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Methods for strengthening the ground and infrastructure of historical monument constructions

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***Abstract* – In this paper, the authors present research conducted through case studies on historical monument constructions situated on challenging foundation soils, where the foundation structure has also been affected. The constructions in question are historical monument buildings, typically over 100 years old. The destructive factors causing foundation degradation and affecting the soil's resistance parameters are mainly leaks from water networks but also include certain intervention works carried out in the immediate vicinity of the monument. The resulting differential settlements motivated in-depth geotechnical studies as well as measures for soil stabilization and infrastructure reinforcement. The results of the research have supported the intervention works adopted by the authors, many of these case studies having also been executed to date. In this context, the article presents highly valuable material for specialists in adopting intervention measures for infrastructure reinforcement.**

Keywords – consolidation, historical monument.

1. INTRODUCTION

Historical monuments are constructions with architectural and historical value, expressing the thought, science, and culture of society at a certain historical stage. As is known, the value of historical monuments is influenced by their age and the preservation of authentic elements over time. In Romania, special attention has been given to historical monument constructions, particularly after the enactment of Law 422/2001, with subsequent amendments and completions. The defining element in adopting an appropriate cultural policy is the specialist's attitude towards restoration methods and techniques so that the measures adopted do not compromise the building's authenticity. The sample analyzed by the authors consists of historical monument buildings located on difficult foundation soils, which have posed significant problems both in terms of resistance and in ensuring a proper transfer of loads from the superstructure to the foundation soil. Thus, the foundation becomes the primary structural element on which the authors take necessary measures to reinforce and restore continuity or as needed, to supplement the contact surface with the foundation soil.

2. GROUND REINFORCEMENT WORKS, REINFORCEMENT OF THE GROUND AND FOUNDATION

Intervention measures must be well correlated with the degree of construction degradation, operating conditions, and environmental factors. When works are required to increase the bearing capacity of the foundation or when intervention works are needed to reinforce and stabilize historical monument constructions, these interventions can also be carried out by improving the bearing capacity of the soils, namely enhancing their bearing capacity, known as ground improvement under existing foundations.

Generally, such works aim to increase the soil's bearing capacity, fill perimeter voids, and solidify the fill with the foundation blocks. Additionally, such measures also aim to seal the infrastructure against water infiltration and accumulation. The advantage of these intervention works is that they are performed without perimeter excavations. These works involve injecting stable, self-hardening suspensions, cement with bentonite, which are easily penetrable into various soil types. These intervention measures have been widely executed on both historical monuments and other buildings, consisting of placing vertical or inclined injectors, which can be positioned on both sides of the foundation or only on one side, solidifying the soil up to 1.0-1.5 meters below the minimum injection level.

2.1. Ground reinforcement of the "Ion Bănescu" house, located in Constanța, Comis Boulevard no. 110

An example in this regard, is the proposal by Af. expert Dr. Eng. Cornel Ciurea for the ground reinforcement of the "Ion Bănescu" House, located in Constanța, Tomis Boulevard no. 110. This building is a historical monument listed in category B - "CT-II-m-B-21100" - "Ion Bănescu" House and classified by order no. 2572 of August 13, 2014.

The "Ion Bănescu" House is situated on the eastern front of Tomis Boulevard, in the central-southern area, integrated since 2004 into the urban site "CT-ll-s-B-02842," which has a building stock from the first half of the 20th century and the years 1960-1989, with four monuments included in the List of Historical Monuments, as well as a series of contrasting, non-specific insertions from after the 1990s. The property consists of the main building, body C1, and annexes. Body C1 has a built area of 217 square meters.

Fig. 1 Main facade of the "Ion Bănescu" House, Constanța Municipality, Source: Mădălina Iordache

The applied solution was based on the results of dynamic penetrations, which indicated that the foundation soil is soft to very soft, as well as the results of numerical modeling, which showed:

"*The results of Stage 2 of the numerical modeling showed that the maximum settlement values (dz = 43.1 mm) and the pressure on the foundation footing (σz, ef = 53.78 kPa) fall within the limits provided by the NP 125 / 2010 and NP 112 / 2014 standards. The bearing capacity of the foundation soil was mobilized to 76.52%. These results confirmed that the foundation width of the Ion Bănescu House, as analyzed in Stage 2, is compliant. The results of Stage 3 of the numerical modeling showed that the maximum settlement values (dz = 44.7 mm) and the pressure on the foundation footing (σz, ef = 75.93 kPa) still fall within the limits provided by the NP 125 / 2010 and NP 112 / 2014 standards. The bearing capacity of the foundation soil was mobilized to 99.57%, with this maximum mobilization located between the axes of the Ion Bănescu House, adjacent to the neighboring building with a height regime of S+P+5E. The maximum displacement and stress values are located at the foundation adjacent to the support enclosure of the excavation required for the neighboring building with a height regime of S+P+5E. In this area, there is also a horizontal displacement of the support wall of the neighboring excavation, with a maximum value of dx = 27.00 mm.*" [1]

