SUCCESSFUL TBM OPERATIONS IN URBAN ENVIRONMENT: THE "ARROYO MALDONADO" PROJECT IN BUENOS AIRES

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The Hydraulic tunnel "Arroyo Maldonado" in Buenos Aires, Argentina, includes the construction of about 15 km of two hydraulic tunnels, with the aim to prevent the floods that periodically inundates the surroundings of the Rio de Plata river. The tunnels are excavated in urbanized areas with low overburdens, therefore the controls of EPB pressures and back-fill grouting injections are very important in order to avoid superficial movements and guarantee safe conditions in the TBM environment.

1. An important urban project for Buenos Aires

A few years ago the government of Buenos Aires commissioned an important hydraulic project, the "Arroyo Maldonado", with the aim to reduce the inundations that periodically hit the Argentinean capital, creating incalculable damages to people and artificial constructions.

The project includes the constructions of two 7.90m diameter tunnels, with the function of catching the rain water and pour it into the "Rio de Plata" river.
Here are the main parts involved in the project:

Client	Gobierno de la Ciudad de Buenos Aires
Designer	GEODATA
Contractor	GHELLA

Two EPB shields by LOVAT were used to excavate the tunnels.
In September 2009 the first TBM was launched for the short tunnel (length of approx. 5 km) and finished it after about 350 working days. The longest tunnel construction started a few months after the first one and was completed in December 2011.
Along the alignment the TBM excavated in very varying geological conditions with low overburdens, generally 15-30 m with particularly challenging passages under artificial manufactures (for example, old hydraulic channels and buildings) at less than 10 m.

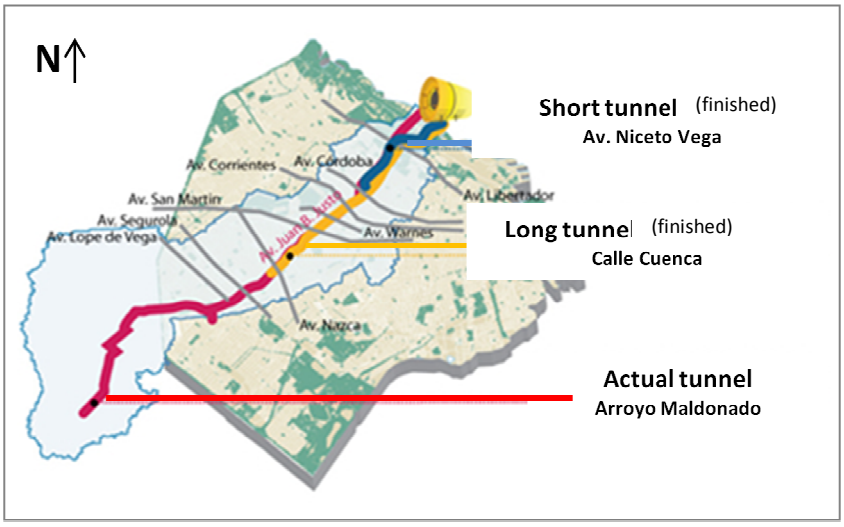


Figure 1. Arroyo Maldonado Hydraulic project alignment at Buenos Aires, Argentina (modified of *Buenos Aires Ciudad* website)

Figure 2. The completed short tunnel

Table 1. Arroyo Maldonado Hydraulic project characteristics.

Tunnel length	Approx. 15 km
Excavation diameter	7.90 m
Lining type	Pre-casted segments
Ring connections	Bolts
Extern ring diameter	6.90 m
Intern ring diameter	6.55 m
Ring length	1.50 m
Width pre-casted segments	350 mm
Number of segments for ring	6 plus crown

