# Crossing of Line H under Line D, Buenos Aires Metro. Logistical challenges, construction and design.

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**Abstract.** The Metro Line H in Buenos Aires, Argentina runs North-South, at the west side of the city's downtown area. The northbound extension of the line started in 2011 using conventional tunnelling methods and is close to completion. Two kilometers of tunnels and three cavern stations, namely Córdoba, Santa Fe y Las Heras stations, were excavated in stiff cemented silts and clays. Close to Santa Fe Station, the tunnel crossed two simple underground tunnels belonging to Line D. These tunnels remained operational and were not interrupted by the construction of the new tunnel, albeit the fact that the new tunnel is in direct contact with the foundations of the side walls of the old tunnel, and that it had no structural invert. In this paper, some design aspects, the logistics and construction issues of the project are described.

**Keywords.** Construction, Underground crossing, Design, Metro, Tunnel.

## 1. Introduction

The northbound extension of the Metro Line H in Buenos Aires is under construction. The evolution of tunneling in Buenos Aires Metro and a description of the project and station caverns have been treated in previous publications [5][7][8][9][10]. This paper focuses on the solution adopted for the crossing of Line H under existing tunnels of Metro Line D.

## 2. Buenos Aires Soils

Buenos Aires City soils have been described in other contributions [1][3][4] and references contained therein. Briefly, the Pampeano formation underneath Buenos Aires downtown area is modified Loess, over consolidated by desiccation and cemented with calcium carbonate in nodule and matrix impregnation forms. Except for the heaved upper three to six meters, penetration resistance is systematically $N_{SPT} > 20$ with some heavily cemented zones that exhibit very weak rock behavior and $N_{SPT} > 50$.

Particular features of the formation are: i) fissures induce a high secondary permeability; ii) thin layers of non-cohesive loamy sands can be found at depths 20m and below; iii) close to the bottom of the formation and right on top of Pliocene clean sands, a poorly cemented non fissured sub-stratum of greenish clays acts as an

hydraulic seal. Pampeano soils are good for underground construction due to high stiffness, reliable compressive strength, rapid drainage and good frictional behavior when drained.

The max allowable unsupported drift is about 2.5m due to crown instability of the fissured soil mass. Table 1 lists a typical set of material parameters used for the design of underground excavations [2][6].

**Table 1.** Typical design material parameters, Pampeano Formation.

| Parameter | Units | 0m-8m | 8m-30m | 30m-40n |
|---|---|---|---|---|
| $c_u$ | kPa | 50-100 | 110-220 | 40-120 |
| $\phi_u$ | ° | 10-20 | 0-10 | 0 |
| $c'$ | kPa | 10-25 | 25-50 | 15-30 |
| $\phi'$ | ° | 30-32 | 30-34 | 29-32 |
| $\psi$ | ° | 0-3 | 0-6 | 0-3 |
| $E_{50}$ | MPa | 60-100 | 70-150 | 60-90 |
| $E_{ur}$ | MPa | 150-250 | 180-300 | 140-220 |
| m | - | 0.0-0.4 | 0.0-0.4 | 0.0-0.4 |
| $\nu$ | - | 0.20-0.30 | 0.20-0.30 | 0.20-0.30 |
| $R_f$ | - | 0.80-0.90 | 0.80-0.90 | 0.80-0.90 |

## 3. Line H northbound

Line "H" C2 Northbound extension consists in 4 stations linked by three double lane NATM tunnels with a total length of 2050m. Three stations, "Córdoba", "Santa Fe" and "Las Heras", with a length of 135m and a transversal excavation area of 220m$^2$, have been excavated between 2013 and 2014. Last one, "Facultad de Derecho" Station, will be excavated during 2015 with Cut&Cover methodology (Figure 1).

