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The archeological evidences of the De Amicis Station in the Milan Metro line 4, Italy

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ABSTRACT: Line M4 will cross Milan with a length of about 15 km from west to east along Viale Lorenteggio, through the south of the old town and along the axes of Forlanini up to Linate Airport. The central part is very close to the historical town and the interference with the pre-existing, especially the monumental and archaeological heritage, shall be carefully investigated. In the stretch between Tricolore and Solari Stations, the metro stations are considered as "deep", reaching depths of 25-30 m below ground level: the stations layout is composed by a central shaft, with transverse dimensions about 10 m located in the main roads or parks, and lateral running tunnels, constructed using a TBM-EPB with a 9.15 m diameter which is able to be lodged inside the tunnel the stations' platforms. The "De Amicis" station is one of these; during the first excavation step of De Amicis Station, an ancient wall which constituted the Naviglio of San Gerolamo, dated back to the Middle Ages (XIII-XIV sec.) have been discovered. Some stones of the wall are from the Roman Era, probably part of a previous structure, reused as a "quarry". The relevance of these findings, located close to the Pusterla area, one of the secondary entrances of the city, forced to modify the layout of the station to create a museum space to host the ancient wall in its original position. The paper describes the "deep station" project, with construction details, and the solution adopted to exhibit the archaeological evidences.

1 INTRODUCTION

The paper deals with the construction of the De Amicis Station of the M4 Underground Project in Milan. After a general description of the entire M4 project, it will be presented the original De Amicis project, designed considering existing buildings and roads before any type of excavation, and the variation project, defined after first excavations and the finding of an old wall, related to the ancient Naviglio of San Gerolamo dated back to the Middle Age (XIII-XIV sec.).

The variation project has been defined in order to valorize the particular finding; for this reason, almost the entire layout of the station has been modified. The paper will also provide information about the management of the finding regarding especially the removal of the ancient wall. The construction works are performing by the "MetroBlu" consortium, composed by Astaldi and Salini-Impregilo.

2 METRO LINE M4

The construction of the new M4 (blue) line, managed according to the project finance formula, has been divided into three different sections. The first section will link Milan Linate airport to the Forlanini railway station and then to the Tricolore Station. The second section will connect the Tricolore Station to Parco Solari Station. The third section will connect San Cristoforo railway stations to section two. The new metro line will link the eastern and western parts of the city and its construction will be completed by 2022. The line has altogether

21 underground stations and will have a total length of 14.2 km. The running tunnels will be bored using six EPB TBMs: 4 TBM for the two single-track tunnels with diameters of 6.5 m for the sections outside the city centre (2 from east and 2 from west). The central part of the track will be constructed using two 9.15 m diameter EPB TBMs, to include the platform for the subway stations.

2.1 *The project*

Line M4 will cross Milan with a length of about 15 km from west to east along Viale Lorenteggio, passing south of the old town and along the axes of Indipendenza, Argonne and Forlanini up to Linate Airport (Figure 1). The M4 route will optimize city coverage, loading options, and interconnection with the metro and suburban rail network, thereby improving the overall network effect of the entire public transport system in the city.

Line M4 will be a "fully automated light rail" system, driverless, and with automatic platform doors and a CBTC (Communication Based Train Control) signalling system. The trains will be 50 m long, considerably shorter than rolling stock in circulation today. Likewise, the 50 m long stations will also be shorter than the 110 m stations on lines M1, M2 and M3. The relatively compact dimensioning of the structures, particularly the stations, means that construction work on the line can be carried out more easily and with less impact. The automation of the system will ensure higher frequencies for the vehicles (90 seconds, theoretically reducible down to 75) providing the capacity to transport 24,000 to 28,000 passengers per hour per direction. The new line M4 will pass through neighbourhoods with high population densities, so the construction methods have been planned to minimize impact at the surface and adapt to an underground affected by a great amount of infrastructure and by the presence of a significant amount of water. The extensive use of mechanized tunnelling, and the selection of a single-track twin tunnel layout help maximize the flexibility and adaptability of the route, which is situated entirely underground except for the depot/office area. There are currently two interchanges with existing Metro lines, one with the red line at San Babila station, and one with the green line at S. Ambrogio station. In the future, there will be three interchanges with suburban railway lines, one with Lines S5, S6 and S9 at Forlanini FS station, one with Lines S1, S2, S5, S6, S13 at Dateo station, and one with Line S9 at San Cristoforo station, where there is also a connection to the Milan-Mortara railway. Lastly, an interchange with Linate airport is planned.

