smaller volume than expected. This fact is due to the filling by the spoil of unconsolidated horizontal zones surrounding the jet column and the additional compaction of the soil mass. The resulting effect, along with vertically arranged columns of jet columns, can be characterized as additional reinforcement of the base with horizontal ground-cement spoil lenses that leads to higher deformation characteristics of the base as the result.

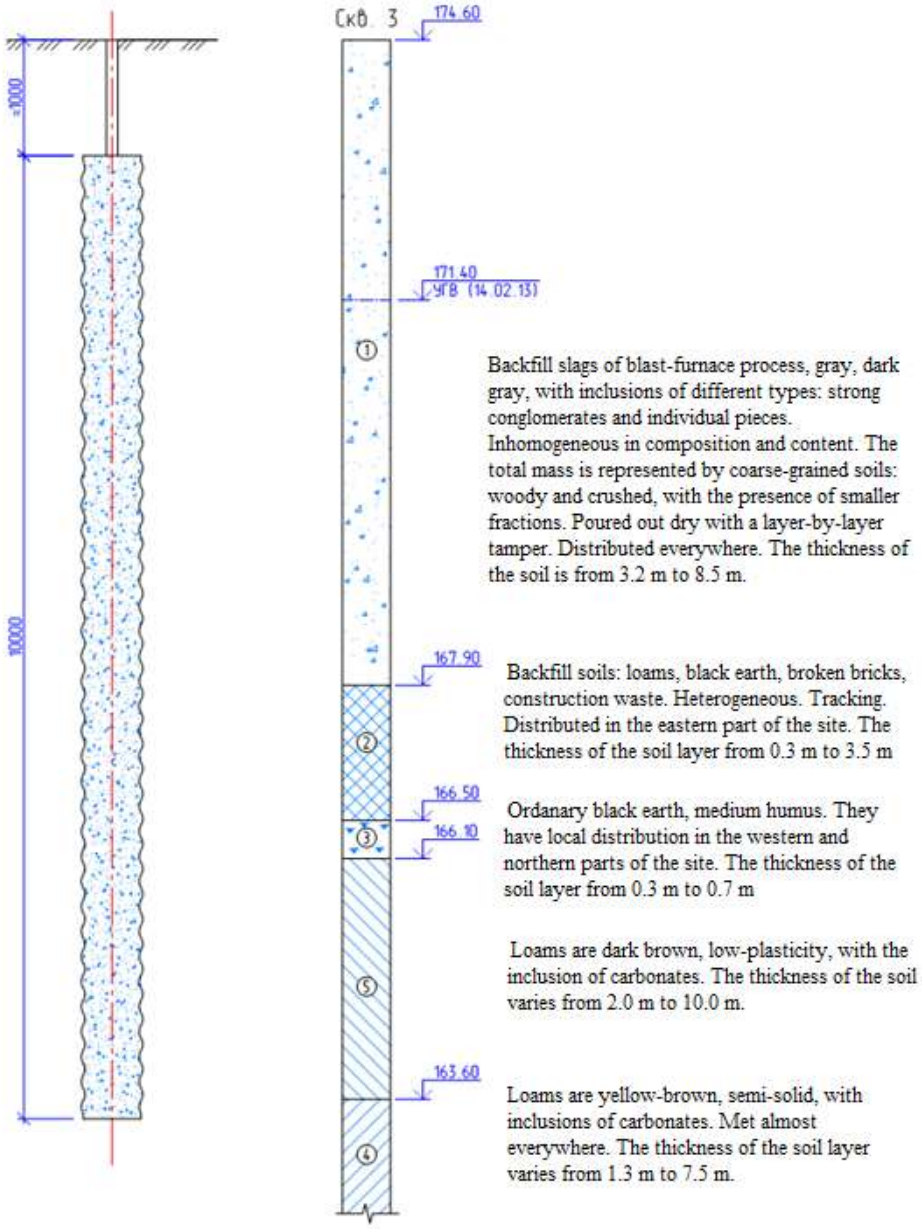

Figure 1 – Test get-grouted column and geological conditions

Figure 2 – Execution of test jet columns by Casagrande C6

Research results

To confirm the geometric dimensions and continuity of the ground-cement body of the jet columns specified by the design documentation, visual and instrumental researches of the test jet columns were carried out.

During the visual examination, it was found that the test jet columns have a cylindrical shape, there are no discontinuities in the body of the jet columns. The measured actual diameters of the upper part of the experimental jet columns are not less than 600 mm specified by the project and it is 610 mm for the JC-1 jet column and 620 mm for the JC-2 jet column (Figures 3 and 4).

The obtained results confirm the correctness of the selection of technological parameters of high-pressure jet injection by the Jet grouting method for arranging ground-cement columns in the slags of blast furnace production massif with zones of varying degrees of compaction.

