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Efficient use of self-drilling bars for consolidation and foundation works

Utilisation efficace des barres autoforeuses pour les travaux de consolidation et de fondation

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ABSTRACT: Self-drilling bars have a wide use for foundation, anchoring and consolidation works, due to their easy adaptability to difficult site conditions, respectively the geometry of the structures, ground conditions, as well as, access capabilities in small spaces. The design of these type of works implies dimensioning of the load bearing capacity of the self-drilling bars (external strength), including the improvements of their surrounding soil and of the steel strength (internal strength). Afterwards, the obtained values are compared to the structural loads and verified with in situ tests, and based on this the final design was the technical and economical optimal solution. The paper presents various case studies regarding these types of works implemented in Romania and their specific aspects. Case studies present, the consolidation works of some retaining walls located in the mountain area through the judicious use of self-drilling bars associated with drainage works, foundation works for riverbanks and abutment for a shipyard near Danube and consolidation works for a historical monument building in the Black Sea cliff area.

RÉSUMÉ : Les barres autoforeuses ont une large utilisation pour les structures de fondation, d'ancrage et de consolidation, en raison de leur adaptabilité facile aux conditions de site difficiles, respectivement a la géométrie des structures, aux conditions du sol, ainsi qu e les conditions de travail. La conception de ce type d'ouvrages implique le dimensionnement de capacite portante des barres autoforeuses (résistance interne), y compris les améliorations de leur sol environnant et de résistance de l'acier (résistance extérieure). Ensuite, les valeurs obtenues sont comparées aux charges structurelles et vérifiées avec des test in situ, et sur cette base, la conception finale était la solution optimale technique et économique. L'article présente diverses études de cas concernant ce type de travaux mis en œuvre en Romanie et leurs aspects spécifiques. Des études de cas présentent les travaux de consolidation de certains murs de soutènement situe dans la zone montagne grâce à l'utilisation judicieuse de barres autoforeuses associées a des travaux de drainage, des travaux de fondation pour les berges et des culées d'un chantier naval près du Danube et des travaux de consolidation pour une construction de monument historique a la zone des falaises de la mer Noire.

KEYWORDS: self-drilling bars, consolidation, foundation works, grouting, micropile

1 INTRODUCTION.

The recent evolution in the construction domain and the development of specific and modern equipment allowed the conception of new execution technologies in the domain of applied geotechnics.

One of them is the self-drilling bars, used as soil anchors and also as micropiles for deep foundation works, which is successfully applied in Romania in numerous projects for consolidation and foundation works of constructions in interaction with the soil for road construction, foundations for civil and industrial buildings, slope protection structures and landslide stabilization etc., in difficult soil conditions.

The principle of the self-drilling bars technology consists in introducing the bars by direct drilling and dynamic grouting till the depth is reached and then up to three subsequent stages of grouting are performed to increase the grout body diameter and build the bulb at the base.

Below are presented case studies developed in Romania for the consolidation works of retaining walls located in the mountain area, foundation works for a river banks and abutments for shipyard near Danube and consolidation works of a historical monument construction in the Black Sea cliff area with their particularities regarding the type of works and soil conditions. In all cases it was necessary to use small but high-performance equipment with the possibility of adapting for work conditions.

2 CONSOLIDATION WORKS FOR EXISTING RETAINING WALLS IN THE MOUNTAIN AREA

The high traffic in the city of Brasov, situated in a mountain area in the center of the country, led to the accentuated degradation of some retaining walls and traffic restriction in the area.

The existing retaining walls were made of raw stone and cyclopean concrete, with a poor strength plain concrete foundation. The walls dimensions were variable as follows: widths between 0.60 m and 3.00 m at the base of the wall, lengths between 40.00 m and 80.00 m and heights varying from 0.90 m up to 10.00 m.

A detailed visual inspection of the retaining walls was performed prior to the consolidation works design which revealed existing degradations such as cracks, displacements, settlements, that endangered the stability and resistance of these structures, the degradations being mostly still an active process. Some of the retaining walls had drainage systems, but due the degradation of the roadway water infiltration took place and led to the sudden collapse of one part of the walls and road, and also affected some houses downstream. These situations with degraded retaining walls and signs of loss of stability have led to the restriction or even stop of road traffic, requiring emergency interventions to ensure the stability of the area.