Most of the underground construction on the route will be carried out by mechanized tunnelling with the use of two TBM geometries, one with a bored diameter of 9.15 m and the other with a bored diameter of approximately 6.36 m. The TBMs with diameters of

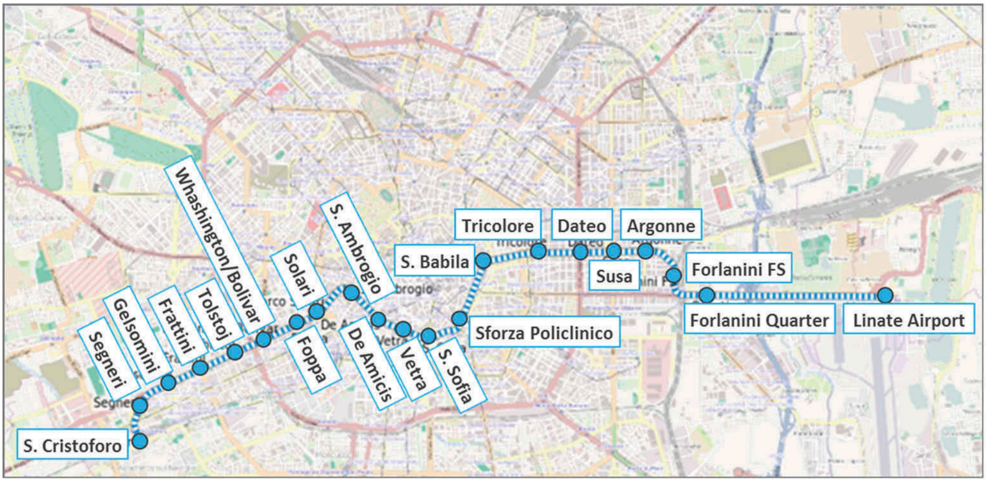


Figure 1. Metro Line 4 Layout.

approximately 6.36 m will be used for the sections from Manufatto Ronchetto, in the San Cristoforo area, to the Parco Solari station and from Linate Airport to the Tricolore station. The TBM with a diameter of 9.15 m will be used for the section from the Parco Solari to the Tricolore station. As indicated, the machine with a diameter of 9.15 m will be used in the section through the deep stations in the historic centre in order to enable the installation of the station platforms directly inside the inner contour of the tunnel in segments. This allows a considerable reduction of the impact on existing structures compared to the use of conventional methods of tunnel excavation, after performing consolidation work (Lunardi 2017).

2.2 *Running Tunnels*

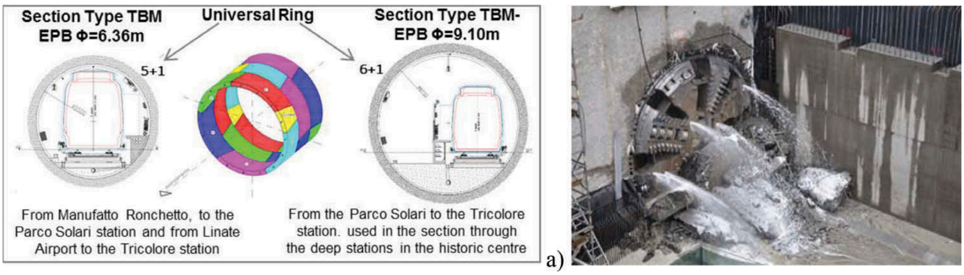
The running tunnels for Line M4 of the Milan Metro will all be constructed using EPB (Earth Pressure Balance) TBMs. The final lining of the tunnel will be made of precast segments placed by the machine immediately after excavation at a small distance behind the face. The ring for the 6.36 m diameter tunnels is composed of six segments (5 + 1 keystone) with a thickness of 28 cm. That of the 9.15 m tunnel is composed of seven segments (6 + 1 keystone) with a thickness of 35 cm (Figure 2.a).