Figure 3 – Jet column JC-1

Figure 3 – Jet column JC-2

To determine the strength characteristics of the ground-cement material of the jet column, horizontal cores for the entire length of the diameter were selected from the body of the JC-1 column. Cores were taken using a Hilti DD 200 concrete drilling machine.

The length of the drilled core was 640 mm (Figure 4), which corresponds to the diameter of the jet column at the core sampling site, and the cement-slag material of the body of the jet column has a uniform structure.

Figure 4 – Core from JC-1 column (total length of core parts - 640 mm)

Four cylindrical samples with a diameter of 120 mm and a length of 240 mm were selected from two horizontal cores for laboratory testing of the material for strength. Three samples (No. 1 ... 3 in the Table 2) were tested in the laboratory of LLC Astor Donetsk Building Materials Plant in Donetsk (Figure 5). Compression testing of the material was performed using the DIGIMAX Plus CONTROLS technical equipment.

Figure 5 – Strength test of a ground-cement sample

One cylindrical sample (No. 4 in the Table 2) was tested in the laboratory of the JV Osnova-Solsif in Kiev (Figure 6).

Figure 6 – Hydraulic press

Table 2

Test results

No.	*Meterial*	*Age, days*	*Sample density, kg/m³*	*Strength, MPa*
1	Ground-cement material	24	1800	7,68
2	Ground-cement material	24	1755	4,76
3	Ground-cement material	24	1730	4,80
4	Ground-cement material	28	1730	7,96

The strength of the cement-slag material of the JC-1 jet column according to the results of a laboratory test ranged from 4.76 to 7.68 MPa for an age of 24 days and 7.96 MPa for 28 days with a required design strength of 2.5 MPa.

To control the length and continuity of the body of the jet-grouted element, in accordance with the test program, a vertical core was selected by the core drilling method in the JC-2 jet column for the entire length.

Figure 7 – JC-2 jet-column and core extraction using core drilling method

Figure 8 – Core parts laid out along the length of the JC-2 jet column

Selected cores along the length of the jet column (Figure 8) confirm the continuity of the body of the jet column and the absence of gaps in process of treating the soil with a high-pressure jet of cement solution. The jet-grouted column has a length of 10 m. A change in core color in the range of 8 m ... 10 m of column length corresponds to a change in soil conditions.

Cylindrical samples were selected of the parts of the drilled vertical core and they met the requirements for compression tests of cylindrical samples – length=2*diameter (marked with numbers on Figure 8). They were tested in the construction laboratory of the JV Osnova-Solsif. The test results for the strength of the samples are summarized in the Table 3, where item No. corresponds to the number of elements on Figure 8.

Table 3

Test results

No.	*Material*	*Selection range, m*	*Age, days*	*Sample density, kg/m^3*	*Strength, MPa*
3	Ground-cement material	0-1	59	1610	8,2
5	Ground-cement material	1-2	59	1510	8,2
7	Ground-cement material	1-2	59	1770	8,9
9	Ground-cement material	2-3	59	1520	9,5
13	Ground-cement material	3-4	59	1490	11,2
17	Ground-cement material	3-4	59	1595	7,4
18	Ground-cement material	4-5	59	1605	7,3
22	Ground-cement material	5-6	59	1660	7,9
26	Ground-cement material	6-7	59	1490	11,0
27	Ground-cement material	7-8	59	1570	9,5
28	Ground-cement material	8-9	59	1540	7,3
32	Ground-cement material	9-10	59	1525	10,8

The minimum strength of cement-slag material according to the results of laboratory tests was 7.3 MPa, the maximum - 11.2 MPa. For cement-clay material: minimum - 7.3 MPa, maximum - 10.8 MPa. The resulting compressive strength of ground-cement material exceeds the design (2.5 MPa).

Based on the experimental data on the implementation of ground-cement elements in various engineering and geological conditions on the territory of Ukraine, we present some comparative analysis with the results obtained when using of jet grouting in backfill slags of furnace production (table 4).

Table 4

Comparative analysis of the compressive strength of ground-cement material

No.	*Soil type*	*Characteristics of the soil*			*The compressive strength of ground-cement material, MPa*
		γ, t/m^3	c, кPa	φ, grad	
1	Deluvial-landslide sandy soils	1,84	8	18	11,9…23,8
2	Soft plastic peaty loam	1,66	19	6	3,7…6,7
3	Loess-like sandy loam, subsidence	1,65	10	22	4,2…12,6
4	Hard sandy loam	1,66	35	24	10,2…14,3
5	Backfill slags of furnace production	1,85	2	36	4,8…11,2

Analyzing the comparative table of the characteristics of the strength of the ground-cement material, we can conclude that the results of the strength of the slag-cement material are closest to the compressive strength of the ground-cement in sandy loam.

