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Bucarest Metro Line M5: Underpassing of existing Eroilor1 subway station during regular train transit

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ABSTRACT: The realization of M5 metro line in Bucarest has foreseen the underpass of the existing semi-shallow Eroilor1 station at a distance of about 1 m from the bottom slab. The excavation was carried out using two TBMs-EPB departing from the new station Eroilor 2. The most critical aspects were the demolition of the concrete DW for the part below the existing station bottom slab and the extreme excavation conditions due to a 20 m hydraulic head in presence of sand. It was necessary to realize preventive soil improvement under the foundation slab of the existing Eroilor1 station with vertical and horizontal injection using both cement and chemical grouting. All activities were carried out in presence of a dewatering system, lowering the water level more than 20 m. An automatic monitoring system of the hydraulic and tenso-deformative state of the area allowed the continous check of safety conditions during the excavation.

1 INTRODUCTION

1.1 *Type area*

The project of the new line 5 “Magistrala” in Bucharest, between station Raul Doamnei - Hasdeu (Opera), has a length of approximately six kilometers and consists of about four kilometers of circular cross section tunnels, using two TBM EPB (Earth Pressure Balance) of diam. 6.6 m with 30 cm thick reinforced concrete lining, and for about two kilometers of top down built stations and shafts, distributed as follow:

- Raul Doamnei
- Brancusi
- Romancierilor
- Parc Drumul Taberei
- Drumul Taberei 34
- Favorit
- Orizont
- Academia Militara
- Eroilor 2

In correspondence of the limit between new Eroilor II station and the old station Eroilor I the new line underpass the old one, with a gap between the existing bottom slab foundation and the top of the TBM shield of just 1.20 m. The underpass has been realized using an EPB TBM. This was necessary to prevent the dismantling of the existing station diaphragms walls made of steel reinforced concrete.

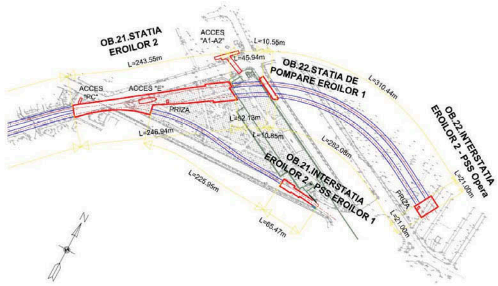

Figure 1. Plan of connection area between New and Old station.

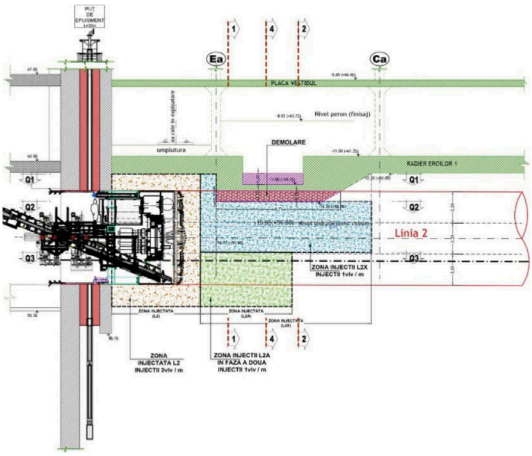

Figure 2. Longitudinal section of connector tunnel.

2 GEOLOGICAL AND GROUND WATER CONDITIONS

The geotechnical characterization of soil in this area derives from several investigations surveys carried out by boreholes and laboratory tests.

The soil profile consists of:

Unit 1: Backfill 0.40–2.60 m thick;
Unit 2: Soft clay and silty clay, grey, maximum depth 5.5 m;
Unit 3: Medium sand and gravel;
Unit 4: Clay and silty clay, brown,consistency medium, maximun depth 16.0 m;
Unit 5: Medium or fine sands with silty sand interbedded, maximum depth 33 m, lacustrian, high plasticity.

Table 1. Geotechnical parameters for soil involved in excavation.

Soil	γ [kN/m^3]	ϕ' [°]	c' [kPa]	Ic	K0
Medium sand	20	30	0	-	0.57
Silty clay	20	24	20	0.75	0.66
Fine sand	20	35	0	-	0.49
Hard clay	19.5	24	15	0.85	0.66

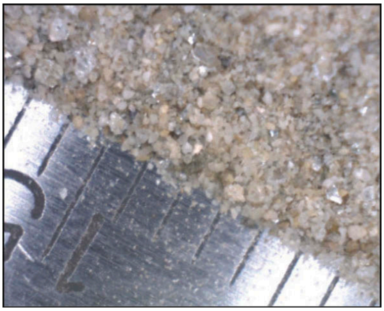

Figure 3. medium sand and gravel, Unit 3.