Based on these aspects, the foundation soil improvement [2] was carried out through the injection of stable, self-hardening cement and bentonite suspension. The injections are performed with metallic injectors, lance-type, both inside and outside the building, on both sides of the foundation, to a depth of about 10 meters from the natural ground level. After these reinforcements were completed, foundation reinforcement was anticipated. [3]

2.2. Ground reinforcement of the "workshops" building in the "Celic-Dere Monastery" Complex, Telița Village, Frecăței Commune, Tulcea County

Another historical monument where the ground reinforcement solution was applied is the "Workshops" building in the "Celic-Dere Monastery" Complex in Dobrogea, Telița Village, Frecăței Commune, Tulcea County. This building is a historical monument listed in category B - "TL-II-a-B-06039" - Celic-Dere Monastery.

Fig. 2 "Workshops" Building in the "Celic-Dere Monastery" Complex, Tulcea County, Source: Technical expert Prof. Dr. Eng. Ana Maria Grămescu in collaboration with Mădălina Iordache

The building is one of the two buildings constructed between 1910-1912 at the Celic-Dere Monastery, two-storey buildings that once housed the "Saint Anne" Church Painting School, a carpet, fabric, and sacred vestment workshop, as well as the Abbot's residence with a terrace supported by five columns, modeled after old boyar manors. In 1954, the weaving workshop was transformed into a chapel and extended with an altar on the right lateral facade. Today, the monastic establishment possesses a rich collection of old ecclesiastical art. The museum of ecclesiastical collections houses objects of historical, artistic, and documentary value. [4]

According to the geotechnical study, the foundation soil at the site, at the level of the existing foundations, is represented by a layer of loess-like clayey sand. Thus, it was recommended to rigidify the infrastructure with the possibility of accommodating probable soil deformations, considering the characteristics of the foundation soil. [5]

Following the geotechnical study and the analysis of the stratification by expert Dr. Eng. Cornel Ciurea, during the collaboration for the restoration of the workshop building within the monastery, mixed intervention measures were adopted as follows:

1. For the area of the new altar, the foundation solution was micro-piles with a diameter of 300 mm and a length of 4.0 m, made of reinforced concrete. [6]

Fig. 3 Micro-piles in the new altar area
Source: Technical expert Prof. Dr. Eng. Ana Maria Grămescu, Af. expert Dr. Eng. Cornel Ciurea

Fig. 4 Micro-piles in the new altar area, lateral façade
Source: Technical expert Prof. Dr. Eng. Ana Maria Grămescu, Af. expert Dr. Eng. Cornel Ciurea

Fig. 5 Detail of micro-piles
Source: Technical expert Prof. Dr. Eng. Ana Maria Grămescu, Af. expert Dr. Eng. Cornel Ciurea

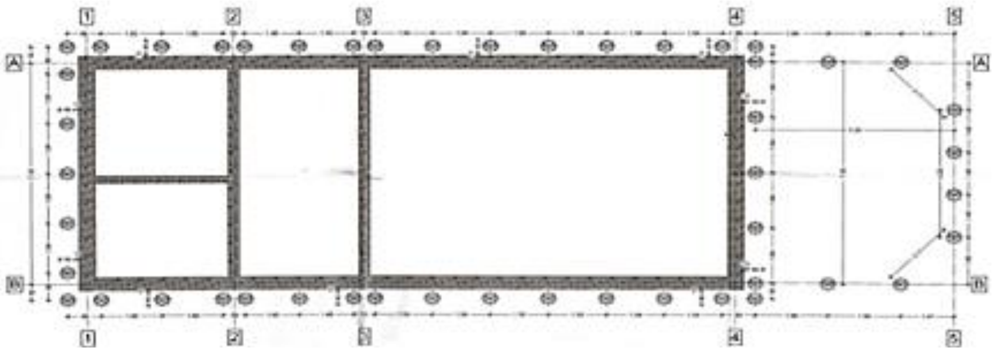

Fig. 6 Pile placement plan
Source: S.C. MISOLI S.R.L. TULCEA, Dr. Eng. Mihaela Pericleanu and Bucur Dan Pericleanu, Project "Restoration and Modernization of the 'Workshops' Building in the Celic Dere Monastery Complex" [7]