The final lining, in addition to performing and ensuring the normal function of support in both the short and long term, must also provide the required hydraulic seal. For this reason, the segments are fitted with watertight neoprene seals along all surfaces in contact with other segments, and arranged in corresponding housings on the sides of the segment, to ensure the required water-tightness under hydrostatic pressures with the planned clamping forces. In order to ensure water-tightness between the segments of adjacent rings, as well as for reasons of safety during the transitory phases of handling and laying the segments themselves, the connection is provided by means of longitudinal mechanical dowels (Biblock System or equivalent type) arranged at regular intervals around the circumference.

The 6.36 m TBM is equipped with 16 thrust plates arranged in groups of three for each segment plus one for the keystone, or a total of 32 jacks acting in pairs on each plate. The dimensions of the plate are 26 × 70 cm. The maximum thrust that the machine can exert is equal to 42,575 kN or 2,660 kN per thrust group. The 9.15 m TBM is equipped with 19 thrust plates arranged in groups of three for each segment plus one for the keystone, or a total of 38 jacks acting in pairs on each plate. The dimensions of the plate are 33 × 100 cm. The maximum thrust force that the machine can exert is equal to 81,895 kN or 4,310 kN per thrust group (Lunardi, 2017).

2.3 *Stations*

For the construction of stations and structures, the planners tried to resort as much as possible to the open excavation method supported by reinforced concrete diaphragm walls (open bottom-up method), which is compatible with the existing road network and construction site areas required for the execution of the works. This type of construction is applicable in the Linate–San Babila axis since the bodies of the stations are manufactured within the central



b)

Figure 2. a) TBM Sections type; b) Forlanini Railway Station: TBM breakthrough odd track.

parterre of the boulevards, minimizing interference with road traffic while providing sufficient construction site areas. The same type of construction will also be used for the stations on the San Cristoforo–Parco Solari section, with the exception of Gelsomini and Segneri stations, for which totally or partially closed bottom-up methodology is planned.

The Line 4 stations, with the exception of those in the central section, generally have a limited depth of about 15 m, through which the two TBMs pass “unloaded”. The level of the floor slab thus remains occupied by the TBM supply site comprising the rails for trains transporting precast segments, conveyor for transporting the muck out of the tunnel, hoses for cooling water and a medium voltage cable for the TBM power supply, for each of the two machines (Figures 3a, b). The use of semi-precast self-supporting structures is planned constructing the horizontal elements of the station. The supporting structures for the excavations, bulkheads, tie rods, and bottom sealing blocks, will be installed by means of clamshell excavation and stabilized with bentonite slurry, tied with anchors outside the aquifer and bored without the use of a preventer and bottom buffers in integrated cement injections.

The stations considered as “deep” are Sant’Ambrogio (Figure 4a), De Amicis, Vetra, Santa Sofia, Sforza Policlinico and San Babila. The functional installation is composed of a central

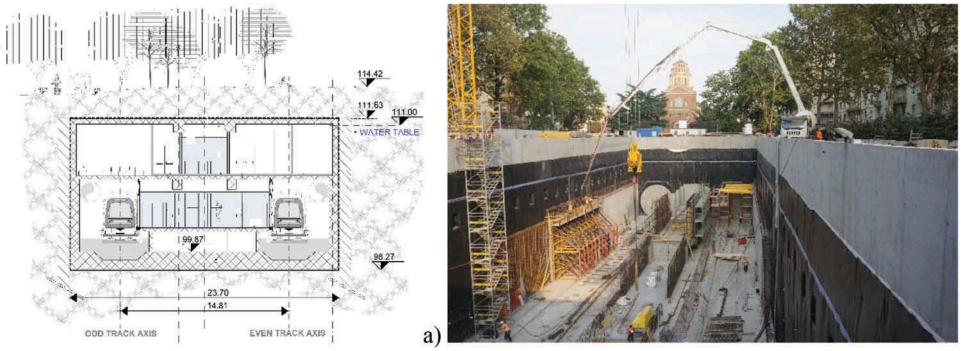


Figure 3. Argonne Station: a) Detail of the reinforced concrete piling; b) general view.

