The High Speed Railway Hub Of Florence: Construction Methodology And Project Management

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ABSTRACT

The General Contractor "NODAVIA", leaded by COOPSETTE, is carrying out the construction of High-Speed railway hub of Florence, one of the most important historical city in the world, including the new HS Station (designed by Norman Foster & Partners) and the construction of twin single-track tunnel to underpass the highly urbanized area of the town. The GC awarded SELI as a subcontractor for the construction of two tunnels using a 9.4-m-diameter TBM, for the excavation of about 5 kms of the total 7.5 kms length of the underground line.

The TBM will advance through very variable geological conditions, such as alluvial deposits made up of sandy and silty gravels and Pliocene clays. The tunnels will be lined with precast concrete universal ring and will have an internal diameter of 8.30 m and an external diameter of 9.10 m.

Due to the particular prescriptions imposed in order to reduce the environmental impact, the logistic concerning transport of the excavated material and the precast lining will be necessarily carried out by railway.

The project developed by NODAVIA, thanks to an appropriate tunnels and station phases execution optimization allows to manage the number of trains for the carriage of the muck, resulting in minimal impact on the railway traffic.

The TBM was tested in Aprilia SELI' factory by the end of October 2011 and will start to bore the first drive in Florence at the beginning of the new year. The duration of the total twin tunnel work will be about 38 months.

1 PROJECT OVERVIEW

The General Contractor "NODAVIA", leaded by COOPSETTE, is carrying out the detail project and the construction of high speed railway hub of Florence, which is part of the new Italian high speed rail network running from Milan to Naples. The project includes the new HS Station (designed by Foster & Partners) and the construction of a twin single-track tunnel to underpass the highly urbanized area of the city, which is well known for its invaluable architectural and historical heritage.

The GC awarded the construction company SELI as specialist subcontractor for the mechanized excavation of the tunnels, concerning about 5 kms of the total 7.5 kms length of the underground line.

The work can be characterized as extremely challenging, due to the building and monumental patrimony of the city that is among the greatest in the world.

Although there are many other interesting parts of the project, such as the technique to for constructing the new HS station, in this paper the focus is posed mainly on the tunnel project and execution by TBM, and the peculiarities of work management required by the contract.
1.1 “Firenze Belfiore” underground HS station

Along the alignment of the tunnels a spectacular high speed station will be built. The rail level, 25m below ground, will be contained within a reinforced concrete diaphragm walls box 454m long and 52m wide, intersected by train tunnels at the north and south ends and connected to the ticket zone at mezzanine level and the ground floor concourse by a system of escalators, travelators and lifts. Above the station there is a roof that consists of a 450m long steel structure defined by a cylindrical surface formed by a steel diagrid structure. The station, designed by Norman Foster and engineered by Arup, will be linked to the existing Santa Maria Novella station 2km to the south. This is the first Italian challenge for this type of vertical structure rail station, a new technology which will show the inner directly from the surface.

The project was further re-engineered by Nodavia, in order to optimize the construction phases under the constraint of the environmental disposition. Thus the top-down technique was chosen.

![figure 1: transversal section and central perspective of the new HS Station, designed by Foster & P (courtesy of Foster & P.).](image)

1.2 “Firenze Passante AV” tunnels

The new underground railway line, known as the “Passante AV of Florence”, will start at Campo di Marte station, on the Florence’s Western border. From there, the tracks will disappear underground to connect to the new HS station, located way north of the city main station, Santa Maria Novella. The second half of the underground tracks lead from the new HS station to the northern entrance, which is located in correspondence of the Rifredi station, on the Florence Northern border.

