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Milan M5 Metro Extension: The “Strange Case” of Lotto Station

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Abstract: This paper describes the construction of a deep station during the work on the extension of Metro Line 5 in Milan, Italy. Operating in an urban context that included the presence of an existing line (Milan Metro Line 1), the work had to grapple with some very particular problems so as not to interfere with the area’s normal city life. Several construction choices and technical solutions were adopted to reduce impacts as much as possible and to suit local needs (hydromill diaphragm walls, top down and bottom up techniques, protected TBM (tunnel boring machine) break-in by false tunnels, precasted and casted solutions for internal structures and construction management, etc.). The contribution points out the attention to the issues that make this activity so particular for excavation, ground support and structural solutions, and also for the split between civil and tunnel works carried out simultaneously on the same site. Underground context, consisting mainly of sands and gravels with presence of water, is shortly presented also in terms of geotechnical parameters.

Key words: Construction management, underground, metro, top-down, precasting.

1. Introduction

In these pages, we present a contribution linked to the “strange case” of the Lotto M5 station, built in the framework of the extension of Metro Line 5 in Milan (Fig. 1). With respect to the other stations of this line, Lotto M5 presents some particularities that, because they were present along with others, required a delicate series of stratagems.

In general, the zone chosen for its construction is very urbanized, affected by the presence of buildings, palaces and heavily trafficked roads. The area is also located very close to Metropolitan Line 1 (M1) and the related Lotto M1 station with which there will be an interchange (Fig. 2).

These elements, together with the geotechnical context of the intervention, constituted of sands and gravels below the water table, caused the planning to be pointed in a specific direction by developing a particular construction system.

In particular, downstream of the use of interpenetrating diaphragms can be realized with a hydromill, completed by a bottom buffer of cement injections, useful elements for creating an “impermeable box” which is indispensable for being able to proceed with the excavations. It is the support system that displays a particularity. It is in fact “hybrid”, constituted at the same time of active steel anchors, metal struts and entire decks realized with top-down technique. This apparently complex result represents the synthesis of a series of different necessities. In some areas of the station, due to the presence of the M1 galleries or of the Lotto M1 station, the anchors proved not to be feasible, requiring their replacement with a system of metal struts. Beneath the water table these elements were deemed incompatible with the construction on account of the time and technology needed to proceed in a suitable manner. In this case, they were replaced by top-down decks, realized during the descent phases and connected directly to the perimeter diaphragms.

Given the dimensions of the station, these decks could not be supported solely with the system of the

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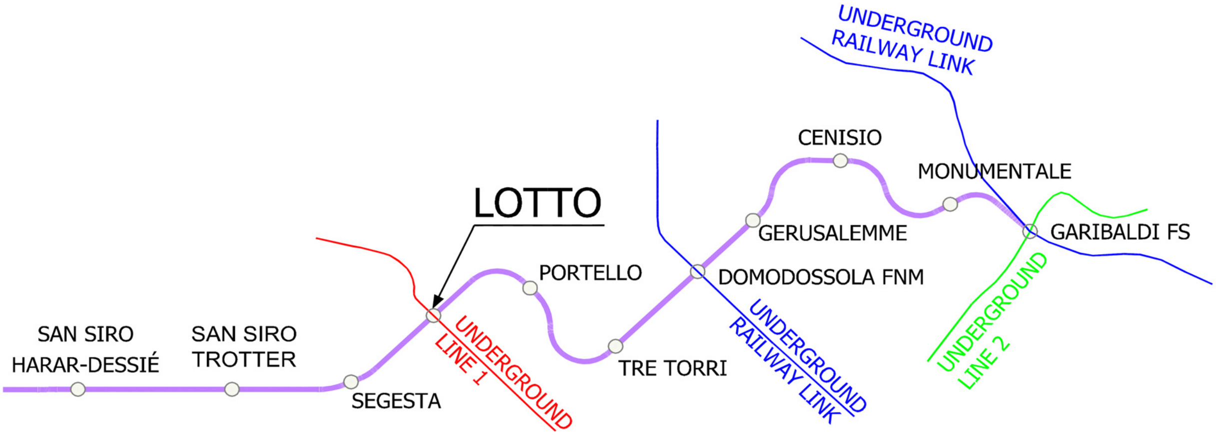