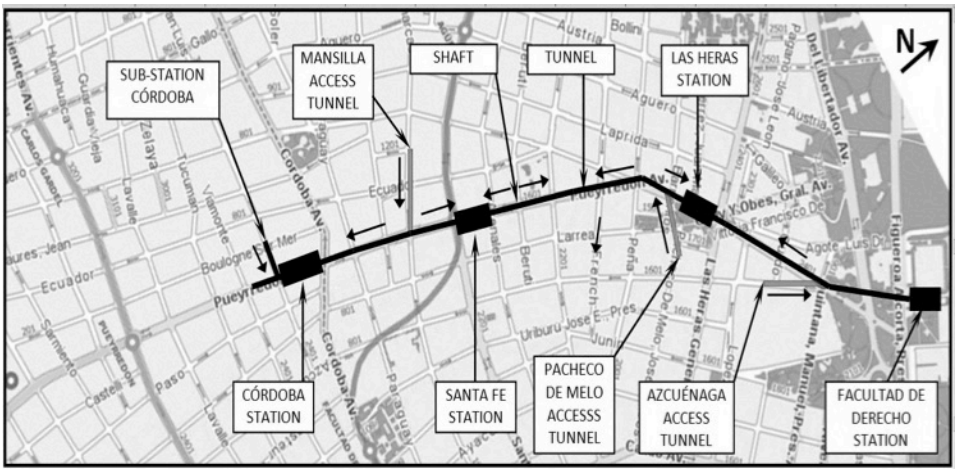


**Figure 1.** Line "H" – C2 northbound Extension, Buenos Aires Metro.

Line "H" Northbound Extension originally was designed to be excavated using three access ramps for concrete supply and soil extraction. Those ramps were located at "Mansilla", "Pacheco de Melo" and "Azcuénaga" streets. In order to speed up the excavation schedule, two new vertical shafts were used to excavate some stretches of the tunnel before the arrival of principal construction faces.

## 4. Crossing of tunnel Line H under tunnel Line D

### *4.1. Problem statement*

Line "H" northbound extension tunnels cross several interferences. The most important are crossing below Line "D" tunnel and above "Arenales" tunnel; both are separated 240m (Figure 2). "Santa Fe" underground station is located between Line "D" and "Arenales" crossings.

Line "H" railway design demands that "Santa Fe" Station must be leveled at Platforms areas. The maximum incline at the exits of "Santa Fe" is 3.5%. Southbound, the tunnel track level is defined by the minimum railway gauge – a rigid catenary is used – and the existent line "D" railway level. This situation implies that "Santa Fe" Station railway level is severely conditioned by these two limits.

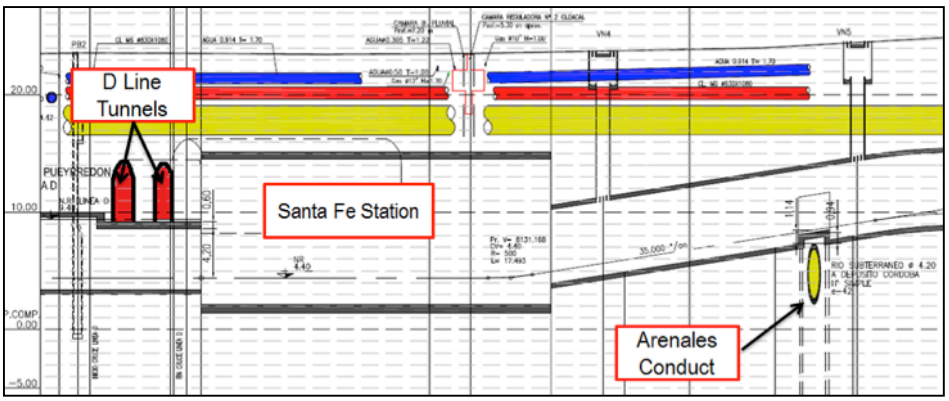


**Figure 2.** Santa Fe Station and interferences at the North (Arenales Conduct) and South (D line Tunnels).

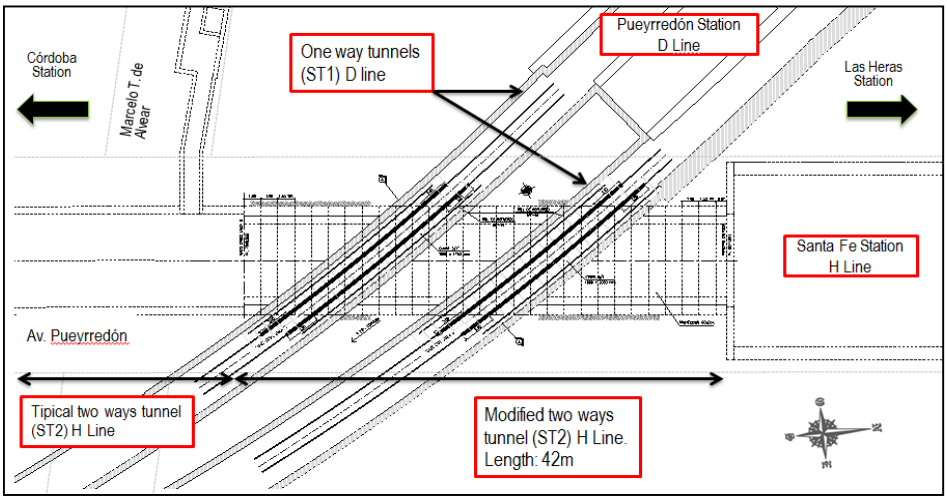


**Figure 3.** Crossing of Tunnel Line H under Tunnel Line D. Plan view.

Basic engineering for the crossing below Metro Line D (Figure 3) considered successive concrete frames (Figure 4). The top slab was specified to be built in two

stages: a concrete slab 0.20m thick is installed from the tunnel above and supports the Line D rails during the lower excavation; and ii) a 0.40m frame slab is cast in place in 2.0m shifts. The closure invert was built far behind the face of the excavation, in shifts of about 6.0m.