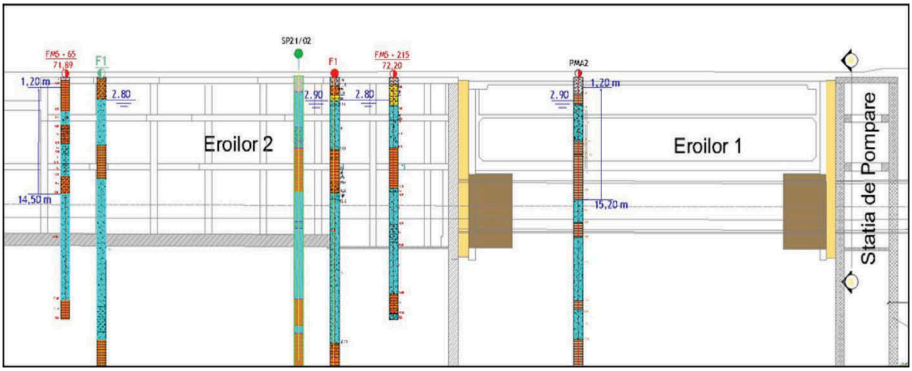

Figure 4. Longitudinal profile with borehole showing presence of sand and clay interbedded.

According to the depth of the sandy layer, the soil interested from TBM cross is characterized by a strong heterogeneity and can be definitively defined as fine medium silty sands with interbedded silt and clay.

However, sand has strongly influenced the demolition works taking also into account the presence of groundwater. The water indeed is located in the sand layers at about 1.5 m below ground level, thereby in the intervention area during the cross passage all digging and demolition operations would have been done under high hydraulic loads up to about 20 m.

3 INTERVENTIONS TO SECURE THE EXCAVATIONS DURING THE DISMANTLING WORKS AND BREAK OUT TBM OPERATION

In order to avoid soil instability and structure failure two different improvement works were designed: soil injection with cement and chemical grouting and use of dewatering wells to lower the hydraulic pressure.

Grouting was done by injecting both in vertical and horizontal direction for a length range from 6 to 12 meters for the horizontal, and of about 22 meters for the vertical: the last ones were positioned in the narrow space available between the diaphragms of the Eroilor 1 and Eroilor 2 station.

All the activities were performed once the effect of wells have been reached, through the use 22 wells (diameter of wells was 700 mm), and 12 horizontal drains equipped with vacuum pumps and realized from the already excavated Eroilor 2 station and SPAI shaft.

Once the lowering of water table was reached as designed, the injection works have been carried out without using preventer system during horizontal drilling.

Taking into account the grain size of soil to be improved it was decide to use cement and chemical grouting. A special field test was performed to define the optimal grouting composition.

Regarding horizontal consolidation and its injection methods (cement and chemical), according to the results of the field test, two different types were chosen:

a first type of injection to strengthen the soil behind the diaphragms walls to be cut in order to create a solid and compact volume core;
a second type around the perimeter of excavation with the purpose to limit possible dispersions into the sandy soil of the grouting injection.

In addition, horizontal consolidation has been designed and subdivided into three different phases:

A. Horizontal drilling 12 m long, insertion of a PVC valved pipe coupled with VTR lamellar with anchor function, injection of the first 6 meters behind the diaphragms by cement (first injection) and then chemical (second injection);
B. Injection between 6 to 12 m in length by injection stept of 1 meter;
C. Consolidation of the space between 0–1 meters and 5–6 m by injections of acrylic solutions: this action was done to have the effect of confining the consolidated soil in step A as a plug, also considering the preexistence of compartment injections around the dismantling zone.

Once executed all the demolition operations, it was positioned the equipment thrust for TBM departing from Eroilor 2 station.

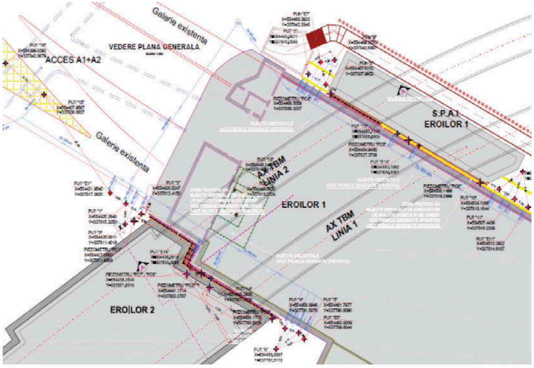

Figure 5. Well location around Eroilor I.