Fig. 1 **Overview of Lotto station on Line 5 extension.**

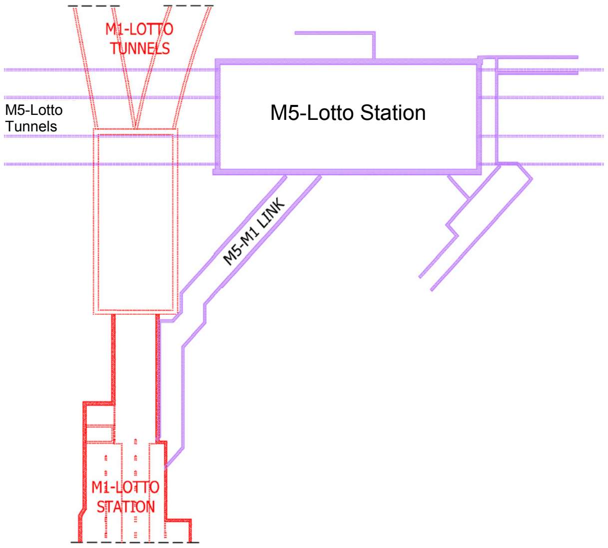

Fig. 2 **Schematic layout of Lotto stations and tunnels (plan view).**

perimeter compartments, however, by exploiting diaphragm technology, the work therefore proceeded with the installation of suitably positioned and founded metal pilasters.

Lotto M5 station has a particularity also for what regards the entry of the two TBMs (tunnel boring machines). Corresponding to the side foreseen for this break-in, there was no possibility of carrying out, unless partially, an adequate soil consolidation and waterproofing treatment. This buffer, necessary to keep the groundwater from entering the body of the station, in fact constitutes a zone in which the machine is protected, avoiding that break-in puts the interior and exterior of the station into hydraulic communication.

Given the situation, two false tunnels were excavated, temporary structures useful in the same way for protection of the machine in the entry phase but built inside the body of the station. The false tunnels are watertight reinforced concrete sheaths able to accept the advance of the machine while resisting the working and hydraulic pressures linked to the presence of the groundwater. Their length is such as to allow the rings mounted by the TBM behind its body to be adequately seated in the perimeter diaphragms of the station, thus preventing any hydraulic communication between the interior and exterior of the station and achieving the same result as the buffer system described earlier.

For the machines’ break-outs, the chosen system was instead that of external buffers, given the absence of particular interferences and the big advantage, in this case, of being able to proceed with their realization independently of the works in the station. Indeed, it is evident that construction of the false tunnel is possible only with the station completely excavated and partially realized.

Below, the themes proposed here are illustrated and discussed case by case.

2. Method

Lotto M5 station is the deepest on the entire Metro Line 5 (approximately 30 m from ground level to the excavation bottom) and constitutes an interchange with Line 1 (Fig. 3).

From the realization standpoint, the excavations were supported by reinforced concrete diaphragms with both short and long term uses. The presence of an important hydraulic head (over 15 m) and the notable excavation depth required the use of a hydromill, a machine able to limit verticality errors and, thanks to interpenetration between primary and secondary diaphragms, ensure good water tightness. During the excavation phases, the diaphragms were supported by several rows of steel anchors and struts and by two decks realized with top-down technique. In the long term, the diaphragms are supported on the totality of the definitive decks.

Base waterproofing was ensured by means of a series of injections, while adding to the ground a mix of water, concrete, silicate and bentonite. The base slab of the station is connected by means of shear keys to the diaphragms, which, in addition to the weight of the station's internal structures, have a stabilizing function in relation to any long-term floating phenomena.

3. Geotechnical Conditions

The context in which the work took place, simply represented in Fig. 4, consists basically of sands and gravels (Levels 1 and 2) in the presence of the water table, even if also silty sands (Level 3) were found during the survey phase. The characterization of the materials in the zone is fairly well known because the city of Milan already has three metropolitan railway lines, an urban link railway line and a large variety of underground structures for different uses. For design and calculation purposes, the underground context has been defined as described in Table 1 and 2.

The law that allows to deduce the value of Young's modulus for Levels 1 and 3 in MPa is, as an indirect function of the depth, defined as:

$$E = 1{,}000\, P_a\, (\sigma_3/P_a)^{0.5}$$

where,

P_a: atmospheric pressure in MPa;

σ_3: horizontal stress in MPa.

Table 1 Design parameters for cohesion, angle of friction and Young's modulus.