The lithology in the site consisted of conglomerate layers that represent the bedrock and, on top of the bedrock, the soil was formed by soft reddish-brown, yellowish-brown clayey silt or silty clay representing the Quaternary age alteration blanket and contains fragments of rocks in variable percentages.

Consolidation works (Figure 1) consisted of micropiles executed by drilling vertically into the body of the retaining wall, with two stage injection, which were connected at the top by a reinforced concrete beam. In addition, the walls were supported by anchors executed on two levels, respectively at the top and center of each wall height, with 45º inclination and lengths of 12.00 – 15.00 m. Both micropiles and anchors were executed by self-drilling technology. Furthermore, the consolidation works involved the restoration of the drainage system, where existing, or otherwise, execution of a new drainage system.

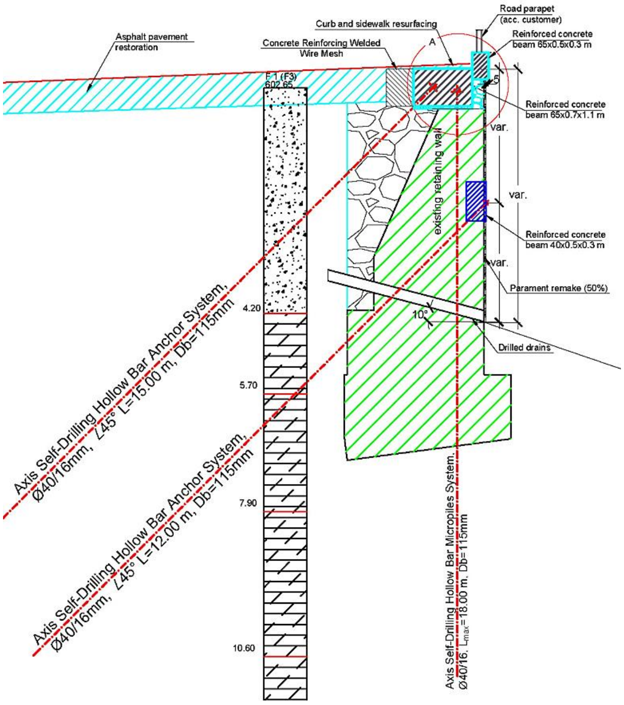

Figure 1. Characteristic section - designed solution for consolidation of the retaining wall.

The works were executed in well-defined steps as the consolidation of the retaining walls had to be done without restricting the road traffic, on narrow streets and without changing the specific architectural aspect of the area.

The geotechnical design of the retaining walls consolidation was carried out in accordance with the fundamental requirements of European and Romanian standards.

The structure was modeled in 2D design software, using both the limit equilibrium method and the reaction coefficient method, and verifications were performed at the ultimate limit states: structural (STR) and geotechnical (GEO). Normal and seismic design situations were taken into account.

In the first step, the equilibrium conditions were verified, through which the dimensions and geometry of the anchors were determinate in order to ensure the stability of the system under the action of the ground pressures and other external loads. Then, in the second step, the structural design, the necessary sectional strength characteristics were established in order for the new system to be able to safely take all the loads and stresses (bending moments, shear and axial forces).

3 CONSOLIDATION WORKS FOR A SHIPYARD LAUNCHING SYSTEM

A shipyard near Danube was performing the upgrade and refitting of their existing launching system to increase the capacity of launching/ towing of ships up to 6000 tons of weight and up to 32 m width.

The launching system is a complex of structures and machines that allow movement of the manufactured ship to/from the mounting places up to the launching/towing of the hull in/from the river in a controlled and safe way.

Figure 2. Picture from the site during execution.