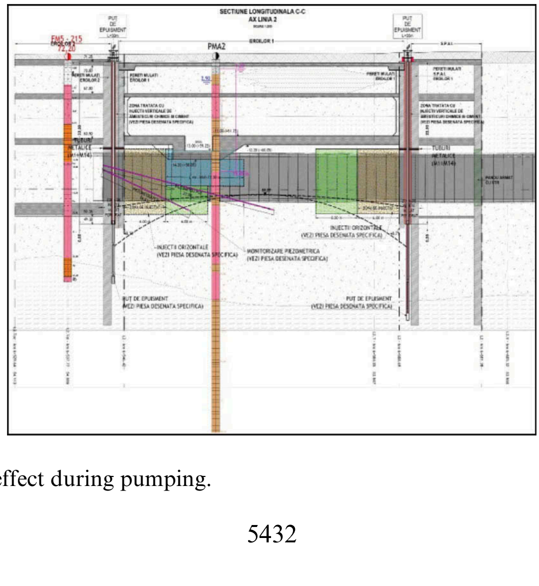

Figure 6. Dewatering effect during pumping.

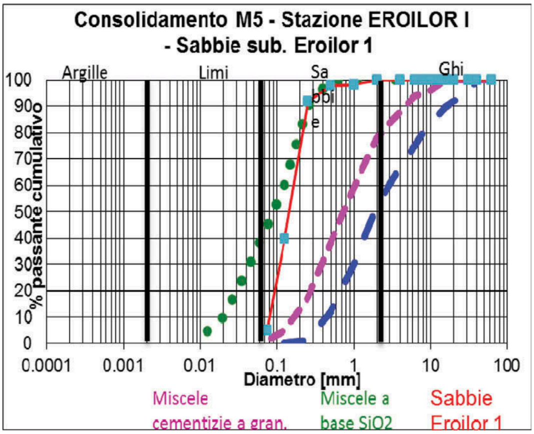

Figure 7. Cambefort curves.

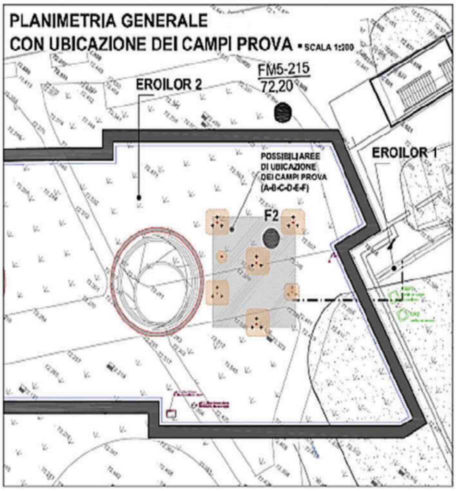

Figure 8. Trial test location.

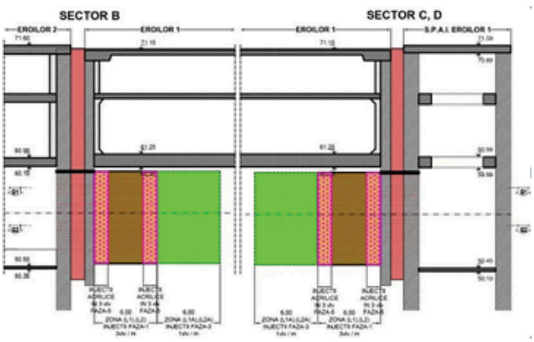

Figure 9. Longitudinal profile of grouted zone.

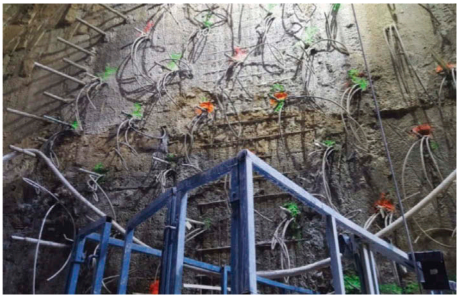

Figure 10. Injection phase.

Figure 11. Diaphragm wall after cutting.

Figure 12. Diaphragm wall during cutting.

4 DESIGN STUDIES AND SETTLEMENT PREVISION

A series of analysis by 3D Fem model were performed to evaluate the stress and deformations status induced by TBM passing on the existing structures. The stress strain state of the whole area interested by the TBM excavation was verified using 3D model in order to simulate the interaction effect during cross passage of TBM.

