THE MANAGEMENT OF THE SOIL CONDITIONING PROCESS FOR THE EXCAVATION OF THE ROME METRO C LINE

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Line C is Rome’s third underground line. Once completed, it will cross the city from Northwest to Southeast, for a total length of about 26 km and 30 stations. At present 22 stations and 19 Km of line are open to public.
T3 stretch starts with San Giovanni station and it is about 3 km in length.

It includes: two stations, Amba Aradam/Ipponio and Fori Imperiali station, and two shafts with ventilation systems (TBM shaft 3.3, and shaft 3.2).
The historic city center of Rome is a UNESCO World Heritage site.
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THE DOWNTOWN SECTION: TBM EXCAVATION

Soil Conditioning for EPB Tunnelling and Backfilling

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The work site is characterized by the following geotechnical units:

- Made ground (R);
- Recent alluvial deposits of the Tiber river and its tributaries (LSO), consisting of silty clays, clayey and sandy silts, sand and silty sands;
- Pre-volcanic fluvial-lacustrine deposits, including two sub-units: an upper unit (AR) formed of clayey silts and silty clays, and a lower unit (SG) of medium-coarse grain sands with gravel;
- Marine sediments (APL), formed of silty clays and clayey silts of a grey-light blue color, with alternating fine-grain sand levels.
CUTTERHEAD 2008: Cutters and (some) scrapers

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CUTTERHEAD 2018 Cutters (7 diaphragm walls to be passed through) - Rippers - Scrapers
THE EXPERIMENTAL ACTIVITIES

In a fruitful cooperation between Metro C, Astaldi S.p.A and Sapienza University of Rome, an intense experimental activity, to be developed preliminarily and concurrently with tunnel excavation activities, was planned to deal with the management of soil conditioning, including blinded tests on samples of foam and conditioned soil with different combination of Cf, FER and FIR values as:

- identification and classification tests on the soil samples
- tests on several foaming agents
- stability (half-life) tests of the foam
- clogging measurements
- tests on samples taken during the excavation
GEOLOGICAL SECTION 3.3 SHAFT-AMBA ARADAM/IPPONIO STATION
THE GEOTECHNICAL CONTEST

The general approach includes the division of the excavation layout into three successive phases:

1. the first one characterized by AR, ARS and LSO lithotypes;
2. the second one by the medium-coarse grain (SG);
3. the last one by the pliocenic grey-light blue clays (APL), encountered by the TBM in this sequence.

At present, only the first phase of the excavation has been completed and, consequently, only the preliminary activity data and the results of the samples taken on site belonging to the AR / ARS and LSO lithotypes are available in the table.
SOILS CHARACTERISTICS

<table>
<thead>
<tr>
<th>Sample</th>
<th>Grain size distribution (%)</th>
<th>Atterberg limits (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gravel</td>
<td>Sand</td>
</tr>
<tr>
<td>LSO</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>AR</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>ARS</td>
<td>0</td>
<td>40</td>
</tr>
</tbody>
</table>

Grain size distribution:

- F: Fine (d <= 0.002 mm)
- M: Medium (0.002 mm < d <= 0.06 mm)
- G: Gross (0.06 mm < d <= 2 mm)
- Cott: Cottle (d > 2 mm)

Atterberg limits:

- WL: Liquid limit
- WP: Plastic limit
- IP: Plasticity index

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Soil Conditioning for EPB Tunnelling and Backfilling
The test consists in letting the soil rotate inside the Hobart mixer and in measuring the amount of soil remaining stuck to the tool, expressed by the $I$ parameter, defined as the ratio between the stuck soil and the total amount of soil.

**CHARACTERIZATION OF THE NON-CONDITIONED SOILS**
The **half-life test** is one of the tests proposed by the EFNARC guidelines (2005) and is performed by filling a glass cylinder with 80 g of foam and **measuring the time necessary to drain 40 ml of liquid** into a graduated cylinder placed underneath a funnel, defined half-life time, hlt.
CHARACTERIZATION OF THE CONDITIONED IN LABORATORY SOILS

The results show that the Metro C-4 and Metro C-5 products are much more effective in reducing the natural tendency of the AR soil to adhere to metal elements and its undrained strength while achieving, at the same time, the right consistency in the soil.
CHARACTERIZATION OF THE CONDITIONED IN SITU SOILS

The results presented in this paper are based on the database of parameters recorded during the excavation of the tunnels of the Metro C line in the section between Shaft 3.3 and Amba Aradam – Ipponio station with two TBMs S409 and S410.

$C_f = 2.5\%$

FER = 6-8
FIR = 70-75%
The **FER** values used were similar to those used for preliminary tests;

The overall average value of the amount of foam injected (**FIR**) is slightly higher if compared to the 60% values obtained from preliminary laboratory tests.

The **$C_f$** value actually used was 0.5% higher.

The reasons are likely attributable to, inter alia, the dispersion of foam during cutter-head rotation and the differences in the mixing process.
The laboratory tests performed on the conditioned soil samples showed a series of issues:

- the samples taken during the "learning phase" in the first 10 digging rings showed lower values than the maximum values recorded on the unconditional sample, but still within the field corresponding to a "high clogging risk";
The laboratory tests performed on the conditioned soil samples showed a series of issues:

- the samples taken during the further advancement $\mathbf{X}$, where the conditioning had gone further and the parameters optimized, are positioned within the curve and are positioned in the "medium clogging risk" field;
The laboratory tests performed on the conditioned soil samples showed a series of issues:

- the variability in the grain size distribution and in the conditioning process effectiveness provides samples having adherence values of about 25% but also samples having values of 40%;
- in this regards differences in the residual volume of air inside the samples play a role.
CONCLUSIONS

The **laboratory tests** have proved to be, as a whole, a reliable tool for the optimization of several operations, from the selection of the most suitable conditioning product to the management of the parameters during the excavation.

The **satisfactory correspondence** between the parameters actually used for the excavation and the parameters tuned in the preliminary laboratory phase lead to conclude that, for the future, similar experimental activities can be helpful to predict the proper soil conditioning parameters (FER, FIR and added water).