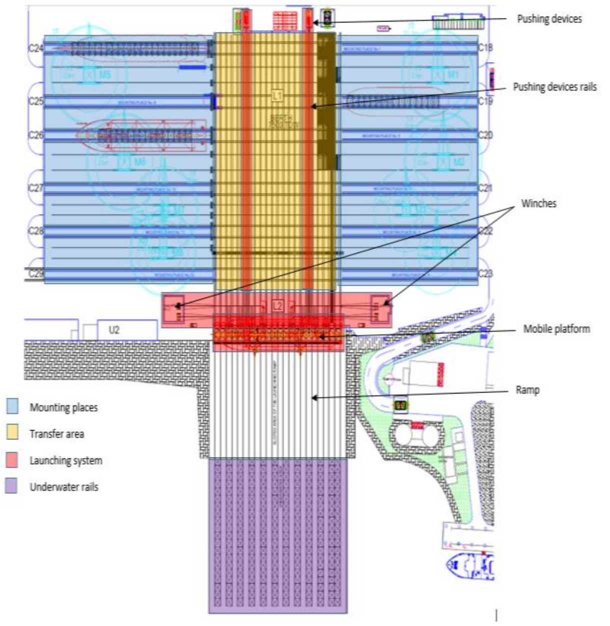

Figure 3. Main parts of the launching/towing system.

The overall upgrading and refurbishment project involved intervening on all the parts of the system to obtain the capacity and safety enhancement. In this regard, geotechnical works were necessary on the foundation blocks of the moving platform in the riverbank area, which are sustaining the new sets of pulleys and anchoring devices of the modified moving platform and reinforcement around the abutment located on the shore area that is sustaining the underwater steel beams. The two areas of intervention are highlighted in the image below.

The lithology is characteristic for the site location, near the riverside of the Danube, and consisted of a superficial layer of crushed stone and sand filling followed by unconsolidated alluvial deposits (silty sands/sandy silts and sands with various thicknesses and depths).

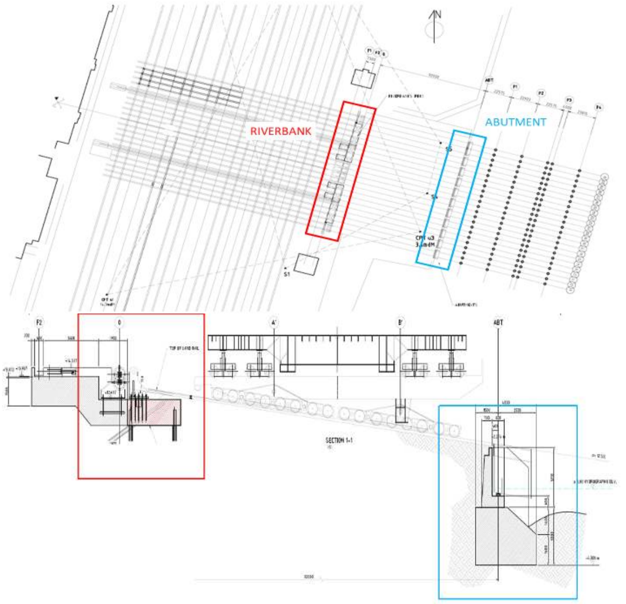

Figure 4. Areas with geotechnical works required.

In order to obtain uniformity of the foundation conditions it was provided that the loads on the foundation base of the Riverbanks and Abutments are to be transferred to the depth or to improved ground, leading to low total and differential settlements. Based on the project particularities the optimal consolidation solution, technological as well as economical, was deep foundations by self-drilling bars (micropiles) grouted in two stages combined with ground improvement by ground injections using the self-drilling bars.

3.1 *Riverbank area*

Micropiles were drilled from the lower level of the existing foundation

For this area it was necessary to drill the micropiles from the lower level of foundation after excavation was done. The micropiles were positioned in two rows at the interrex distance of 1.00 m (1.10 m) and the distance between rows 2.00 m (2.50 m) according to the figure below. Inclined micropiles was positioned at 1.00 m (1.10 m) distance and interspersed with vertical micropiles. The length of the bars for vertical micropiles was 12.00 m of which 0.80 m was embedded in the foundation. The length of the inclined micropiles bars was 20.00 m of which 2.25 m (2.00 m) embedded in the foundation.