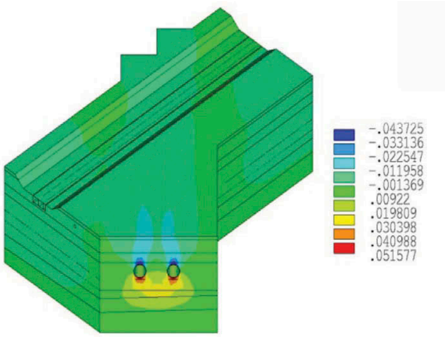

Figure 13. Analysis results.

5 MONITORING SYSTEM

In the same time a sophisticated ad intense monitoring system was placed at level of platform of Eroilor 1 station and on the rails.

The monitoring system has provided essentially

- Measures of deformation of structures using Optical targets, miniprism and crackmeters
- Biaxial clinometers
- Levelling of rails
- H-level monitoring system
- Monitoring of ground water

The result were very positive and showed maximum settlements lower than 1 cm (8mm). The two TBMs have crossed the station in 21 days.

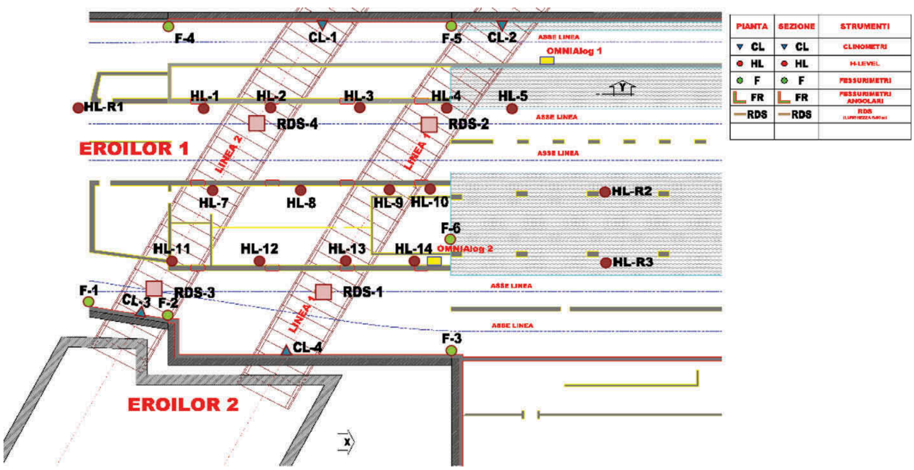

Figure 14. Monitoring plan.

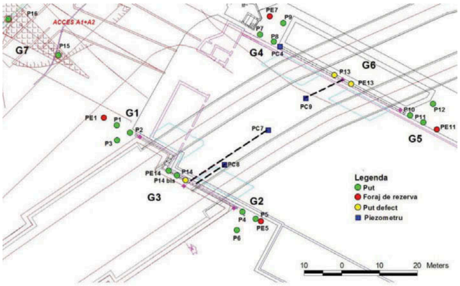

Figure 15. Dewatering wells.

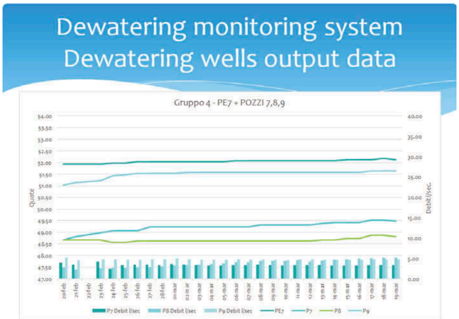

Figure 16. Ground water lowering (TBM invert az z = 52).

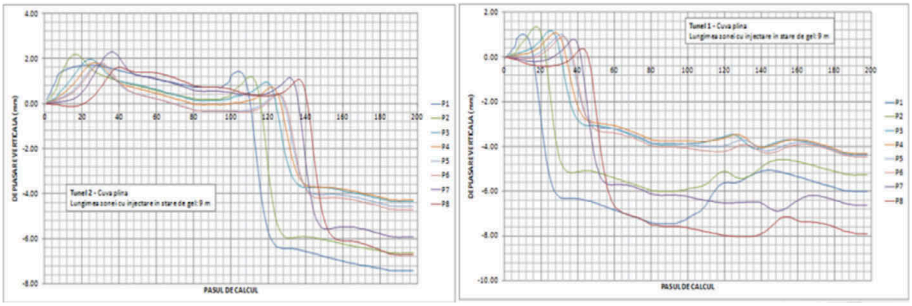

Figure 17. Maximum settlement and recorded stress.

6 CONCLUSION

The underpass crossing of the station Eroilor I was a classic example of geotechnical engineering that only through the improvement of the soil it was possible to complete. Injections of cement and chemical grout and an efficient dewatering have allowed to carried out the complex work in safe conditions and by the scheduled deadline.

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