The biggest risk associated with this structural solution comes from the possible lack of monolithism between the two stages of execution of the lintel. From a construction point of view, the upper half of the slab is curved and oblique with respect to the tunnel alignment, and so is the orientation of the reinforcement bars. Moreover, the solution was slow and produced a significant delay in the start date of the excavation of Santa Fe Station, affecting the critical path of the project.

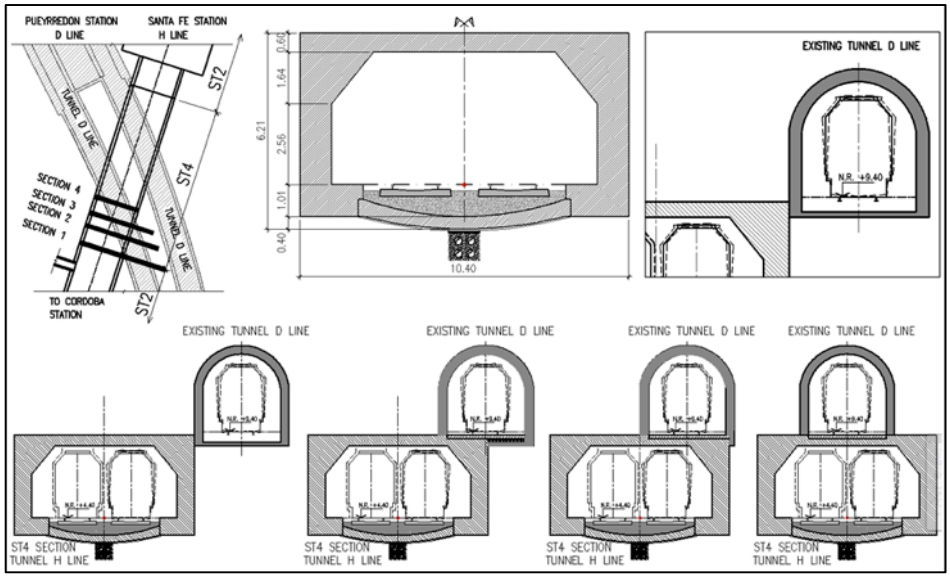


**Figure 4.** Crossing of Tunnel Line H under Tunnel Line D. Tender document.

## 5. Proposed executed alternative

A temporary tunnel of small dimensions was executed to gain early access to the excavation of Santa Fe Station. This facilitated the immediate access of the excavation equipment to the station. The tunnel was integrated into the final design as a side drift in an integrated design which is a typical tunnel but having a flat crown.

The rail level of the station was lowered 0.30 m. at the expense of increasing the slope northbound. Line D tunnel's invert was demolished because it interfered with the new Line H tunnel. It was replaced with a new 0.30m width flat invert built right under the rails. The construction procedure can be resumed in the following sequential tasks:

1. execution of the drainage gallery for dewatering;
2. excavation and shotcreting of the upper west drift in 3.0m shifts;
3. excavation and shotcreting of the lower west drift;
4. tasks 1 to 3 repeated until the completion of west drift;
5. use of the west drift tunnel as a link between the Mansilla ramp and Santa Fé Station for heavy vehicle access and soil extraction;

6. tasks 1 to 4 repeated for the east drift;
7. construction of the lower and upper secondary lining of the side-walls;
8. construction of the new invert for the Line D tunnel in 6.0m shifts;
9. excavation and shotcreting in tunnel's crown in 1.50m shifts with progressive demolition of the temporary walls from side drifts;
10. task 9 repeated until it reaches 6.0m long;
11. excavation of the lower central bench and execution of the concrete invert 6.0m long from 3.0m of the front excavation.