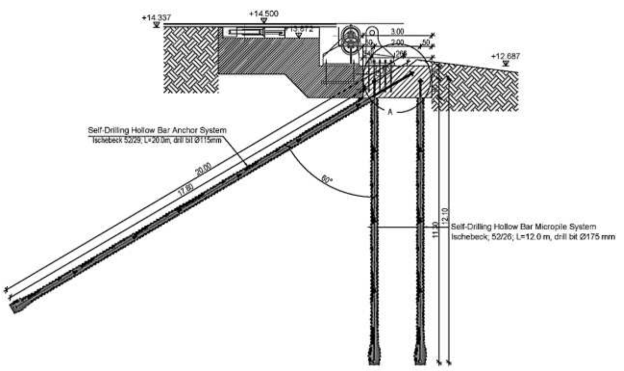

Figure 5. The designed solution for Riverbank foundation works.

3.2 *Abutment area*

For Abutment area it was necessary to increase the load-bearing capacity of the soil up to a pressure of 300 kPa. On the depth of the crushed stone filling layer with high porosity the injection of ground with cement suspension was adopted. For this, the technology of self-drilling bars with additional holes Φ=3.5 mm at 1.50 m and 2.00 m in length of bar (3.00m), as well as through the drilling bit. A conical metal plug was used for back pressure at the top of the bars. In general, the layout of the works consisted of two rows spaced at 1.25 m x 0.50 m (L x H). Also, on the area between the concrete slabs, were proposed two injectors with lost bars.

The designed works are executed in two stages as follows:

Stage 1. Injection of the ground by the self-drilling bars with additional holes to the depth of 3.00 m. At this stage the injection was done at a pressure of 5 atm in order not to affect the existing structures. At the end of stage 1 the bars were extracted from the drilling hole.

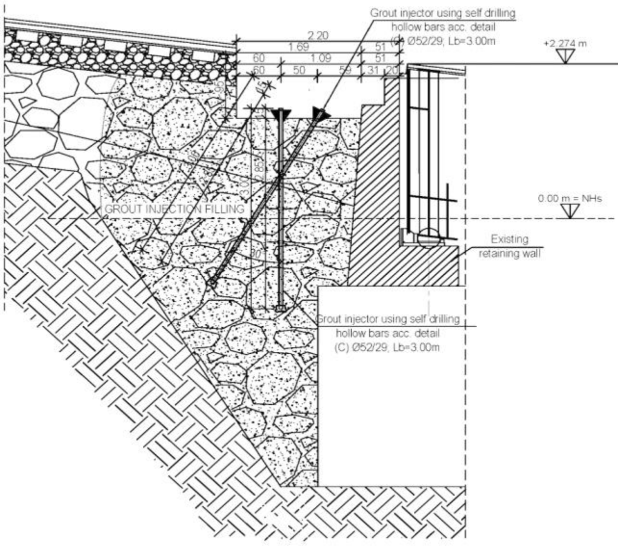

Figure 6. Designed works for stage 1.

Stage 2. Drilling of micropiles from self-drilling bars 12.00 m long with secondary injection up to 50 atm through the drilling bit, on the same position with stage 1. Given the soil nonuniformity, for safety reasons as well as to obtain a better transfer of the loads to the foundation soil, it resulted necessary to continue stage 1 in depth.

On the area between the foundation of the retaining walls, near water, were provided groups of two injectors with lost bars of 9.00 m length.

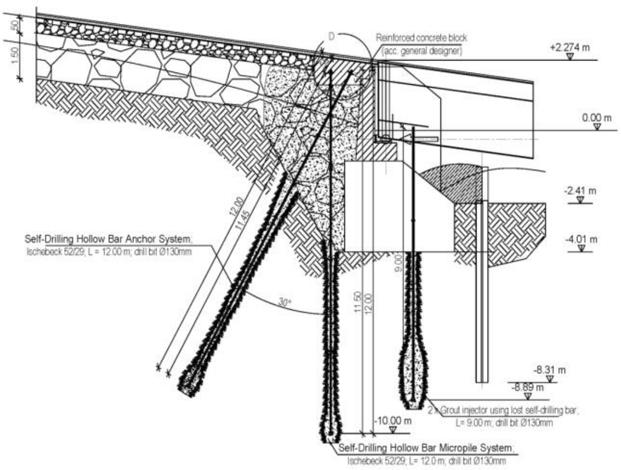

Figure 7. Designed works for stage 2.