Level	c' (kPa)	ϕ' (°)	E (MPa)
1	0	35	see text
2	20	22	30
3	0	37	see text

c': cohesion;

ϕ': internal friction angle;

E: modulus of elasticity or Young modulus.

Table 2 Design parameters for natural weight and Poisson's ratio.

Level	γ (kN/m^3)	ν (-)
1	18	0.3
2	19	0.3
3	19	0.3

γ: natural soil weight;

ν: Poisson's ratio.

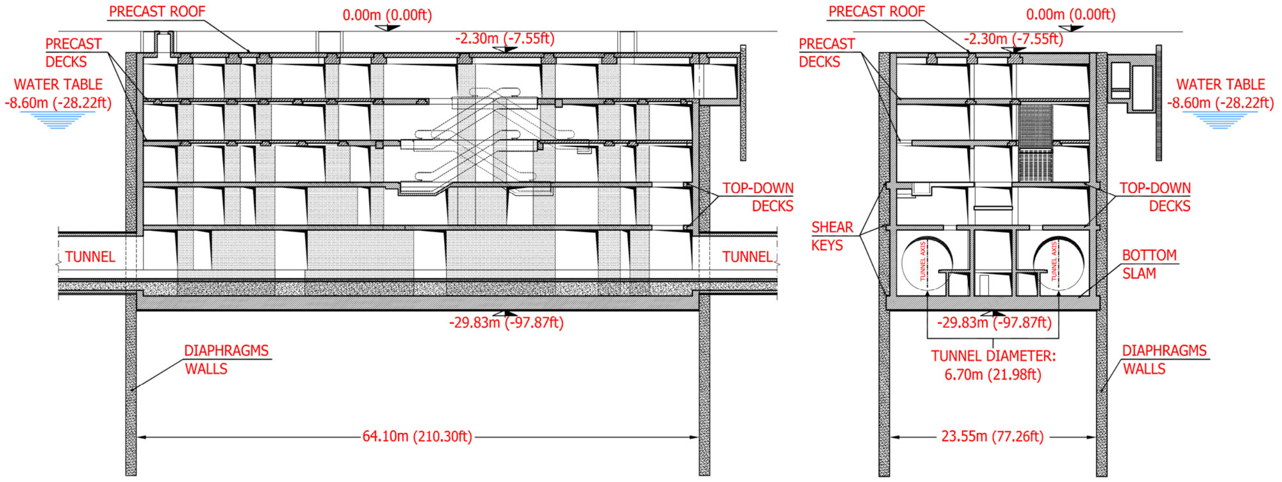

Fig. 3 Longitudinal section and transversal section.

