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Novruz Shiraliyev
Water and Amelioration Scientific Research Institute PLE
novruzs@gmail.com
https://orcid.org/0009-0006-4189-462X
Banovsha Mehdiyeva
Water and Amelioration Scientific Research Institute PLE
Doctor of Philosophy in Technical Sciences
banovsha-64@mail.ru
https://orcid.org/0000-0001-6867-7198
Asmar Abbasova
Water and Amelioration Scientific Research Institute PLE
esmer_sq@mail.ru
https://orcid.org/0009-0009-4047-5127
Narmina Iskandarova
Water and Amelioration Scientific Research Institute PLE
nrmin.sgndrova@mail.ru
https://orcid.org/0009-0002-6374-2338

Protection of Underground Parts of a Multi-Storey Building from the Negative Impact of Groundwater Using Jet Grouting Technology

Abstract

Protecting part of the zero cycles of multi-storey residential buildings built in areas with a complex geological structure and dense urban development from the negative effects of groundwater is one of the most important problems arising in modern urban planning.

Although the specified groundwater level during engineering and geological surveys is considered when designing multi-story buildings, in many cases, the possibility of groundwater level changes due to natural-technogenic, physical-geological, physical-geographical, and anthropogenic factors is not considered. Therefore, after the buildings are constructed and put into operation, the parts of the building located below the zero level (car garage, basement, etc.) are exposed to the negative effects of groundwater. In addition to the discomfort caused by groundwater penetrating the foundations and other structural elements of multi-story buildings, depending on the degree of aggressiveness of these waters, they also cause wear and corrosion of reinforced concrete structural elements and generally reduce the service life of the building. The development of engineering protection measures to eliminate the aforementioned problems, prevent the causes of these problems, or minimize the negative impacts arising from these problems has become a necessary component of the construction process due to its relevance.

The main objective of this article is to protect the zero-cycle structural elements of multi-story buildings from the negative impact of groundwater by using Jet Grouting technologies to prevent the aforementioned negative phenomena. The article is based on the results of real research and actual work performed.

Keywords: *multi-storey building, groundwater, soil-concrete column, Jet Grouting, foundation, underground part, protection*

Introduction

As in all developed and developing countries, in the Republic of Azerbaijan, due to the increase in population, acceleration and expansion of civil, industrial and infrastructure construction works (Shiraliyev et al., 2024), the location of large industrial enterprises and business centers in the country's central and large cities, and other factors, construction and installation work such as the rapid development of urban planning activities, the construction of new multi-storey residential buildings, the demolition and reconstruction or restoration of old buildings, and the creation of green spaces, parks, and recreational areas have become widespread.

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Cities around the world are significantly expanding in terms of size and population, potentially resulting in more than two billion additional urban residents by 2030. To date, around 54 % of the global population lives in cities, and this fraction is expected to rise to 60 % - 92 % till the end of the 21st century (Jing et al., 2023; Connor, 2015; Jiang et al., 2017).

Due to the above factors, the design and construction of multi-story residential buildings with deep foundations have accelerated significantly in the cities of Baku and Sumgait, which are located on the Absheron Peninsula, which has a complex geological structure and hydrogeological conditions.

High-rise apartment buildings, which house a significant proportion of the urban population, constitute an important part of the housing stock in many cities around the world (Nguyen et al., 2024; Dang, 2021; Yuen et al., 2006).

Currently, the most intensive construction, restoration, and reconstruction work on housing construction in Baku is carried out mainly in the central parts of the city, and by the distinctive feature of modern urban development, special attention is paid to the maximum and effective use of underground spaces of the construction site.

The most intensive construction work related to the construction of multi-story residential buildings is carried out in the central part of the city. In many cases, these buildings are built near each other in dense urban development conditions and have deep foundations.

Incorrect assessment of hydrogeological conditions during the design of buildings, the negative impact of the foundations of buildings built close to each other on the natural regime of groundwater, and changes in the physical and chemical properties of water lead to the emergence of certain problems during the operation of buildings and a reduction in the service life of buildings.

Groundwater, which is a weak solution of chemicals, at a certain concentration forms an environment that is aggressive towards the materials of underground structures.