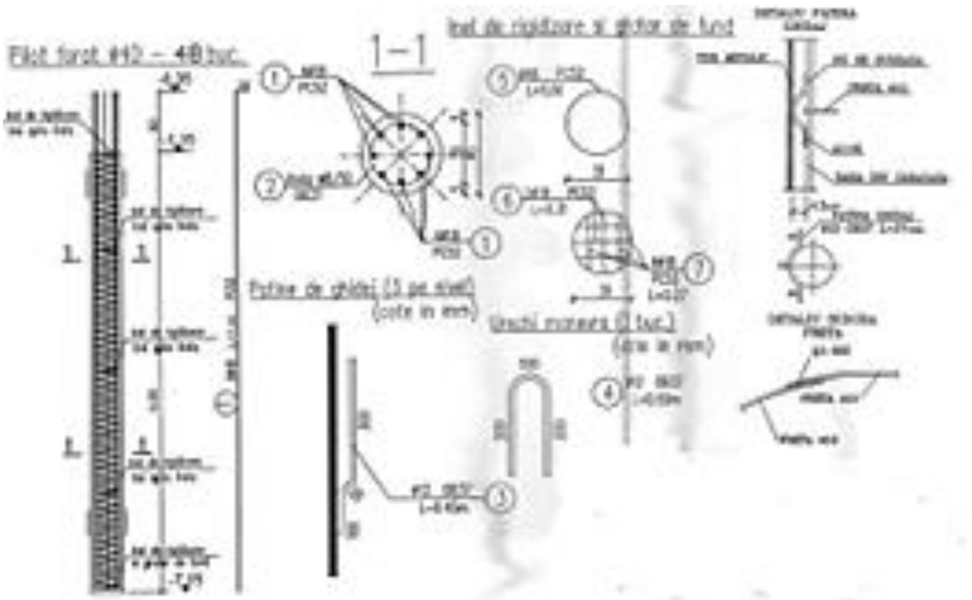

Fig. 7 Pile reinforcement details
Source: S.C. MISOLI S.R.L. TULCEA, Dr. Eng. Mihaela Pericleanu and Bucur Dan Pericleanu, Project "Restoration and Modernization of the 'Workshops' Building in the Celic Dere Monastery Complex" [7]

2. For the consolidation of the foundations of the workshop building, injections with a stable suspension of bentonite and cement were planned, abandoning the execution of a curtain of bored piles. [6]

The injection variant was adopted due to the fact that, after uncovering the foundations, it was found that they were made of river stone, which no longer had a binder, posing a risk that the structure of the stones could shift during the creation of the piles.

Therefore, injectors were placed in close proximity to the foundation, both inside and outside, creating a compact mass and rigidifying the building's foundation.

Fig. 8 Area for injection with stable suspension of bentonite and cement
Source: Mădălina Iordache

Fig. 9 Injection with stable suspension of bentonite and cement
Source: Technical expert Prof. Dr. Eng. Ana Maria Grămescu, Af. expert Dr. Eng. Cornel Ciurea

2.3. Consolidation of the soil and foundation of the "Water Castle," located in the Municipality of Brăila, 20 Public Garden Street

Another objective where foundation soil improvement works were carried out is the "Water Castle," located in the historic center of Brăila, 20 Public Garden Street. The building, a historical monument, is listed in the historical monuments list of the Municipality of Brăila, with category B and code "BR-II-m-B-02104."

The Public Garden is the green oasis of the city of Brăila, where the bases of the former Brăila fortress are located, being one of the entrances to the city's main catacomb. The "Water Castle" was built in the Public Garden due to the increase in population and the significant rise in water consumption.

The tower had a height of 35 meters in 1912 when it was put into use and was considered the tallest water supply tower in Romania.

Fig. 10 Main facade of the "Water Castle," Municipality of Brăila, Source: Mădălina Iordache

According to the geotechnical study prepared by technical expert Prof. Dr. Eng. Romeo Ciortan, the foundation soil belongs to the group of difficult foundation soils. The consistent loess layer at the site is sensitive to moisture throughout its thickness, has high porosity, and shows high to very high compressibility, both in its natural and saturated states. The foundation soil was affected due to significant water infiltrations from the damaged supply networks feeding the structure. [8]