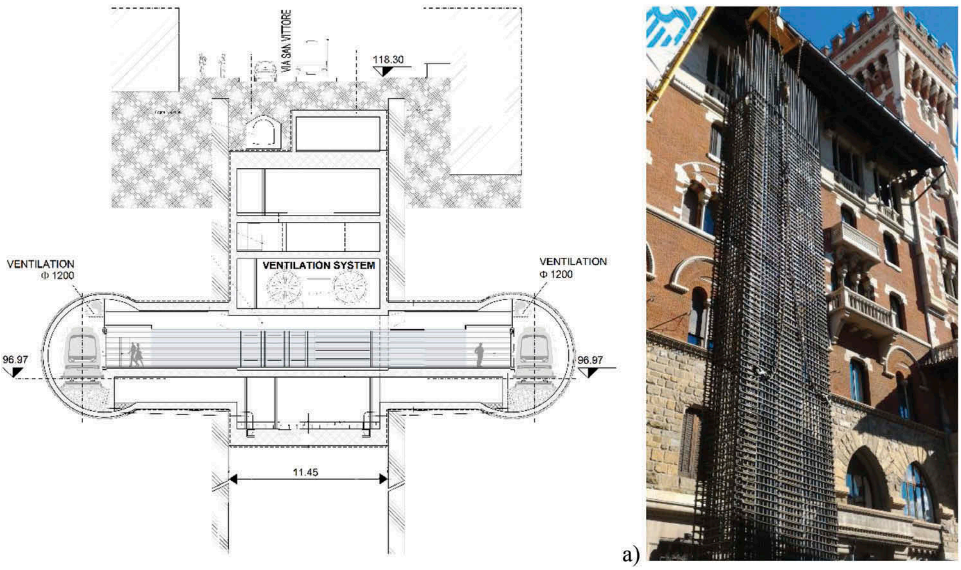


Figure 4. a) Sant’Ambrogio deep station - interconnection with Line 2; b) detail of the reinforced cage.

shaft with an excavation depth up to approximately 30 m and transverse dimensions limited to approximately 10 m. Outside this, running tunnels are constructed using a TBM with 9.15 m diameter, which is sufficient to accommodate the platforms of the stations. The station have been excavated by means of lateral retaining walls, represented by RC diaphragm, supported by anchor or steel frame (locally by slabs, for top-down system) and with a grouted plug at the base able to prevent water inflow. This plug for the deep stations are pushed to a consistent depth below the bottom of the excavation, up to 16–17 m, bringing the total length of the retaining walls up to approximately 50 m, with a lot of construction problems (connections for reinforced cages, amount of reinforcement, Figure 4b). The connecting bypass between the station shaft and the platforms will be excavated after the soil has been grouted from ground level with the continual use of cement and silicate mixes (Lunardi 2017).

The project included an analysis of the interference between the excavations of the running tunnels with the surface buildings and structures. The subsidence basin were evaluated in detail relatively to the excavation. Furthermore, the subsidence/displacements were determined at ground level as well as at the level of the foundation, assessing the damage class expected for each building. In subsequent stages of the project, on the one hand, the interference analysis will be more highly developed with numerical analysis methods, and on the other hand, the detailed findings for some of the buildings in the area of the subsidence trough will be completed.

2.4 *The interferences*

The hazards associated with the tunnel construction in urban areas include poor ground conditions, presence of water table above the tunnel, shallow overburden and ground settlements induced by tunneling with potential damage to the existing structures and utilities above the tunnel. A fundamental aspect of metro line design is the evaluation of the excavation interference (Cassani, 2005; Mancinelli, 2009). In case of M4 metro line a study to assess the interference between underground excavations and the existing buildings has been developed. The excavation takes place with a mechanized system, adopting an EPB type TBM. The subsidence basins and the settlements related to the excavations have been evaluated to assess the expected damage class for each building.

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3 DE AMICIS STATION & THE AERCHAEOLOGICAL FINDINGS

One the deep station is located at De Amicis Street. During the first phases of construction of this station, realizing the guidance structures for diaphragms excavations, an ancient wall dated back to the Middle Age (XIII-XIV sec.) has been found. These findings forced to revise the station layout as described in the following. Preliminary to the intervention description, a brief historical review and a description of the archeological findings are proposed.

3.1 *The archaeological finding of the M4 Line*

The central section of the M4 line between S. Babila and S. Ambrogio stations touches locations of major importance for the historical memory of Milan, following the periphery of the Roman city of Mediolanum and meeting the city walls, the major roads out of the town, the early Christian basilicas and the cemeteries.