At a high level of groundwater, the territory is flooded, which causes, to a certain extent, difficulties in the construction and operation of buildings and structures (Kurmanov et al., 2017).

After the construction and commissioning of the building under study, under the influence of various factors, the engineering and geological conditions of the construction site changed, the groundwater level increased, as a result of which the underground part of the building was flooded, and the structural elements of the underground part of the building were subjected to weak aggression from soil and water.

It was considered necessary to implement measures to protect the underground part of multi-story buildings to prevent the above-mentioned negative situations, protect building structures from the negative effects of groundwater, ensure the stability of the building, and prevent flooding.

Research

Research works were carried out in the location of a 9-story building located in the central part of Baku city (Fig. 1).

Figure 1 Research area. Baku city, Narimanov district

The geological structure of the research area at a depth of up to 25 meters includes deposits of the Holocene and Pleistocene stages of the Quaternary system.

Technogenic deposits were found in depth intervals of the geological structure of 0.0-1.9 meters and, according to their lithological composition, consisting of clay, loam and various types of plant remains.

The deposits of the Caspian tier consist of clays with gravel fragments and sand layers, medium- and fine-grained sand with clay and sandstone layers, clay layers with sandstone layers and were formed in the geological structure in the depth range of 1.9-19.8 meters.

The deposits of the Baku stage of the Pleistocene consist of semi-hard clay rocks, formed in the deepest part of the research area and were found in the depth range of 19.8-25.0 meters.

The groundwater level is 4.5 m.

Based on statistical processing of laboratory analysis results, 4 Engineering-geological (EGE) elements were identified (Fig. 2):

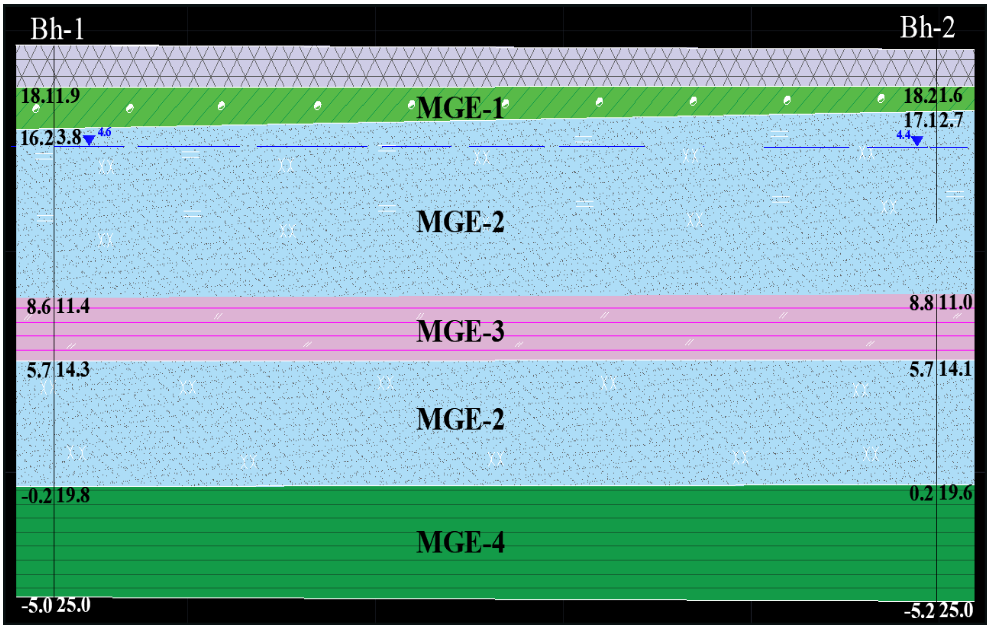
EGE-1. Loam, hard, W= 16.5, P=2.0 g/sm^3, P_d=1.73 g/sm^3, e=0.572, S_r= 0.77, W_L= 29.8, W_P=18.5, I_P=11.3, I_L< 0, C= 0.36 kg/sm^2, tgφ=0.466, E=32.8 MPa.

EGE-2. Medium-grained sands, W=8.0(26.0), P=1.75 g/sm^3, e=0.569, Sr=0.37(0.87), φ=34^0, E=12.0 (35.0) MPa.