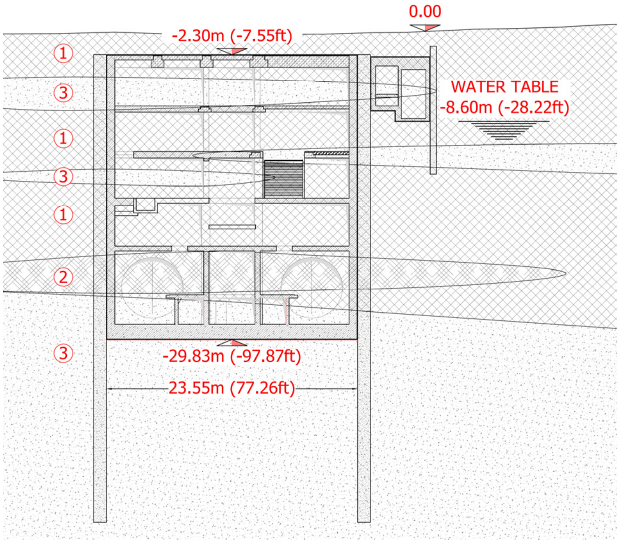

Fig. 4 **Transversal section with geotechnical layout.**

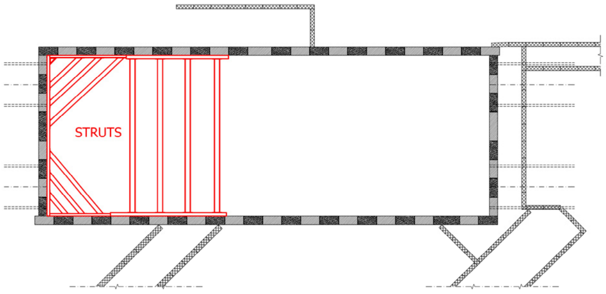

Fig. 5 **Struts plan.**

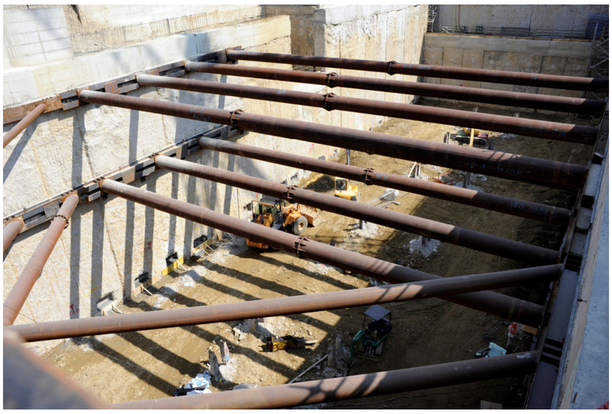

Fig. 6 **Struts system.**

4. Particular Design Aspects Linked to the Urban Context

As mentioned in the introductory section, some design choices resulted from the insertion of the work in a densely urbanized context characterized by important pre-existing underground structures, constituted for example by the existing Lotto M1 station.

4.1 Two-Level Struts

The presence of the M1 section adjacent to the new station did not allow the realization of anchors for at least a third of the perimeter. As shown in Fig. 5 and 6, in this area, the anchors were replaced with metal struts. These struts have spans of up to 23 m and diameters of up to 90 cm (slenderness 70-110).

In addition to the usual operational difficulties connected with the realization of the bottom-up casting of the internal structures (e.g., interruption and resumption of reinforcement and pouring of the cavity walls beneath every row of struts), it was a contractual requirement to contain the realization times (Fig. 7).

This aspect led to the use of prefabrication technology for the three foreseen bottom-up decks.

4.2 False Tunnels inside the Station

At the entrances and break-outs below the water table of the TBMs from the stations (Fig. 8), soil treatments were carried out behind the pilings aimed at reducing the permeability. In order to avoid water inflows in the entrance/break-out phase, the plugs must be sufficiently broad, in the longitudinal sense of the station, to enable assembly of at least one segment ring before the cutter head goes beyond the grouted face. In many cases of excavation in urban environments, it is

Fig. 7 **Excavation phase.**

Fig. 8 TBM break-in from the Lotto station.

not possible to execute a complete treatment because of interferences with existing buildings or roads. To get around this problem, in the Lotto station worksite it was decided to make false tunnels, thus shifting the entry/exit phase of the cutters laterally within the station (Fig. 9).

The dimensions of the concrete blocks that constitute the false tunnels were derived as a function of those of the TBM, and the circumferential framing support for containing the radial pressures of the machine in the thrust phase is disposed externally with respect to the footprint of the shield. To avoid slippage and raising, the false tunnels are connected to the base slab by means of ribbed bars.

For waterproofing in the break-in and break-out phases of the cutters in the station, the advantage that the presence of the false tunnels offers inside the station is that of being usable in the presence of a partial treatment of the soil behind the pilings.

On the other hand, this temporary protection work presents the disadvantage of having to be demolished in any case since it interferes with the architectural layout of the station.

4.3 Separation Worksite Shaft/M1 Connection

A further aspect linked to the surface traffic regards the separation, also at the level of preparatory works, between the construction phases of the station shaft with respect to the exits and to the connection with the M1, which in other situations presenting less interference has not been necessary.

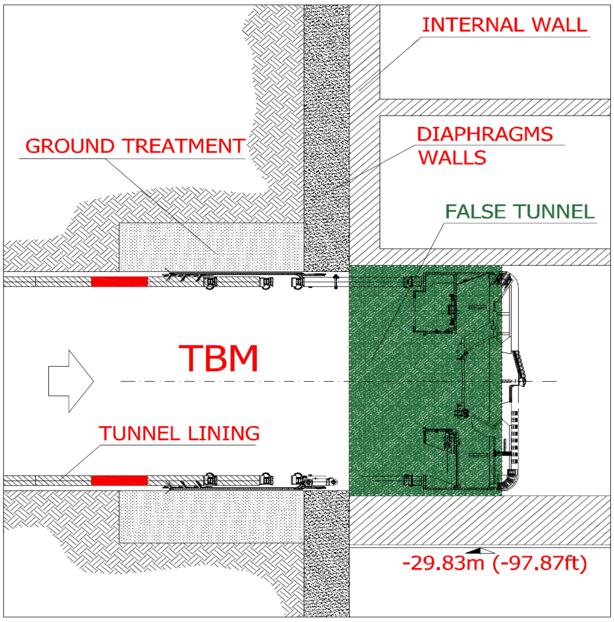

Fig. 9 TBM break-in.