Starting from Campo di Marte (TBM launching site) toward north side of Florence, where TBM will be disassembled, the project concerns (see also fig. 2 and 3) the following sections:

- South junction for connecting the existing surface railway (direction Rome) to the underground line, which consists of a cut-and-cover tunnel, with lateral reinforced concrete diaphragm walls, and lower and upper r.c. slabs; this section is approximately 800 mt in length;
- South Tunnel section: twin tunnel of circular section, hosting a single rail track, 2935 mt long, located at a depth from ground level varying in the range 10 mt to 27 mt;
- Two double rail track, each 70 mt in length, connecting the circular section tunnels to the HS station box;
- The HS station box, described in the previous paragraph;
- Two double rail track, each 60 mt long, connecting the HS station box to a service shaft;
- North Tunnel section: twin tunnel of circular section, hosting a single rail track, 2050 mt in length, located at a depth from ground level varying from 10 mt to 18 mt;
- North junction for connecting the existing surface railway (direction Milan) to the underground line, which consists of a cut-and-cover tunnel, with lateral reinforced
concrete diaphragm walls, and lower and upper r.c. slabs; this section is approximately 300 mt in length;

Track presents 2 bends of 300 and 400 meters radius and the lower point of alignment is before entry in the station (26 meters of coverage).
The south tunnel section will underpass the central area of the city, while after the HS station and up to the end of the underground line, tunnels will run straight under existing railway with a simpler context on the surface.
Twin tunnels will run at a mean distance of 20 meters between their axes, nearing to a minimum value of 11 meters in proximity of the tunnel launching portal in Campo di Marte and of the Rifredi TBM retrieval shaft.
The design choice of having twin tunnels instead a single tube originates by safety reasons, in order to allow the transit of passengers from a tunnel to the other one in case of danger. For this reason the twin tunnels are linked by means of by-passes every 500 meters along the alignment.
By-passes and double rail track tunnels construction will be effort by ground freezing consolidation method and subsequent full face advance conventional excavation.

1.3 Critical features

The first half of the tunnel track, is expected to be the most critical part of the work. TBM will bore under a very urbanized area, underpassing a bridge, the railway connecting Milan to Rome, and many structures, including hospitals, public buildings and famous Monuments. The most important of which is the ‘Fortezza da Basso’, a masterpiece of the military Renaissance architecture, that was designed by Antonio da Sangallo and commissioned by
Duke Alessandro de’ Medici, and it was built between 1534 and 1537. Due to the historical and architectural relevance of the building, the compensation grouting technique will be used during the TBM passage. It is also to report the extremely difficult context nearby the tunnel portal, where at a distance of 100 meters from TBM launching pit, the preventive consolidation of the foundations of the railway bridge “Ponte al Pino” was required, together with two critical buildings which also need compensation grouting to minimize the subsidence caused by tunneling.

2 GEOLOGICAL CONDITIONS AND MONITORING SYSTEM

The low coverage of the tunnels, the different stratigraphy geology crossed and a strongly urbanized area on the surface of Florence brought to a necessary detailed technical-geological study, together with a complex analysis of the underground conditions and building structure interested.

A considerable amount of geotechnical data were achieved, concerning about n° 160 surveys with in situ tests, such as SPT, pressiometric tests, Lefranc, cross-hole and down-hole. Consequently, many samples were subjected to laboratory analyses. Thus a total length of 7000 mt of investigation was performed, with a medium frequency of 1 survey every 50 mt along the alignment.

Due to the extreme spatial variability of the soils, it was necessary to divide the geological contest in 4 main categories called *Superintemi*. With reference to the longitudinal sections of the tunnels (see Fig. 2), the stratigraphical succession is the following:

- **R**: is formed of heterogeneous antropic filling soils of a more or less recent epoch. The layer consists mainly of silts ranging from weakly sandy often with pebbles, from medium dense to dense.
- **A** (*Supersintema of the Arno river - Olocene*): is formed of alluvial soils consisting mainly of well-graded gravel, sand and pebbles in a mainly silty-clayey matrix with intercalations of sandy silt to clayey silt, mostly sporadic and with a variable thickness.
- **F** (*Supersintema of Florence - Pleistocene*): formed of sandy or silt clays, with intercalations of gravels.
- **C** (*Supersintema of the Florence-Prato-Pistoia lake - Pliocene*): mainly made up of consistent over-consolidated blue clay or clayey silt, at times with inclusions or intercalations of gravel and sand.