Conclusion

In accordance with the test program for get-grouted columns performed by Jet Grouting technology at the construction site of VRU-1400, two test jet columns were completed.

Based on the results of the visual inspection, the cylindrical shape of the jet-grouted elements was confirmed and the actual diameters were measured, which amounted to 610 ... 640 mm that is more than the required for the project - 600 mm.

To determine the strength characteristics of the ground-cement material, core samples in horizontal and vertical directions were selected from jet columns. Horizontal cores once again confirmed that the actual diameter exceeds the design diameter (640mm> 600mm) and that the cement-slag material has a

uniform structure. The selected vertical core confirms the design length of the jet column, the continuity of the body of the jet column and the absence of gaps in the processing of Jet Grouting were affirmed.

According to the results of laboratory tests of cement-slag cylinders, selected from horizontal cores (JC-1 jet-column), the strength of the material ranged from 4.76 to 7.68 MPa for 24 days of age and 7.96 MPa for 28 days.

According to the results of testing cylinders made of vertical core (JC-2 jet column), the minimum strength of cement-slag material was 7.3 MPa, and the maximum - 11.2 MPa. For cement-clay material: minimum - 7.3 MPa, maximum - 10.8 MPa.

The obtained results of the compressive strength of ground-cement material exceed the design strength equal to 2.5 MPa.

As a result of the test work on the construction site of the VRU-1400 for the carrying out jet-grouted columns, the correctness of the technical solution for the selection of Jet Grouting technology for reinforcement the foundation soil in difficult engineering and geological conditions, namely blast furnace slags, was confirmed.

REFERENCE

1. A.L. Shagin, Yu.V. Bondarenko, D.F. Goncharenko, Reconstruction of buildings and structures. Study Guide for Builds. specialist. universities. Moscow, Russia: Higher School, 1991, 352 pp.
2. P.A. Konovalov, Basements and foundations of reconstructed buildings. Moscow, Russia, 2000, 308 pp.
3. N.A. Tsytovich, V.G. Berezantsev, B.I. Dalmatov, Basements and foundations. Moscow, Russia: Higher School, 1970, 384 pp.
4. P. Croce, A. Flora, G. Modoni., Jet Grouting. Technology, Design and Control. NW: SRS Press Taylor & Francis Group, 2014, p. 9.
5. I.I. Broyd, Jet Grouting Geotechnology: A Training Manual. Moscow, Russia: Publishing House of the Association of Building Universities, 2004, pp. 71-124.

СПИСОК ЛІТЕРАТУРИ

1. А. Л. Шагин, Ю. В. Бондаренко, Д. Ф. Гончаренко, Реконструкция зданий и сооружений. Учебное пособие для строит. спец. вузов. Москва, Россия: Высшая школа, 1991, 352 с.
2. П.А. Коновалов, Основания и фундаменты реконструируемых зданий. Москва, Россия, 2000, 308 с.
3. Н. А. Цытович, В. Г. Березанцев, Б. И. Далматов, Основания и фундаменты. Москва, Россия: Высшая школа, 1970, 384 с.
4. P. Croce, A. Flora, G. Modoni., Jet Grouting. Technology, Design and Control. NW: SRS Press Taylor & Francis Group, 2014, p. 9
5. И. И. Бройд, Струйная геотехнология: Учебное пособие. М., Россия: Издательство ассоциации Строительных вузов, 2004, с. 71-124.

Gubashova Valentina Evgenivna - Leading Engineer of Design Department of Special and Hydrotechnical Works Department, JV Osnova-Solsif LLC, Kiev, Ukraine, ORCID:0000-0003-4235-4440,
e-mail: v.gubashova@gmail.com.

В. Е. Губашова

ОПЫТ ВЫПОЛНЕНИЯ ГРУНТОЦЕМЕНТНЫХ ЭЛЕМЕНТОВ ПО ТЕХНОЛОГИИ СТРУЙНОЙ ЦЕМЕНТАЦИИ В ШЛАКАХ ДОМЕННОГО ПРОИЗВОДСТВА

ООО СП "Основа-Солсиф", Киев, Украина

В статье рассмотрен первый в Украине опыт выполнения грунтоцементных колон в шлаках доменного производства.

В соответствии с проектом усиления грунтового основания при реконструкции помещения с навесом в станцию по производству продуктов разделения воздуха с установкой ВРУ-1400 в г.Енакиево на территории завода были выполнены экспериментальные работы с целью подтверждения правильности выбранных технологических параметров струйной цементации (Jet Grouting) в фактических инженерно-геологических условиях строительной площадки и контроля геометрических и прочностных параметров грунтоцементных колонн.