EGE-3. Hard plastic clay, W=23,5, P=2.02 g/sm3, Pd=1.64 g/sm3, e=0.671, Sr= 0.96, W_L= 36.6, W_P=17.2, I_P=19.4, I_L=0,3, C= 0.54 kg/sm2, tgφ=0.315, E=19.5 MPa.

EGE-4. Semi-hard clay, W=20,7, P=2.0 g/sm3, Pd=1.66 g/sm3, e=0.654, Sr=0.86, W_L= 37.7, W_P=18.7, I_P=19, I_L=0,11, C= 0.68 kg/sm2, tgφ=0.364, E=24.0 MPa.

Figure 2 Engineering-geological model of the building's soil foundation



Taking into account the physical and mechanical properties of the soil, the depth of groundwater, and the negative impact of groundwater on the building structures located in the zero cycle, it was decided to develop measures to protect the underground parts of the building from the impact of groundwater using Jet Grouting technology.

Jet grouting is the youngest major category of grouting for ground treatment. The ASCE Geotechnical Engineering Division Committee on Grouting (1980) defined jet grouting as a "technique utilizing a special drill bit with horizontal and vertical high-speed water jets to excavate alluvial soils and produce hard impervious columns by pumping grout through the horizontal nozzles that jets and mixes with foundation material as the drill is withdrawn". The jet grout execution is schematized in Figure 3 (Guler et al., 2021).

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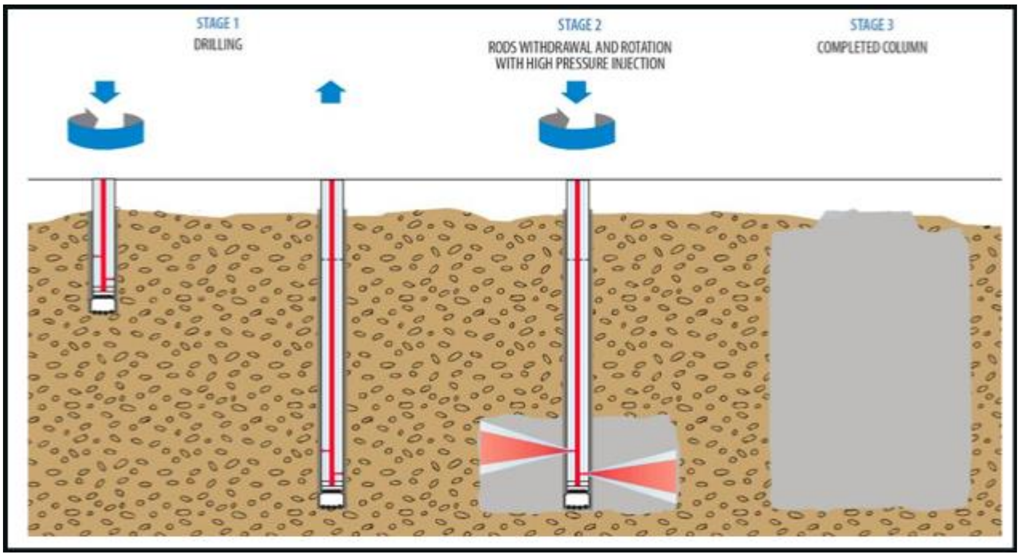
Figure 3 Jet grout column execution



Soil concrete columns installed using Jet Grouting technology, which is used to prevent groundwater from entering the building's soil foundation and to increase the strength of wet sands, perform two important functions:

1. Accepts part of the pressure created by the mass of the building and transfers it to the more reliable soil at the base of the soil-concrete column;
2. It serves as the most reliable waterproofing device, preventing liquefaction processes from suffusion and seismic impacts, and also protecting the underground part of the building from groundwater penetration;

Jet grouting techniques are frequently adopted to ensure the stability and waterproofing required for constructing high-risk and challenging underground infrastructures. Over the past decades, significant progress has been made in Jet Grouting technology, especially in quality control and quality assurance methods for jet-grouted columns (e.g., drilling alignment, diameter inspection/monitoring, and strength control of jet-grouted columns). It has made jet grouting easier and less expensive to implement. Also, the bearing capacity and the waterproofing performance of the jet-grouted columns are significantly improved (Cheng et al., 2023).