In the case at hand, the internal structures of the station shaft, up to the pouring and the backfilling of the roof, were planned so as to divert the traffic on the station. This will make it possible to open the worksite in the adjacent area and to excavate the connecting corridor to Lotto M1 between pilings. Placed between the two structures, the station and the connecting corridor is a piling of reinforced concrete diaphragms that will have to be cut and demolished to open the connection. The choice of separating the work made it necessary to reinforce the piling, even if subject to future demolition.

5. Particular Design Aspects Linked to Worksite Requirements

The economic/organizational requirements of the worksite often affect the construction design of an infrastructure work. This section describes some design choices adopted as valid solutions to these problems.

5.1 Steel Anchors Head above the Water Table

The level of the water table in relation to the depth of the excavation often requires anchors with submerged head. In these cases, it is necessary to use a more sophisticated drilling technology than that which makes it possible to realize anchors above the water table.

For this reason, the implementing enterprise requested that an alternative solution to the anchors be studied, which led to the use of a mixed top-down method (Fig. 10). By this, we mean that the decks realized in the first phase, together with anchors above the water table and struts, are part of the horizontal contrast system of the pilings. In addition, in this context, the top-down method was not used in the classic sense which calls for covered excavation. Indeed, intermediate floored retaining walls subject to an important state of membrane and bending stress are realized.

5.2 Top-Down Decks: Opening Sizes and Pouring Phases

The top-down decks of the Lotto M5 station have a short-term function as horizontal contrast for the pilings, and a long term one in which the slabs are subject to heavy gravitational and horizontal loads. This dual function determines a different load condition and a different geometry of the holes in the short and long term.

In this case, the enterprise requested larger opening sizes for lowering materials and machinery for service into the station worksite and the TMB worksite (Fig. 11). The construction system used gave the possibility of a separation of the TMB and station worksites. In this way, the activities were conducted simultaneously without interfering with each other.

To make the opening sizes conform to the architectural layout, pourings in the subsequent phase were necessary, connected to those of the first phase by means of mechanical joints (threaded/sleeved bars).

Temporary metal struts were placed in critical zones of the slab for more effective redistribution of the membrane stresses generated by the thrusts of the earth and water on the diaphragms.

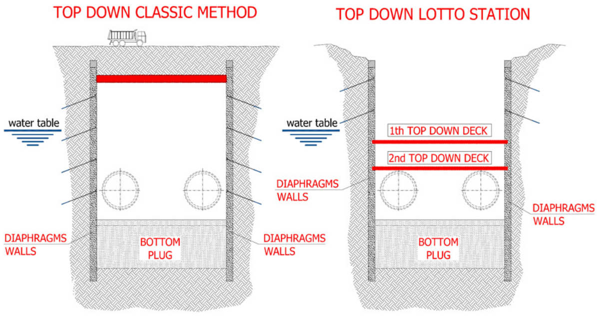

Fig. 10 Top-down classic method vs. top-down Lotto M5 station.

Fig. 11 Top-down decks: opening sizes.

5.3 Precasted Decks

In order to speed up the delivery times of the work, the executing enterprise chose the prefabrication solution to realize three floors of the Lotto M5 station, including the roof (Fig. 12). The floors are constituted of prefabricated concrete beams reinforced with non-prestressed reinforcement and of slabs, lightened or solid according to the structural needs. The beams rest on the pilasters, dividing walls and supporting walls realized in the work. Structural requirements

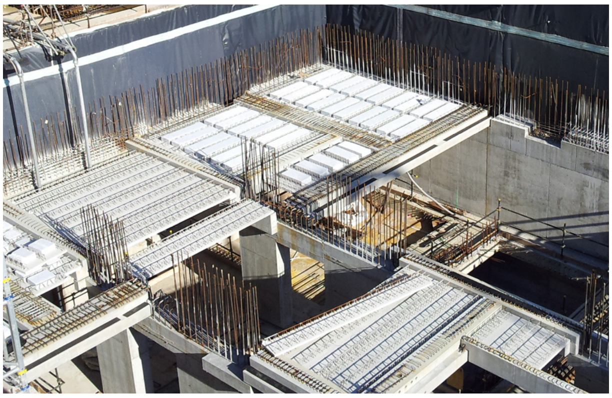

Fig. 12 **Assembly phases of beams and slabs.**

linked to the geometric complexity of the floor in the area of the side escalators made it necessary to realize some portions of floor during the work.