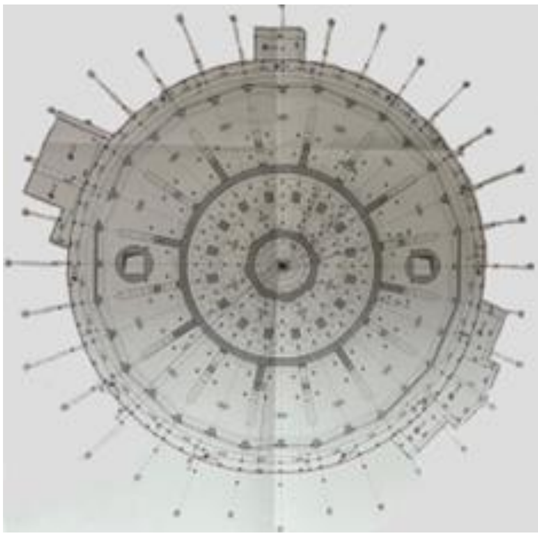

Fig. 11 Plan for injection placements for foundation soil consolidation. Source: S.C. OPTIMAL PROJECT S.R.L. IAȘI, Project "Rehabilitation of the Water Castle in the Public Garden, Brăila, 20 Public Garden Street, Municipality of Brăila" [9]

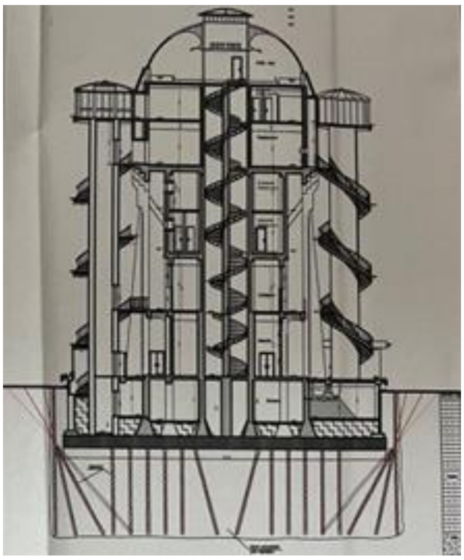

Fig. 12 Consolidation by injection of loess soil - drilling. Source: S.C. OPTIMAL PROJECT S.R.L. IAȘI, Project "Rehabilitation of the Water Castle in the Public Garden, Brăila, 20 Public Garden Street, Municipality of Brăila" [9]

To improve the foundation soil throughout its thickness, up to the level of the groundwater, technical measures were taken following a technical-economic analysis, specifically consolidating by creating a vertical screen of injected soil around the foundation and injecting the soil in the space between the vertical screen, the foundation slab, and the sand layer at the base.

By adopting these solutions, the risk of foundation soil collapse was reduced, thus allowing it to bear the loads transmitted by the structure with acceptable deformations under various calculation hypotheses.

According to the resistance memo from the project "Rehabilitation of the Water Castle in the Public Garden, Brăila, 20 Public Garden Street, Municipality of Brăila," the injection of the soil under the foundation slab was of the "lost cone lance" type, with the injection process being "ascending."

Drilling for the introduction of injection lances was performed in cored holes with a diameter of Ø111 mm in the reinforced concrete slab (-5.10 / -6.10 m) and continued vertically to a depth of -13.00 m.

Fig. 13 Penetrometer tests to verify the consolidation of the foundation soil after injection, Source: Mădălina Iordache

Fig. 14 Penetrometer tests to verify the consolidation of the foundation soil after injection of the loess soil under the foundation slab, Source: Mădălina Iordache

According to the resistance memo from the project "Rehabilitation of the Water Castle in the Public Garden, Brăila, 20 Public Garden Street, Municipality of Brăila," to create a vertical screen of injected soil around the foundation slab, injection through sleeve tubes was used, and the injection process was "ascending."

Drilling for the introduction of sleeve tubes with a diameter of Ø80-100 mm was performed inclined, oriented inward, to a depth of 13.00 m.

Soil injection was carried out with a cement-based solution with the addition of bentonite, forming a stable, self-hardening suspension. [9]

Fig. 15 Injection through sleeve tubes of the soil, Source: Mădălina Iordache

3. CONCLUSIONS

The research conducted through case studies, corroborated with the principles of the specialized literature, highlights that in the field of historical monuments, restoration principles must follow the criteria that formed the basis for their classification as monuments, and intervention measures should not damage the monument.

In the process of rehabilitating and restoring historical monuments, it is essential to consolidate the foundation soil in conjunction with the foundation.

To choose the optimal type of intervention, it is necessary to conduct all required studies, thus analyzing the soil type through a geotechnical study and identifying all causes that led to the deformation of structural elements.

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