Taking into account the soil conditions of the foundation base, a single-component technology (Jet-1) was used when forming the soil-concrete column using Jet Grouting technology. With single-component cementation under pressure, the soil was washed and mixed with cement mortar only by jet cementation.

When using a single-component technology (Jet-1), under a jet of cement mortar with a pressure of 400-600 atmospheres, the soil is destroyed and then mixed with the mortar, resulting in the formation of a soil-concrete column with a diameter of 0.6-1.2 meters. This technology is simple, since a minimum set of equipment is used (Zhadanovsky et al., 2024).

The main parameters accepted during soil processing for the creation of a soil-concrete column using Jet Grouting technology: cement mortar injection pressure – 35-40 MPa, productivity of the introduced cement mortar – 120 liters/minute, number of nozzles – 2 pieces, nozzle diameter 3.2 mm, height of cyclic monitor lift – 4 cm, drilling column lift speed – 30 cm/min, monitor rotation speed – 10 rpm, cement-sand mortar ratio – W/S = 1.0, nozzle rotation – 360˚.

To calculate the technological indicators, the frequently used cyclic mode of the device of a soil-concrete column with a diameter of D (Fig. 4) is considered when in each cycle the monitor is raised by the value of the step S. The step value is determined empirically from the point of view of achieving high homogeneity of the soil and in practice is S = 4...10 cm. After processing the soil during the time interval, the monitor is further raised by step S, etc. (Malinin, 2003).

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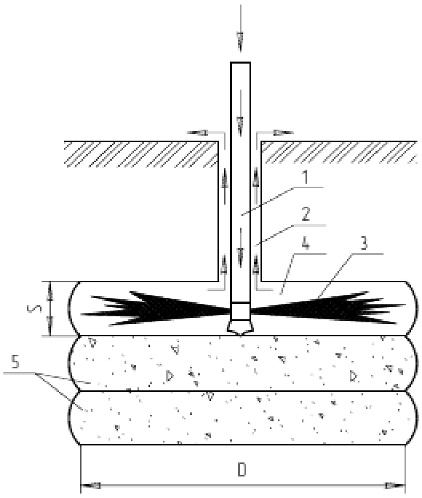
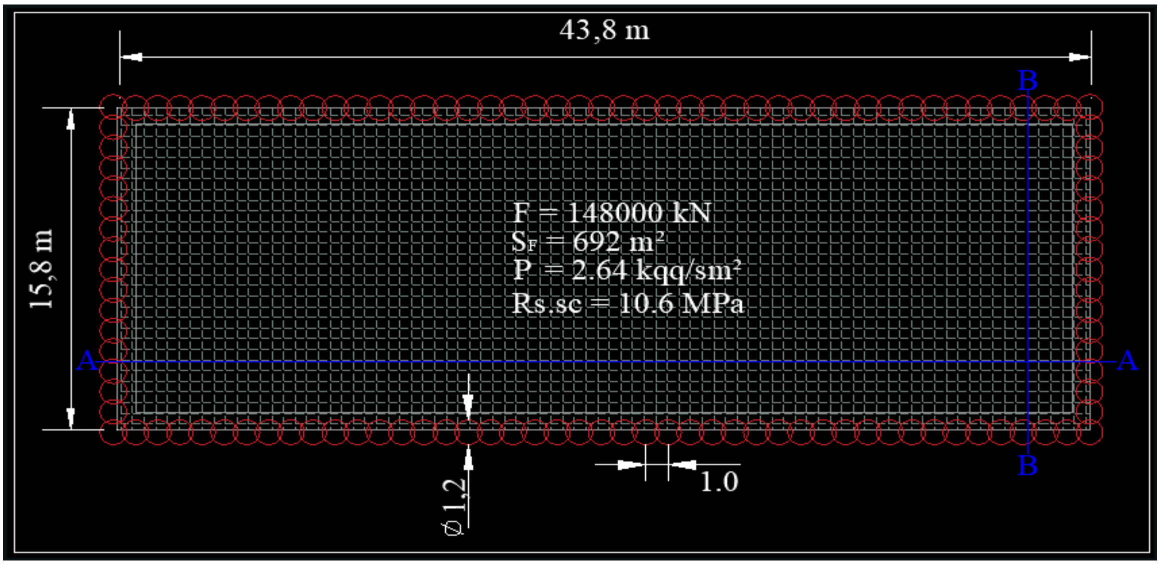
Figure 4 Scheme of formation of a soil-concrete column



1. Cement slurry inlet.
2. Pulp outlet through the annulus.
3. Water-cement jet.
4. Volume of soil being processed.
5. Soil processed during previous cycles.