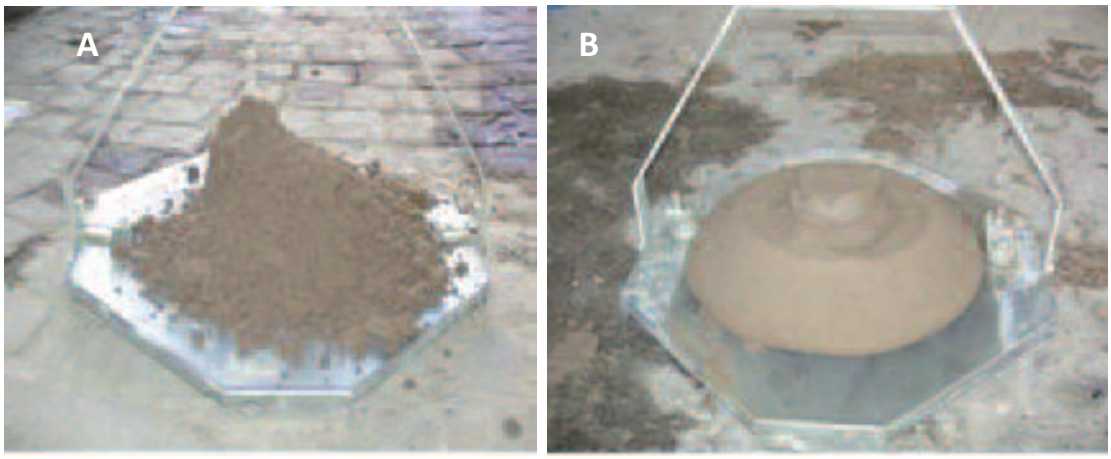
Figure 3. The cutting wheel of a LOVAT EPB used for the Hydraulic tunnel “Arroyo Maldonado”.

2. Choice of a suitable ground conditioning system

The choice of the most appropriate products and parameters for the ground conditioning is of paramount importance to achieve satisfactory TBM performances.
In particular, the attention that had to be given to the ground conditioning in the "Arroyo Maldonado" tunnels was even greater than in "standard" tunnelling projects, because of the continuous variations of geological profiles to excavate and the low and sometimes very low overburdens.
Sometimes ground conditioning is described as a "black art", anyway some parameters can be taken in consideration in order to "rationalize" it. In particular the following steps were followed in Maldonado tunnels:

- Significant laboratory tests: a series of tests were carried out in the laboratories located at the Technical University in Turin (Italy) with representative samples of the different types of soil to be excavated.
  This first step allowed to find out the most appropriate foaming agent and to give the Contractor a first approximation of the ground conditioning parameters and consumptions.
  The laboratory tests gave indications that the product POLYFOAMER FP (biodegradable foaming agent in combination with a lubricating polymer), produced by MAPEI, was totally compatible with the types of soils to be excavated.
- Optimization of the ground conditioning system directly on the TBM: the parameters found out in laboratory were used as reference and modified with the aim to achieve the most appropriate solutions from technical and economic points of view.
- Adjustments of the ground conditioning parameters during the advance, focusing the attentions on every geological variations.
- Continuous controls of the consistency of the muck extracted by the screw conveyor and of the TBM parameters, such as cutting wheel and screw torques, advance speed, working pressures, etc., in order to understand as early as possible eventual problems or difficulties in the EPB operations which can be solved (partially or totally) changing adequately the ground conditioning system.

During all these 4 steps the cooperation between the Contractor and the supplier was proficient and useful to solve the eventual problems encountered during the TBM operations.



Figures 4A and 4B. Same sample of ground before and after the addition of foaming agent by Mapei during the laboratory tests in Turin.

A rational ground conditioning system used during the whole tunnel alignment and the choice of appropriate foaming agents allowed the Contractor to achieve satisfactory advance performances in both short and long tunnels.