Particularly in the sites of these two stations, S. Babila and S. Ambrogio, touching testimony of the identity and history of the inhabitants of two millennia ago came to light: tombs of men, women and children containing objects of daily life, preserved intact a few feet below today's streets and pavements.

Around the stations of S. Sofia, S. Calimero and Vetra, traces were discovered of the complex network of canals and bridges. Near of the De Amicis station, close to Piazza Resistenza Partigiana, mediaeval defense works were recovered together with a bridge over the historical S. Girolamo canal.

The most touching testimonies that reveal the identities and stories of two thousand years ago emerged in the construction sites of the San Babila and Sant'Ambrogio stations: tombs of men, women and children, sometimes buried with a trousseau that has been preserved intact at a shallow depth, under the sidewalks and roads that people tread daily. While the work on the construction site of the S. Ambrogio station were in progress, in the sites for the maintenance of the "TBM", located in the churchyard of San Vittore al Corpo and the Basilica of S. Ambrogio archaeological excavations unearthed some burials (Figure 5), expected on the basis of the archaeological surveys. The churchyard of San Vittore al Corpo was the location of an Imperial Mausoleum dates back to IV sec. and usually around the Mausoleum were buried the important persons of that time.

Another important archeological item is the Milan historical water system, which was developed since X-XI century b.C. during Middle Ages period. It had principally defense function and it was also used for commercial reasons. The water system later developed and increased its extension but principally it kept the same geometry until the coverage of XX century, after 1929 (Lunardi, 2018).

The first layout of Navigli also included the zone of the actual Carducci and De Amicis streets. On De Amicis Street, the ancient Roman brick wall has been discovered and it seems that it was part of the ancient water course of the Medieval Naviglio, the Inner Circle of Navi-gli ("Cerchia interna dei Navigli"). Figure 6a represents the Milan's Medieval Map and of its water courses: Figure 6b shows the actual position of the De Amicis Station and it can be seen that it's positioned just over the ancient Naviglio of San Gerolamo, from Carducci to De Amicis Street and continuing on Santa Sofia Street.

Photos taken at the beginning of the 20th century shows the road axe Carducci, De Amicis and Molino delle Armi streets with water courses still open could help knowing how and where the old Naviglio was placed (Figure 7a). Figure 7b is a street view of the actual situation.

Figure 5. San Vittore al Corpo churchyard: a) archaeological excavations; b) archeologist compiling the anthropological data sheet; c) unearthed burials.

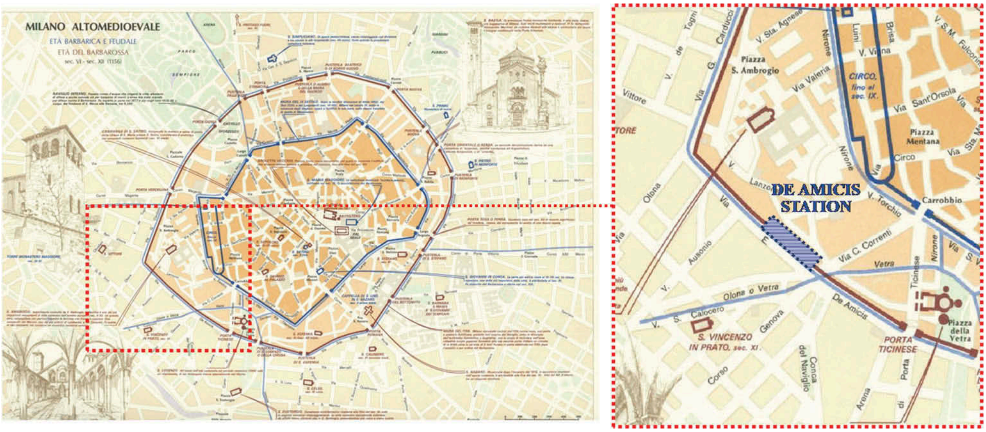
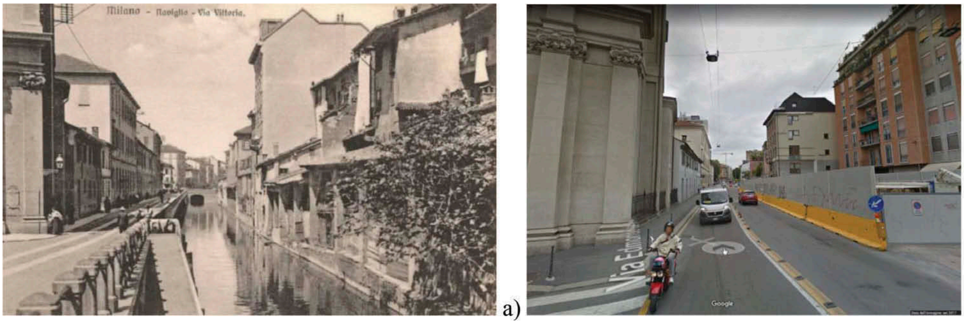