While carrying out work on protective measures against the negative effects of groundwater using the Jet Grouting method, the technological sequence of installing soil-concrete columns in various areas of the foundation perimeter (Fig. 5) was followed.

Figure 5 Scheme of application of Jet Grouting technology for protection of underground part of the building from groundwater



The strength of the soil-concrete column resulting from the processing of the soil with the single-component Jet Grouting technology depends on the properties of the soil and also on the amount of cement used to wash and mix the soil.

In this regard, the amount of cement to be used to prepare the soil-concrete column according to the required parameters must be determined.

The cement consumption required for soil treatment in one cycle (S=4 cm) was calculated as follows:

The density of the solution at a water-cement ratio wc will be

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$$P_{wc} = (1 + wc) / (1/P_c + wc/P_w) = 1.46 \text{ g/sm}^3$$

Where Pc, Pw are the density of cement and water particles, respectively.

The volume of soil processed during one cycle

$$V_s = \frac{\pi D^2}{4} S = 0.045 \text{ m}^3$$

The volume and mass of cement slurry entering the well during the time interval

$$\Delta V_1 = q * \Delta t_1 = 8 \text{ L} = 0.008 \text{ m}^3$$

$$m_{wc} = P_{wc} * \Delta V_1 = 1.46 * 0.008 = 11.68 \text{ kg}$$

Determination of cement consumption q_c and water q_w

$$q_c = 1/ (1/P_c + wc/P_w) * q = 87.6 \text{ kg}$$

$$q_w = wc/ (1/P_c + wc/P_w) * q = 87.6 \text{ kg}$$

The entry of cement and water into the soil in mass terms

$$m_c = q_c * \Delta t_1 = 5.8 \text{ kg} \qquad m_w = q_w * \Delta t_1 = 5.8 \text{ kg}$$

Determination of the mass of soil and water contained in the volume Vs

$$m_g = (1 - P_0) * P_g * V_s = 144.7 \text{ kg}$$

$$m_w = P_0 * P_w * V_s = 36.0 \text{ kg}$$

The amount of cement, soil, and water remaining in the soil-concrete column in the first stage,

$$m_c = q_c * \Delta t_1 * \theta_1 = 5.0 \text{ kg}$$

$$m_g = (1 - P_0) * P_g * V_s * \theta_1 = 61.5 \text{ kg}$$

$$m_w = (q_w * \Delta t_1 + P_0 * P_w * V_s) * \theta_1 = 5.0 \text{ kg}$$

The amount of cement, soil and water remaining in the soil-concrete column in the second stage,

$$m_c = (q_s * \Delta t_1 * \theta_1 + q_c * \Delta t_2) * \theta_2 = 9.2 \text{ kg}$$

$$m_g = (1 - P_0) * P_g * V_s * \theta_1 * \theta_2 = 52.3 \text{ kg}$$

$$m_w = [(g_w * \Delta t_1 + P_0 * P_w * V_s) * \theta_1 + q_w * \Delta t_2] * \theta_2 = 9.2 \text{ kg}$$

The soil-concrete column, constructed using the Jet Grouting method, has the following main properties: the column cementation period is 200 seconds, and the amount of cement in 1 m3 is 403.0 kg.

The installation of soil-concrete columns was carried out in two stages;

I – A borehole with a diameter of 90 mm was drilled to the design depth by introducing a monitor;

II – Simultaneously with the cutting and dispersion of the soil, the cement mortar pumped into the borehole under pressure was intensively mixed with the cut and crushed soils, resulting in the formation of a homogeneous soil-concrete column with a density of 1.4-1.9 t/m^3.