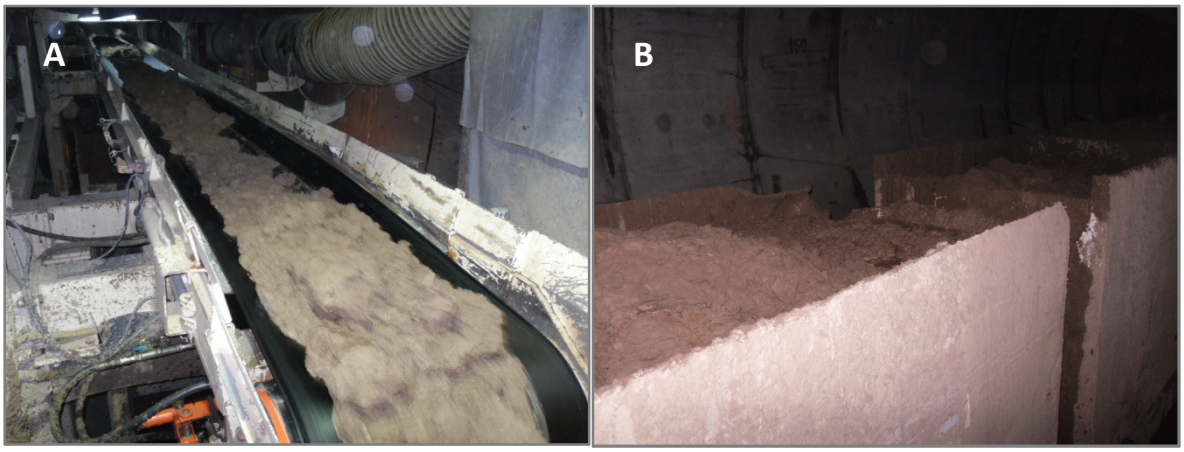
Table 2. Monthly production of the TBM excavating the short tunnel.

Month	N. of rings excavated	N. of meters excavated
Oct 09	22	33
Nov 09	87	131
Dec 09	80	120
Jan 10	165	248
Feb 10	315	473
Mar 10	365	548
Apr 10	233	350
May 10	393	590
Jun 10	475	713
Jul 10	304	456
Aug 10	421	632
Sep 10	182	273
Average	254	380

Table 3. Monthly production of the TBM excavating the long tunnel.

Month	N. of rings excavated	N. of meters excavated
Feb 10	1	2
Mar 10	65	98
Apr 10	127	191
May 10	108	162
Jun 10	286	429
Jul 10	267	401
Aug 10	348	522
Sep 10	435	653
Oct 10	274	411
Nov 10	482	723
Dec 10	214	321
Jan 11	328	492
Feb 11	352	528
Mar 11	221	332
Apr 11	493	740
May 11	392	588
Jun 11	286	429
Jul 11	346	519
Aug 11	463	695
Sep 11	355	533
Oct 11	350	525
Nov 11	366	549
Average	298	447

The appropriate use of conditioning products allowed to control the EPB pressures during the whole advance within the design ranges of minimum and maximum pressures, including the most challenging passages.



Figures 5A and 5B. The figures show the ground conditioned on the muck transportation systems at the job site. **5A** Shows the conditioned ground at the transportation belt.**5B**. Shows the ground conditioned once at the transportation trucks.

For example, the long tunnel excavated under the "Rio Subterraneo" with a minimum overburden of just 6 m. It is clear that in such conditions the EPB pressured must be controlled perfectly: the result was that no movements were registered by the several instruments installed.
A proper addition of foam gives the soil a consistency able to transmit pressures to the face and decrease significantly its permeability, thus better controlling the water ingress inside the chamber. In conclusion, the surface settlements can be better controlled.

3. Two-component backfill grout injection for a complete filling of the annular void

The filling of the annulus void created during the shield advance was carried out in Maldonado with a two-component grout, made of:

- A very fluid and stable cementitiuos grout, with long workability properties thanks to the addition of the retarding agent Mapequick CBS System 1, produced by MAPEI.
- An accelerator admixture, Mapequick CBS System 2, added to the cementitious grout and able to react with it giving a thixotropic and not-washable gel.

Several tests carried out firstly in the MAPEI laboratory (using the raw materials received from Buenos Aires) and later at the job-site were useful to find out the most appropriate mix-design according to all the specific requests coming from the project, in terms of pumpability, volumetric stability, jellification, mechanical strength development, etc.

Two factors were considered by the Contractor during the injection to control the real complete filling:

- The volume: known the theoretical empty volume left by the shield behind the segments, a slightly higher amount of grout must be injected.
- The pressure: the injection was carried out during the advance with average pressures slightly higher than the EPB ones, until achieving a maximum pressure at the end of every advance.

These two parameters were continuously checked and allowed to properly fill the annulus space in both short and long tunnels.