Figure 6. a) Medieval map of Milan and of its water courses X-XII century b) detail view with the overlap of the De Amicis Station.



a) b)

Figure 7. Road axe Carducci, De Amicis and Molino delle Armi a) at the beginning of the 20th century b) street view of the actual situation.

3.2 *The original station design*

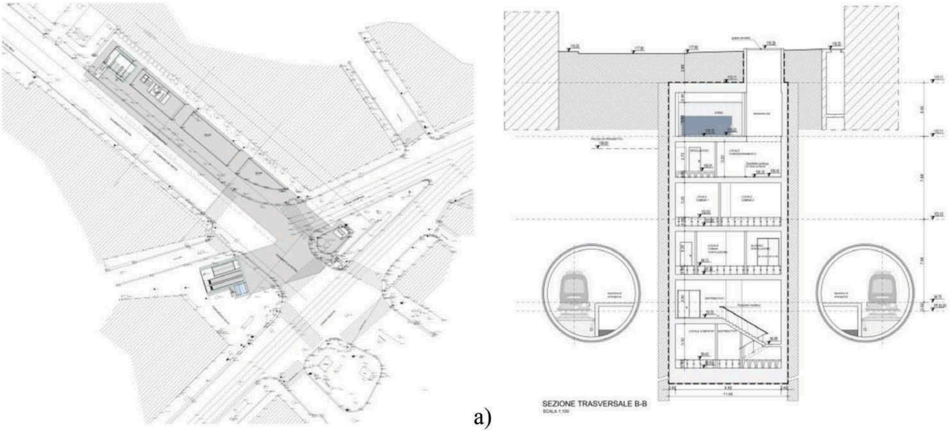
De Amicis Station is located in the central part of the M4 track along via De Amicis close to the crossing between via Correnti and Corso Genova (Figure 8a). The station is approximately 70 m long and 12 m large for a medium depth of 30 m. The tunnels are approximately 25 m deep.

The station is realized between concrete diaphragms wall 40-42 m long, 1 m thick. The construction is realized initially, after few meters of excavations, by the cast of the concrete top-slab of the station. Then, 4 orders of steel struts and perimetric beams are provided in order to reach the bottom of the station. Afterwards, the base floor is casted and, going towards the surface, all the other floors, removing each order of steel retaining structure (Figure 8b).

3.3 *The Ancient Roman wall & station design revision*

During the excavation for diaphragms of De Amicis Station, an ancient wall dated back to the Middle Age (XIII-XIV sec.) has been found. The wall belonged to the Naviglio San Gerolamo and an initial analysis of the mortar dates back to a period between the thirteenth and sixteenth centuries (Figure 9).

The importance of its discovery lies in the particular techniques with which it was built and in the position in which it was found, at the height of the Pusterla: one of the secondary accesses to the city. The roman wall was an unexpected discovery and it will be preserved,



a) b)

Figure 8. Original project of De Amicis Station: a) layout; b) transversal section.

Figure 9. Roman wall unearthed during the excavation for De Amicis Station.

enhanced and exposed transforming the atrium of De Amicis station into a museum hall. The monument, 12 metres long and 3 metres high, will located immediately before the turnstiles, putting back in its original position inside the M4 station.

The wall has been completely removed from its original position cutting it by diamond wires (Figure 10a), waiting to came back in the same place when the station will be completed.

a) b)

Figure 10. a) Diamond wire used for wall cutting; b) Roman wall detail.

According to these findings, an archaeological revision of the station layout has been proposed. The intent of the project is hosting the historical wall in the station so that passengers can see it while attending the underground line.

For this reason, the original layout of the station has been revised defining a specific area to store the wall: from an archaeological point of view the original position of the historical find has been maintained the same (Figure 11).