5.4 Metal Columns Encased in Concrete Pilasters

The top-down decks were supported in the short term by metal struts founded on reinforced concrete diaphragms (Fig. 13) realized at the same time as the perimeter pilings. The beams are encased in lean concrete, removed in the excavation phase.

All the metal elements were calibrated so as to be kept inside the reinforced concrete pilasters definitively, although not being considered long term for resistance.

6. Conclusions

The "strange case" of the Lotto station required a particularly complex planning and decision-making process. Starting from the preliminary study, it was necessary to evaluate all the technological requirements, comparing them with the builder's requests. A particularly important role was played in this by the general timing and especially the integration of the schedule of the work on the station with that of the tunnel system. This subject is a particularly delicate one, considering that the construction works inside the station were coordinated with the TBM break-ins and break-outs, with an extensive presence of plants and conveyors for mucking, and with particular attention to safety and control.

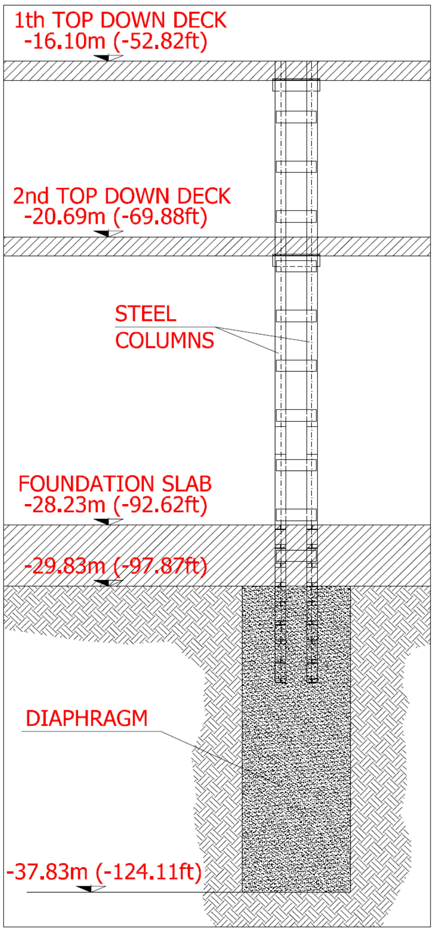

Fig. 13 **Metal support columns-scheme.**

Once all the main concerns were identified a synthesis was made, followed by a proposed solution which led to the construction of the work in a fast-paced process of discussion and eventual agreement on the choices.

In short, the Lotto M5 station represents a good example of a work in which the various passages that lead from the initial idea to construction were followed with success to overcome the many difficulties present. The structure, as described extensively in the foregoing pages, has a number of particularities linked to its inclusion in a dense urban fabric, the presence of a running metro line, the context of excavating in the presence of ground water, and work times which overlapped the tunnel digging activities with those of realizing the interior structures.

As known, building a metro station is one of the most complex and impactful activities in the area of infrastructure. The difficulties of realization, as well as the inconveniences for the population during the construction phases, were "repaid" with a very important result for the entire collectivity, a result that enables an improvement in people's lives through the mobility provided by public transport.

Bibiography

[1] G. Lunardi, G. Cassani, L. Mancinelli, Project financing in underground works: The case history of Milan's Metro Line 5, in: Proceedings of Under City Congress, Dubrovnik, 2012.

[2] R. Lancellotta, Geotecnica, Zanichelli Publisher, 1987.

[3] J. E. Bowles, Fondazioni, Mc Graw Hill, USA, 1991.

[4] L. Mancinelli, Reinforced Concrete Diaphragm Walls, Flaccovio Publisher, 2007. (in Italian)

[5] L. Mancinelli, M. Gatti, G. Cassani, Milan Metro 5th Line, in: Proceedings of ITA-AITES Association Congress, Vancouver, 2010.

[6] L. Mancinelli, M. Gatti, Ground improvement for the foundation of a high-rise building, Ground Engineering, Apr. 2013, pp. 28-32.