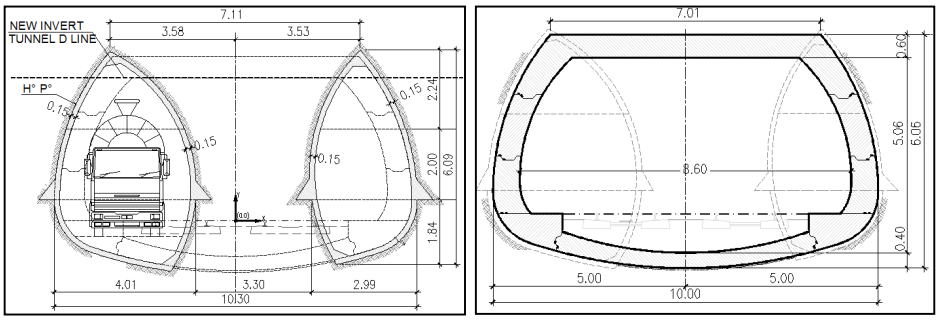


**Figure 5.** Tunnel Line H crossing under Line D. Cross section and indication of construction procedure.

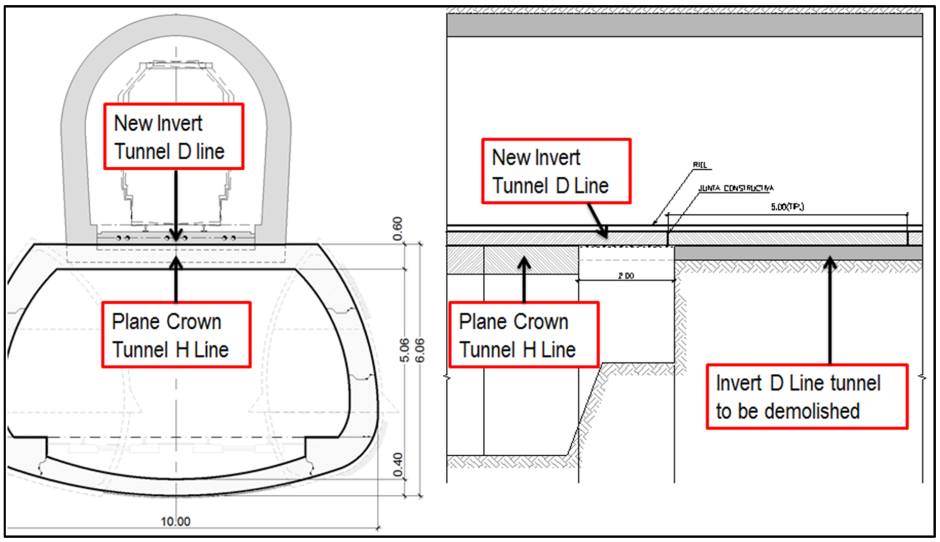


**Figure 6.** Detail of the replacement of the invert in Tunnel line D.

In Figure 7 and Figure 8, the construction procedure is sketched. Figure 9 shows the measured settlement of the tunnel Line D, showing a maximum value of 6 mm. The estimations obtained from finite elements models using Plaxis were in the range 6mm to 8mm for drained conditions.