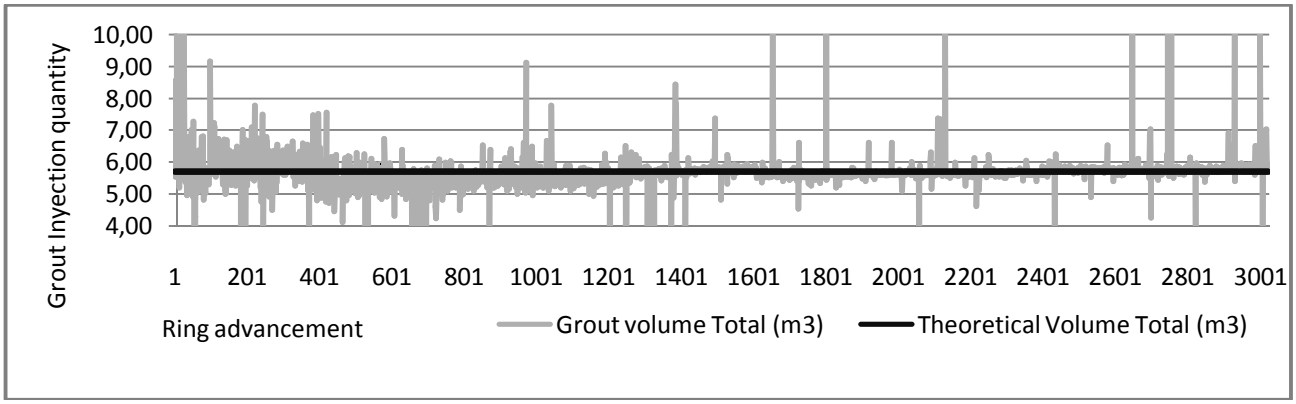


Figure 6.Total and theoretical volume injected vs ring advancement, Short Tunnel "Arroyo Maldonado".

The grout volume injected per ring graphs allowed to control and confirm the complete filling of the empty spaces behind the tunnel segments. At figure 6, it is clearly showed an homogeneous grout volume injected with an average of approx. 6.1 m^3 per ring. The theoretical volume to be injected per ring it is showed (5.7 m^3) per ring.

By using a proper mix-design and specifically designed equipments, the risks of clogging the pipes was minimized, ensuring a constant and continuous injection of the mix. If the injection lines are often clogged, the injection cannot be constant and it is more probable to leave empty spaces behind the lining.

The durability of the two-component backfill grout is guaranteed in the natural conditions of humidity present in the underground excavations.
In the short tunnel, it was possible to directly observe the backfill grouting material thanks to the removal of superficial ground until the tunnel depth a few months after the TBM passage. As shown in the figure 7, the two-component material was found in perfect conditions, hardened and perfectly filling the space between the tunnel lining and the surrounding ground.

Figures 7. The image shows the hardened grout after removing the ground above the short tunnel.

Figures 8A and 8B. The images show the storage tanks (8A) and batching plant (8B) of the back-fill grout components at Hydraulic tunnel "Arroyo Maldonado" job site.

4. Conclusions

Details regarding ground conditioning and backfill grouting carried out in the "Arroyo Maldonado" project are described in this paper. Both these operations are of paramount importance to minimise the surface settlements, in particular in difficult conditions like it was in Buenos Aires: very urbanized areas, reduced overburden, presence of underground water (average pressure of 2.0 bar).

Table 4. Surface settlements along the short tunnel.

	Last data	Settlement [mm]
0+048.00	16/12/09	-2.6
0+087.50	04/01/10	-0.7
0+243.89	06/02/10	-1.0
0+682.80	16/04/10	-2.0
0+866.82	13/04/10	0.6
0+904.70	13/04/10	-0.7
1+549.34	16/04/10	-0.1
1+929.72	22/12/11	-1.6
1+934.09	22/12/11	-1.0
1+954.09	28/06/10	0.0
2+146.00	01/12/11	-1.9
4+459.60	12/12/11	-2.1

An appropriate use of the foaming agent Polyfoamer FP allowed a correct ground conditioning, improving the pressure transmission trough the soil mass, leading to better face stability and guaranteeing the TBM satisfactory advancement and performance.

The two-component backfill grouting injection allowed to fill completely and immediately the annular void behind the tunnel lining, minimizing the "volume lost" around the tunnel and therefore the superficial settlements.

5. References

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