![Figure 3: Longitudinal Profile](image)

The water table is located in the recent alluvial sediments of the Arno river and its tributaries, thus at a depth ranging between 5m to 10m below the ground level. Consequently, all the tunnel excavation is carried out under a hydraulic pressure from 1,0 – 2,0 bar.

Due to the aforementioned geological complexity, characterized by quick stratigraphical changes and different conditions at the front of excavation, under a delicate urban situation on the surface, special attention was posed on the effects of the expected settlements following excavation.

More than 300 buildings were carefully recorded and analyzed in order to assess any future potential damage, due to civil works or tunnel excavations.
A complete monitoring system is already at work and will be implemented along the alignment, where it is planned to put under monitoring system about 150 buildings during the tunnel excavation.

3 TBM AND BACK-UP SYSTEM DESCRIPTION

The three priorities in function of which the choice of the excavation method was operated, are the following:
1. Maximum safety for all operators inside the tunnel;
2. Maximum safety for the buildings or other elements on the surface;
3. Minimum open-front area of the tunnel in all circumstances.

The Risk Management assessment proved that the mechanized excavation method with an earth pressure balance (EPB) shield was judged to be most suitable.

3.1 TBM and equipments manufacturing

TBM, back-up system and rolling stock were designed and manufactured by SELI Technologies in the Italian factory of Aprilia (Rome) to ensure the maximum performances of the TBM under variable ground condition which will be encountered during Florence tunnels excavation, through the complete mechanization of all operations related to handling and installing of the precast segment.

<table>
<thead>
<tr>
<th>TBM TYPE</th>
<th>Earth Pressure Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation diameter</td>
<td>9,402 mt</td>
</tr>
<tr>
<td>Outer Shield diameter</td>
<td>9,364 mt</td>
</tr>
<tr>
<td>TBM Shield Length (Including tail shield)</td>
<td>11,5 mt</td>
</tr>
<tr>
<td>TBM &amp; Back-Up Length</td>
<td>100 mt</td>
</tr>
</tbody>
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**CUTTERHEAD AND CUTTERS**

- Opening Ratio: Approx. 30%
- Cutting tools: 92 (No. 38 housings can host both ripper tools or twin disc cutter 15 ½” disc cutters; No. 54 housings can host only ripper tools)
- Water/Foam Spray system: No. 8 spraying nozzles for water or foam
- MAIN DRIVE
  - Electric motors: No. 9, 300 kW each water cooled
  - Maximum torque @ 1.0 rpm: 25,000 kNm (100% efficiency)
  - Thrust Cylinders / Maximum total thrust: No. 36 / 90,000 kN @ 345 bar
  - Tail sealing system: No. 2 wire brush rows + 1 multiple spring steel
  - Two component grout injection: 6 lines + 6 lines spare for grout-A component (each line can be removed from the shield carpentry); 6 lines + 6 lines spare for grout-B component (each line can be removed from the shield carpentry)

The typology of lining is of the kind of universal precast steel reinforced concrete ring (6 elements and 1 key element), with a thickness of 40 cm, and inner/outer diameter respectively of 8.30/9.10 mt. The average length is 1500 mm, ranging from 1537.91 to 1462.09 mm, to allow curves of 250 m minimum radius.

SELI precast segments are produced in Calcinate factory (near Bergamo city). The plant hosts 48 moulds (6 complete rings) and will cast two shifts of production per day, in order to produce at least 12 rings per day (TBM daily average estimation is 15 meters/day).
4. WORK MANAGEMENT

The great complexity of the infrastructure integration with the urban context, required for the General Contractor engineers a considerable effort in the planning phase, to ensure a proper and effective management of the work to be done.

In the previous project stages it was determined that the excavated material coming from the High-Speed railway hub of Florence, for a total amount of 2.800.000 m³, should be used to build a hill, within an ex-mining site environmental rehabilitation, in an area located near S. Giovanni Valdarno, 50 Km south from Florence.