Considering the non-aggressive nature of groundwater about concrete structures, cement grade PC 500 was used in the manufacture of soil-concrete columns. It is possible to use cement-grade PC 400 with the addition of a plasticizer.

Taking into account the inclination of the soil layers that form the geological environment, the direction of groundwater flow, the porosity of medium and fine-grained sands saturated with water, and other factors, the sequence of creating the soil-concrete columns to be installed in the underground part of the building was chosen in such a way that a decrease in the groundwater level in the building's foundation was observed under the sequence of the work process.

When implementing the Jet Grouting technology to protect the underground part of the building from the negative impact of groundwater, a small-sized Keller (AFR) SC-1 device was used. The compressive strength of the installed soil-concrete columns along the perimeter of the building foundation (Fig. 6 and Fig. 7) was 10.6-14.4 MPa (SP, 2017).

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Figure 6 Construction of soil-concrete columns using Jet Grouting technology. The section along line A-A

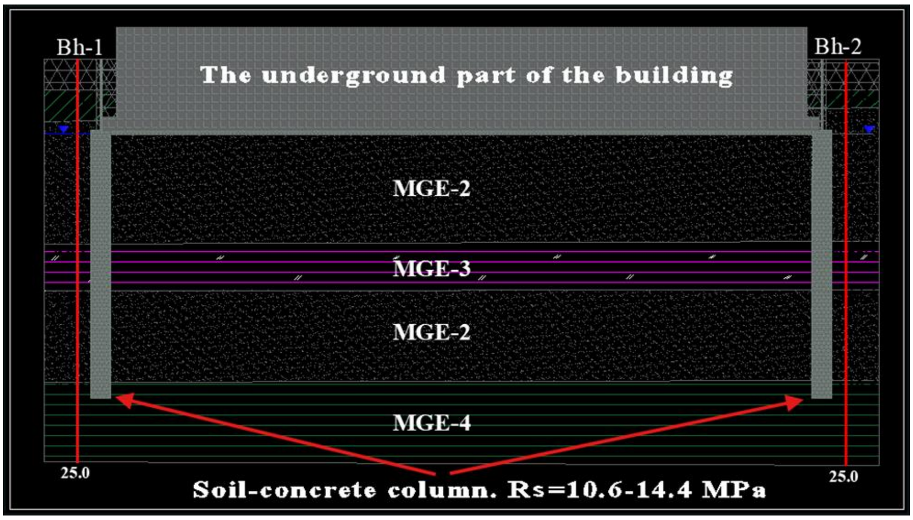
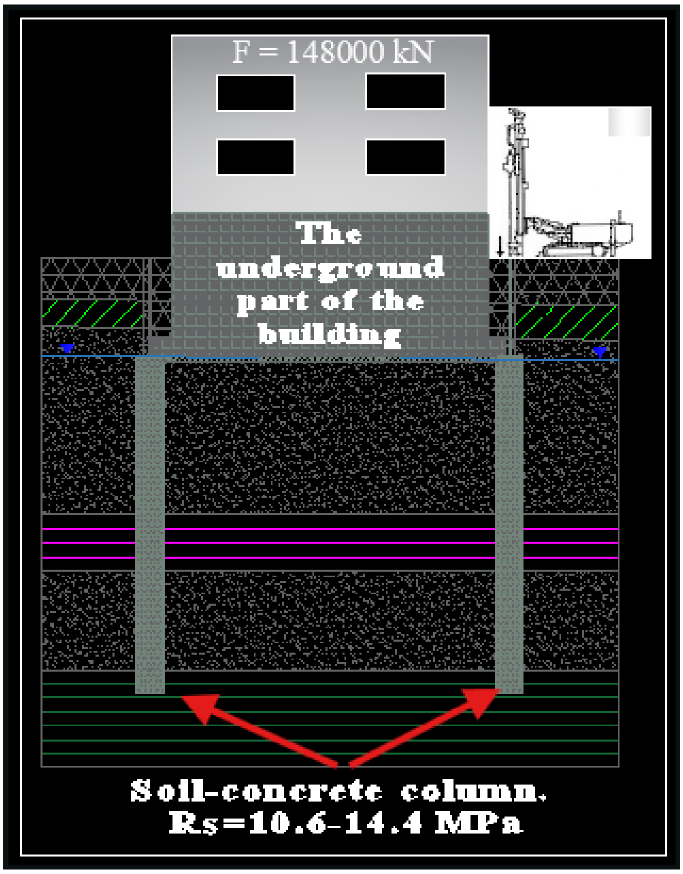