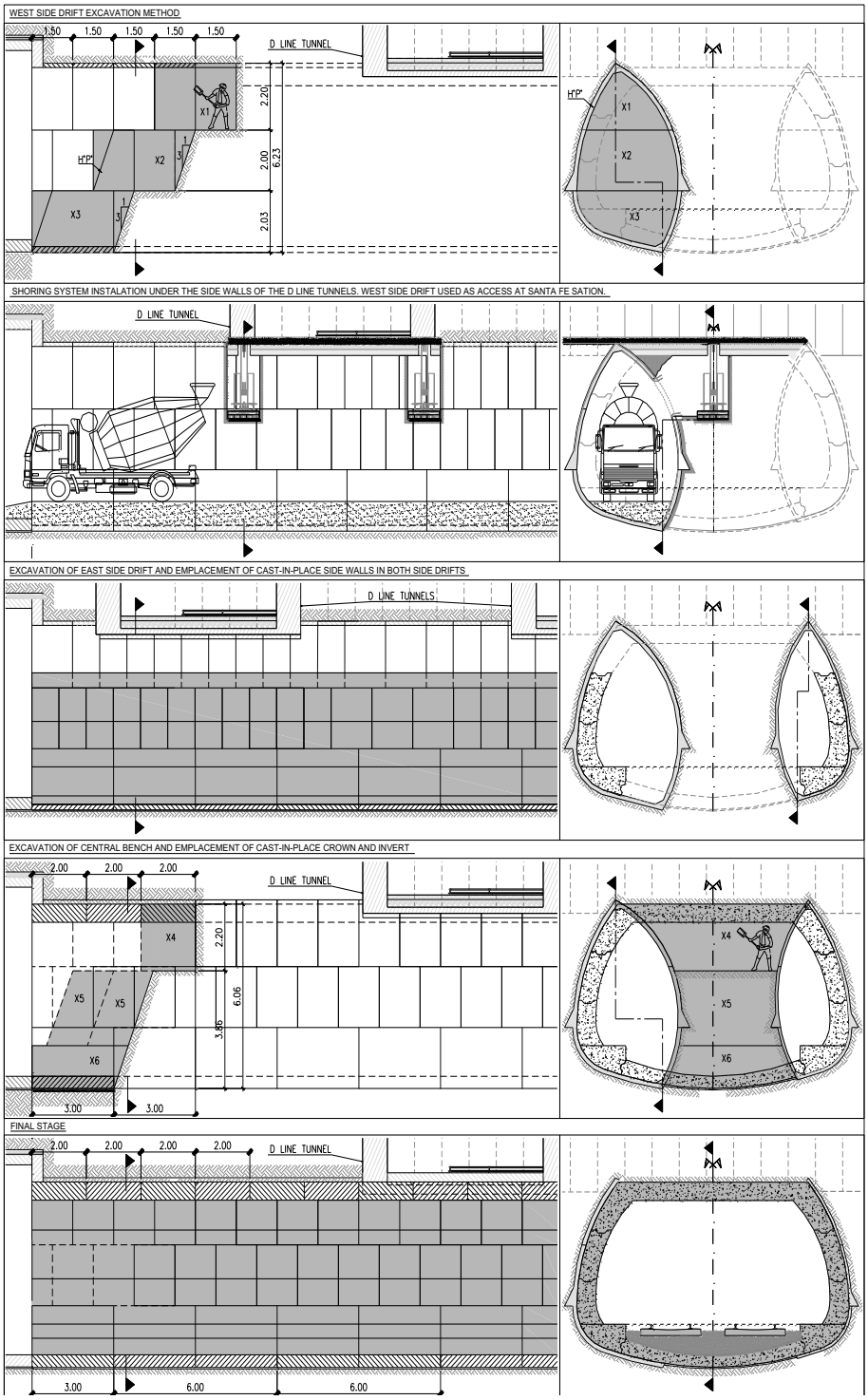


**Figure 7.** Constructions stages of the crossing.

**Figure 8.** Constructions stages.

## 6. Conclusions

The crossing of the Line H tunnel below the existing D Line tunnel has been performed successfully. The subway service was not interrupted at any time. The settlements of existing tunnels were in the range of 3.0mm to 6.0mm, which was acceptable and has no structural implications. The proposed construction procedure for the crossing allowed the early start of the excavation and construction of the Santa Fe station, with significant impact in time deadlines. The experiences and lessons learned to run this crossing of tunnels will solve more effectively the upcoming interferences.

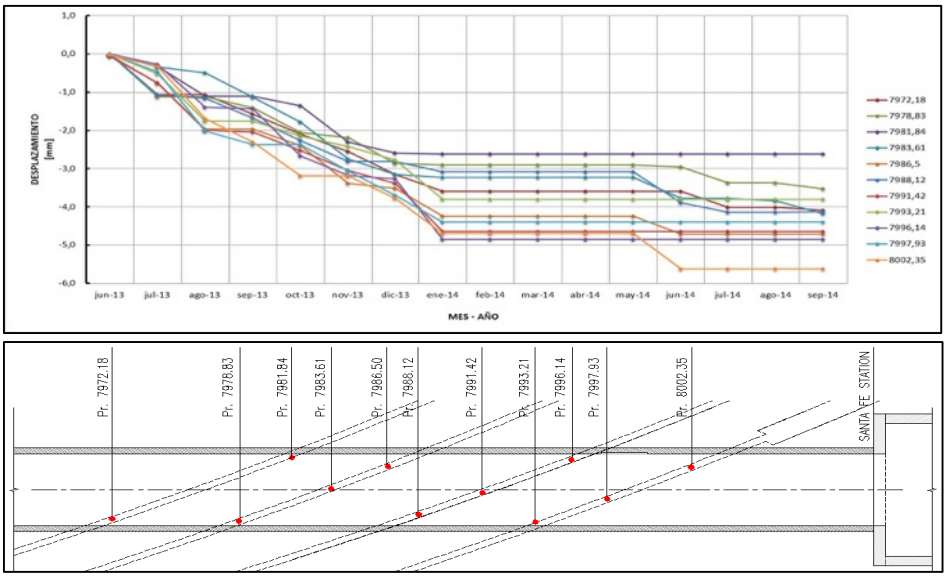


**Figure 9.** Evolution of settlements in Line D during the under-crossing of Line H.

## 7. Acknowledgements

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