To verify the load bearing capacity provided by the project, the capacity of the micropiles was verified thru in situ tests for one vertical (Q_{max}= 300 kN) and two inclined micropiles (T_{max}=150 kN) from Riverbanks area.

Figure 8. Picture from the site during test execution.

For the compression test the maximum registered displacement was 4.38 mm, and for traction test the maximum displacement was 2.05 mm, so it is considered a good behavior of the tested micropiles. The low displacement values indicate that is an excellent cooperation of the metal bars with the ground, carried out by the multiple injection's operation.

4 CONSOLIDATION WORKS FOR A HYSTORICAL MONUMENT IN THE BLACK SEA CLIFF AREA

In order to consolidate the construction of the Casino, built in 1910 on the seafront of Constanta, the technology of micropiles made by self-drilling bars was adopted, especially for the indirect foundation of the new vertical structural elements. The foundations of the original building were made of boulder masonry located at approximately 4.30 m depth from the level of the basement floor, respectively at 7.00 m depth from the elevation of the arranged terrain, the foundation ground is constituted by the limestone layer.

The geotechnical study highlighted a soft clay layer above the limestone layer.

In order to obtain uniformity for foundation conditions for the old construction and the later enclosed construction (with foundation on the soft clay layer), it was provided that all the loads, both from the old and the new areas, should be transferred in depth to the limestone layer by self-drilling micropiles injected in two stages, 6.00 m long.

The works were executed from the basement of the construction, which required the use of a small equipment adapted to the difficult condition with limited space.

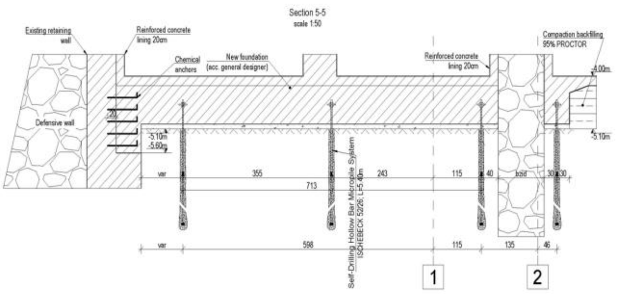

Figure 9. The designed solution for foundation works.

As provided in the project, the capacity of the micropiles was verified thru in situ tests - in this case a compression test conducted to a load of 300 kN. The maximum registered displacement was 2.04 mm, with a residual displacement of 0.65 mm (Figure below), so it is considered a good behavior of the tested micropile.

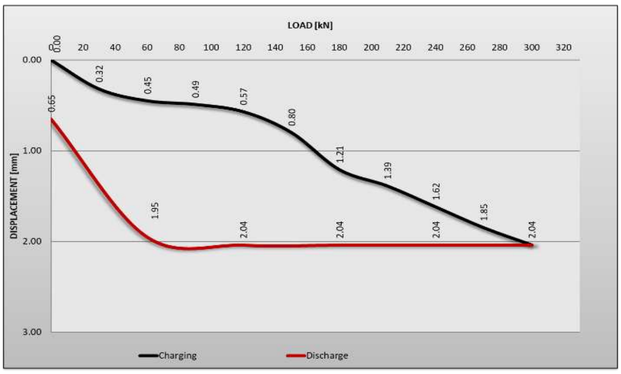

Figure 10. Load-settlement curve from the micropile compression test.

It is considered that the adopted solution with injected self-drilling micropiles corresponded to the requirements resulting from the constraints imposed by the importance of the construction - historical monument, the difficult execution condition inside the basement and the aggressiveness given by the marine environment.

5 CONCLUSIONS

According to the specific of the works, where it is important to keep the initial appearance, the consolidation solution for both structural damage and soil degradation that appears due to the actions of natural or anthropic factors, it is very important to be minimally invasive and highly effective. Dynamic grouting during drilling process offers the advantage of improving the near soil by injection, also the execution can be performed with modern small dimensions equipment. The use of self-drilling bars for consolidation and foundation works of old and new structures is a modern and efficient solution.

The test loads showed the external strength at vertical loads, highlighting the cooperation with the surrounding soil which is improved by injection with the introduction of the self-drilling bar. Inclined self-drilling bars are required for taking on horizontal loads, the kinematics of the machine allowing their drilling at any inclination.

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