Figure 7 Construction of soil-concrete columns using Jet Grouting technology. The section along line B-B



Conclusion

Based on the engineering protection measures implemented using Jet Grouting technology, the following results were achieved:

− The ingress of groundwater into the soil mass of the building foundation and the negative impact of groundwater on the structural elements of the building in the zero cycles were completely prevented, and closer to the end of the work on the construction of soil-concrete columns, the groundwater level dropped to a depth of 17-18.0 meters

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− As a result of the decrease in humidity, and increase in the density and resistance force of wet sands, which are the main soil in the geological structure of the building construction site, the seismic properties of the soils that make up the geological environment decreased from 9 points to 8 points;

− The process of liquefaction of water-saturated sands in the foundation of the building was completely prevented;

− The level of risk to the safe operation of the building was minimized and the safe operation of structural elements in the underground part was restored.

References

1. Connor, R. (2015). *The United Nations World Water Development Report 2015*: *Water for a Sustainable World*. UNESCO Publishing.
2. Cheng, Sh., Chao, K., Wong, R., & Morris I-Min Wang, M. I. (2023). Control of jet grouting process induced ground displacement in clayey soil. *Transportation Geotechnics*, 40, 100983. https://doi.org/10.1016/j.trgeo.2023.100983
3. Dang, T. (2021). Spatial distribution of high-rise buildings in Hanoi city inner. *International Journal of Advanced Research in Engineering and Technology*, 636–643. https://doi.org/10.34218/IJARET.12.3.2021
4. Guler, E., & Gumus Secilen, G. (2021*)*. Jet grouting technique and strength properties of jet grout columns. *Journal of Physics: Conference Series*, 1928012006. https://iopscience.iop.org/article/10.1088/1742-6596/1928/1/012006
5. Jing, M., Pujades, E., Liu, J., Jurado, A., & Lu, Ch. (2023). Effect of underground structures on groundwater residence time distributions in confined aquifers. *Journal of Hydrology*, 624, 129938. https://doi.org/10.1016/j.jhydrol.2023.129938
6. Kurmanov, A. K., & Askarov, D. A. (2017). Influence of groundwater level during construction and reconstruction of buildings and structures. *Science and Technology of Kazakhstan*, UDC 624.131.6
7. Leiwen Jiang, & Brian, C. O'Neill. (2017). Global Urbanization Projections for the Shared Socioeconomic Pathways. *Global Environmental Change*, 42, 193-199.
8. Malinin, A. G. (2003). Justification of cement consumption in jet grouting of soil. *Appendix to Underground space of the world "Problems of development of transport structures and engineering communications*, 2-3.
9. Nguyen, L. P., Paulin, E. V., Kemperman, A., & Mohammadi, M. (2024). Social impacts of living in high-rise apartment buildings: The effects of buildings and neighborhoods. *Journal of Urban Affairs*. https://doi.org/10.1080/07352166.2024.2311165
10. Shiraliyev, N., Khalilova, A., & Abbasova, A. (2024*)*. Geotechnical Justification for Designing Landslide Prevention Measures. *Nature & Science*, 6(10). https://doi.org/10.36719/2707-1146/49/28-38
11. SP. (2017). SP 291.1325800. *Soil-cement structures. Reinforced. Design rules.* Standartinform.
12. Yuen, B., Yeh, A., Appold, S. J., Earl, G., Ting, J., & Kwee, L. K. (2006). High-rise Living in Singapore Public Housing. *Sage Journals*, 43(3), 583-600. https://doi.org/10.1080/00420980500533133
13. Zhadanovsky, B. V., Graneva, A. V., & Abramova, S. V. (2024) Modern Possibilities of Jet Grouting of Soils. *Engineering Bulletin of the Don*, 1. http://ivdon.ru/ru/magazine/archive/n1y2024/8919

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