Furthermore, due to the particular prescriptions imposed to reduce the environmental impact, the logistic concerning transport of the excavated material and the precast lining of the tunnel must be necessarily carried out by railway.

Due to technical issues, such as the existing rail infrastructures configuration and, above all, the impact over the railway traffic, the total daily amount of material that can be conveyed is limited to 5.000 m³, which corresponds to 7 trains per day.

Thus Nodavia, together with SELI, developed a project management which, allowing the contemporary excavation of the tunnel and the station’s box, under the constraint of the aforementioned limitation, ensures the respect of the overall duration of work, which was imposed by the contract. Consequently a considerable effort was done to develop the project management in order to match together logistic, financing and organization issues. The work planning itself required a detailed assessment, involving risk analysis and multicriteria evaluation, aimed to define the appropriate execution phase sequence.

As result of this optimization process, the TBM will bore first the northbound tunnel from Campo di Marte to Rifredi retrieval shaft, where the TBM will be disassembled and transported back. After being reassembled at Campo di Marte worksite, the shield will bore the southbound tunnel. During first drive the TBM will cross the HS Station box boring the full section. For the second drive it will not be necessary because Station’ structure will be completed for TBM translation.

TBM will work 7 days per week, 24 hours per day and will produce approx. 750.000 m³ of spoil (roughly 1.500.000 tons). In order to accomplish to the disposition of transporting the muck by train, an appropriate designed system of belt conveyor will transfer the excavated material from the front face to a dedicated train, located on the surface at the portal area (fig. 4).

By means of a specific reversible conveyor belt 70 mt long, the muck will be loaded directly into the containers positioned on the train. Each train will be 300 meters in length and will host 20 containers open top 60", allowing the transport of 1000 tons of excavated material.

![figure 4: Tunnel portal worksite plan of Campo di Marte](image)

In the prefabrication factory the segments will be produced and stocked in a proper yard, from where they will be shipped by train to Campo Marte worksite where a specific railway track will be ready to receive them. According to the TBM daily production estimation, 1 train loaded with 18-20 rings will be shipped each 2 days from Bergamo Station toward jobsite, running along the Italian public railway for 350 Km.
5. CONSTRUCTION EXPERIENCES

The work progress at the end of 2011 reveals the completion of the North junction (fig. 6), which was the first to start, and with regard to the South junction, where the TBM will be launched, the civil works progress reached the 80% of completion (fig. 5). The EPB-TBM, called Monnalisa (fig. 7), was fully assembled and tested in the factory in June 2011. Major components and parts of Back-Up were delivered to jobsite in December to allow to start assembly operations and welding of the cutterhead and shields. Rest of the TBM and all equipment will be delivered at the beginning of the 2012 in order to complete all assembly and tests latest at the end of April 2012. At the beginning of springtime TBM Monnalisa will start to bore the first drive of 5,5 Km under Florence.

figure 5: Tunnel portal worksite of Campo di Marte, with the rail tracks for muck and lining transport already set down

figure 6: view of the north junction
6. CONCLUSIONS

The High Speed Junction of Florence represents one of the most important railway infrastructure under construction in Italy at present. The Construction of this important hub should mean to link directly the major cities of the country with an high speed rail connection from Naples to Milan.

The aim of the General Contractor and of the partners involved in this challenging work, is the respect of the contractual completion of work, facing the typical uncertainties of urban tunneling and focusing to terminate the hub infrastructure works within 2015.

TBM is almost ready to be completely delivered to the job site. Monnalisa and all equipment assembly are estimated to finish latest at the end of the first quarter of 2012, in order to start the excavation and to carry it on according the scheduled time.

PROJECT PARTICIPANTS:

Client:
RFI S.p.A (Rete Ferroviaria Italiana) company of the Public Railway Group

Work and Project Supervision:
Italferr S.p.A – engineering company

General contractor (Project and Construction Management, and Execution)
NODAVIA scpa
Subcontractor for tunnels excavation
SELI S.p.A.