In the revised project, along the De Amicis Street side, there's now a superficial body, just over the odd tunnel (Figure 12). This part of the station is realized between concrete diaphragms and internal structures are provided with a precast coverage in order to foresee different yard phases, especially related to traffic superficial deviations. During station's construction, in the last phase, after some demolitions of existing retaining structures, the

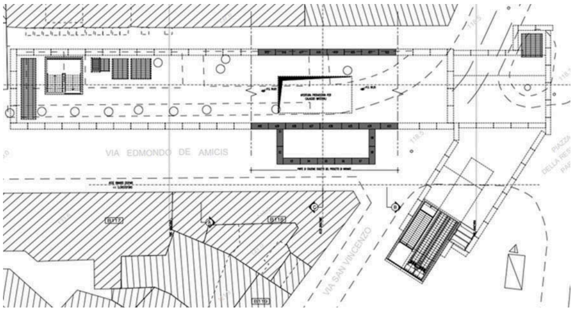


Figure 11. Plan of the revised station project.

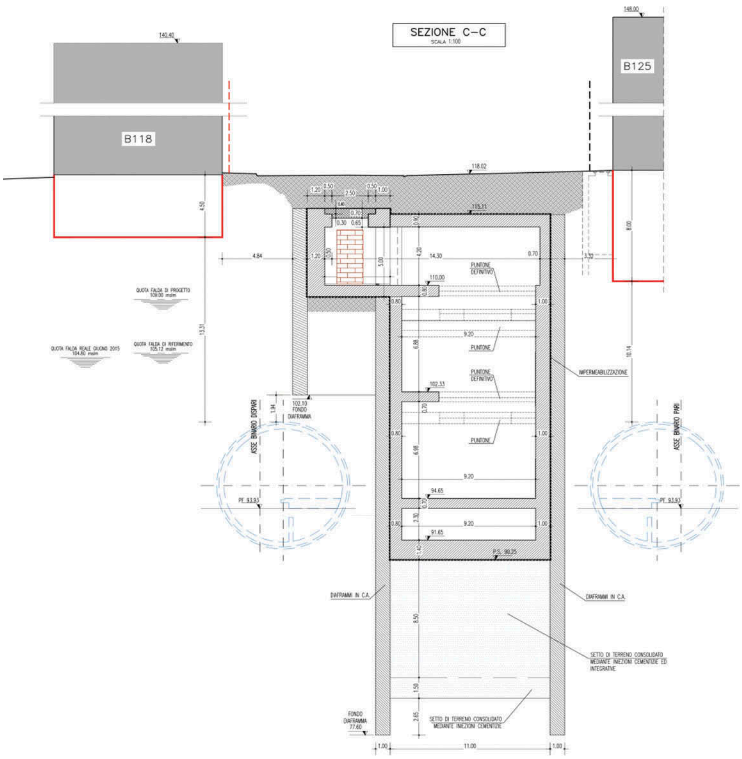


Figure 12. Section of the revised station project, with the position of the ancient wall.

precast coverage will be removed in order to place parts of the historical wall. In the following Figure 12, the revised project is presented.

4 CONCLUSION

The paper presents a general description of the M4 underground project in Milan. Some information about the alignment in its various parts, about the TBMs involved in excavations and about underground stations are also reported.

The central part of the M4 line interests the downtown of the old city of Milan and archeological findings were found during the investigation period and the first time of construction. This especially between S. Babila and S. Ambrogio stations, which touch locations of major importance for the historical memory of Milan, following the periphery of the Roman city of Mediolanum and meeting the city walls, the major roads out of the town, the early Christian basilicas and the cemeteries. Another important historical item is water system, which was used for defense function and for commercial reasons.

A significant archeological finding is located at the site of the De Amicis Station: during the first excavations activities, an ancient wall dated back to the Middle Age (XIII-XIV sec.) has been discovered. It's a part of the ancient Naviglio of San Gerolamo.

According to these archaeological findings, the original station's project was fully revised. The intent of the new project is to host the ancient Roman wall trying to keep it, as possible, in its original position and valorizing it, so that passengers are able to visit it while attending the underground metro. Some details of the wall, during its excavation, and of the new station layout are presented.

The De Amicis station it's a great example: when engineer and archaeologist work together, they are able to build a bridge between past and future, so that the today's subway passengers can see the past's passenger route.

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