Выполнены две опытные грунтоцементные колонны, выполнено визуальное и инструментальное обследование джет-колонн, высверлены керны из тела джет-колонны в горизонтальном направлении и испытание материала на прочность на сжатие, а так же отбор кернов в вертикальном направлении на всю длину джет-колонны, испытание грунтоцементного материала и подтверждение сплошности выполненной

джет-колонны.

По результатам визуального обследования была подтверждена цилиндрическая форма струйно-цементационных элементов и замерены фактические диаметры, которые составили 610…640 мм, что больше требуемого по проекту – 600 мм.

Отобранный вертикальный керн подтверждает проектную длину джет-колонны, сплошность тела джет-колонны и отсутствие разрывов при обработке грунта высоконапорной струей цементного раствора.

По результатам лабораторных испытаний цементно-шлаковых цилиндров, отобранных из горизонтальных кернов прочность материала составила от 4,76 до 7,68 МПа для возраста 24 суток и 7,96 МПа для 28 суток. По результатам испытаний цилиндров из вертикального керна минимальная прочность цементно-шлакового материала составила 7,3 МПа, максимальная – 11,2 МПа. Полученные результаты прочности на сжатие грунтоцементного материала превышают проектную прочность равную 2,5 МПа.

В результате проведенных опытных работ на площадке строительства ВРУ-1400 по выполнению грунтоцементных колон была подтверждена правильность технического решения по выбору технологии Jet Grouting для усиления грунтов основания в сложных инженерно-геологических условиях, а именно насыпных шлаках доменного производства.

Ключевые слова: технология струйной цементации, струйно-цементационная колонна, шлаки доменного производства, грунтоцементный материал.

Губашова Валентина Евгеньевна – ведущий инженер Департамента специальных и гидротехнических работ ООО СП "Основа-Солсиф, Киев, Украина e-mail: v.gubashova@gmail.com.

В. Є. Губашова

ДОСВІД ВИКОНАННЯ ҐРУНТОЦЕМЕНТНИХ ЕЛЕМЕНТІВ ПО ТЕХНОЛОГІЇ СТРУМЕНЕВОЇ ЦЕМЕНТАЦІЇ В ШЛАК ДОМЕННОГО ВИРОБНИЦТВА

ТОВ СП "Основа-Солсиф", Київ, Україна

У статті розглянуто перший в Україні досвід виконання ґрунтоцементних колон в шлаках доменного виробництва.

Відповідно до проекту підсилення ґрунтової основи при реконструкції приміщення з навісом в станцію з виробництва продуктів розділення повітря з установкою ВРУ-1400 в м. Єнакієве на території заводу були виконані експериментальні роботи з метою підтвердження правильності обраних технологічних параметрів струменевої цементації (Jet Grouting) у фактичних інженерно-геологічних умовах будівельного майданчика і контролю геометричних і міцнісних параметрів ґрунтоцементних колон.

Виконано дві дослідні ґрунтоцементні колони, виконано візуальне та інструментальне обстеження джет-колон, висвердлені керни з тіла джет-колони в горизонтальному напрямку і випробування матеріалу на міцність на стиск, а також відбір кернів у вертикальному напрямку на всю довжину джет-колони, випробування ґрунтоцементного матеріалу і підтвердження цілістності виконаної джет-колони.

За результатами візуального обстеження була підтверджена циліндрична форма струменево-цементаційних елементів і заміряні фактичні діаметри, які склали 610 ... 640 мм, що більше від необхідного за проектом - 600 мм.

Відібраний вертикальний керн підтверджує проектну довжину джет-колони, суцільність тіла джет-колони і відсутність розривів при обробці ґрунту високонапірним струменем цементного розчину.

За результатами лабораторних випробувань цементно-шлакових циліндрів, відібраних з горизонтальних кернів міцність матеріалу склала від 4,76 до 7,68 МПа для віку 24 діб і 7,96 МПа для 28 діб. За результатами випробувань циліндрів з вертикального керна мінімальна міцність цементно-шлакового матеріалу склала 7,3 МПа, максимальна – 11,2 МПа. Отримані результати міцності на стиск ґрунтоцементного матеріалу перевищують проектну міцність рівну 2,5 МПа.

В результаті проведених дослідних робіт на майданчику будівництва ВРУ-1400 по виконанню ґрунтоцементних колон було підтверджено правильність технічного рішення щодо вибору технології Jet Grouting для підсилення ґрунтів основи в складних інженерно-геологічних умовах, а саме насипних шлаках доменного виробництва.

Ключові слова: технологія струменевої цементації, струменево-цементаційна колона, шлаки доменного виробництва, ґрунтоцементний матеріал.

Губашова Валентина Євгенівна – ведучий інженер Департаменту спеціальних та гідротехнічних робіт ТОВ СП "Основа-Солсиф, Київ, Україна e-mail: v.gubashova@gmail.com.