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CONSTRUCTION OF A COLLECTOR SEWER IN ROME, BY MICROTUNNELING IN GEOLOGICALLY COMPLEX SOLIS AND IN AN URBAN CONTEXT OF PARTICULAR ENVIRONMENTAL AND ARCHAEOLOGICAL VALUE

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ABSTRACT:
The construction of underground sewers is a very complex issue, especially in urban areas of particular environmental and archaeological value. The Crescenza sewer collector in northern Rome, which takes its name from the river that flows nearby, is an important sewer system under completion.

The sewer will collect the wastewater of a large urban area of considerable archaeological and environmental importance - as it is located within the park of Vejo, and then convey it towards the Roma Nord treatment plant.

To minimize excavation works, the owner ACEA S.p.A. decided to construct seven microtunnels for a total length of approximately 5,500 meters, and approximately 1,800 meters by open trench. GRP pipes DE 2047 were laid in the trenchless section of the main pipeline.

The microtunnelling sections, all completed, presented considerable technical complexities due to:
- very long drives, especially considering the type of pipes to install. 3 drive with a length of more than 1,000 meters, and the longest drilling carried out in the world using GRP pipes, section B-C having a length of 1,215 meters;
- considerable variety of soils crossed, from gravel to sand, from silt to clay, even over-consolidated; even in a single drive;
- remarkable overfill above most crossings. In section D-C there were more than 60 meters of overfill;
- unforeseen ground conditions during the crossings, such as pushing clays with groundwater under pressure, required the use of complex techniques to allow the completion of the drilling.

1. GENERAL OVERVIEW

The Vejo Nature Park is located along the National Road no. 8 “via Cassia” in northern Rome. This is an area of high archaeological, historical and environmental value, with a rich variety of topography.
Until today, these features made difficult the construction of an efficient system for collecting sewage and wastewater from residential areas, even large ones, that developed there in time precisely because of the particular value and amenity of the place.
Thanks to the use of low environmental impact pipe laying solutions (NO DIG), the Metropolitan City of Rome has largely overcome the issues connected with the difficulty of carrying out massive excavations in such a complex area, and, with the support of ACEA S.p.A., has drawn up a project for the construction of a sewage system that will convey wastewaters to the Roma Nord treatment plant, running through the valley of an existing watercourse, the Fosso della Crescenza, which is the current main wastewater collector.
Two separate lots of this new sewer, called “della Crescenza”, had already been built within the Grande Raccordo Anulare ring road.

The works described below refer to Lot 3 of the Crescenza sewer collector, running through the Vejo Park, from the Grande Raccordo Anulare to the historic village of Isola Farnese.

2. THE PROJECT

The new "Collettore di Isola Farnese - Crescenza" is an extensive sewage system for collecting and conveying wastewater, designed and built with the aim to solve the deficit of sewage collection and treatment that affected the Isola Farnese and Giustiniana area, since the sewage was previously discharged directly into ditches without any treatment. The new sewage system has a total length of approximately 7,300 meters, of which about 5,400 meters were designed and built by the microtunnelling method.

Figure 1 shows the general project chorography.

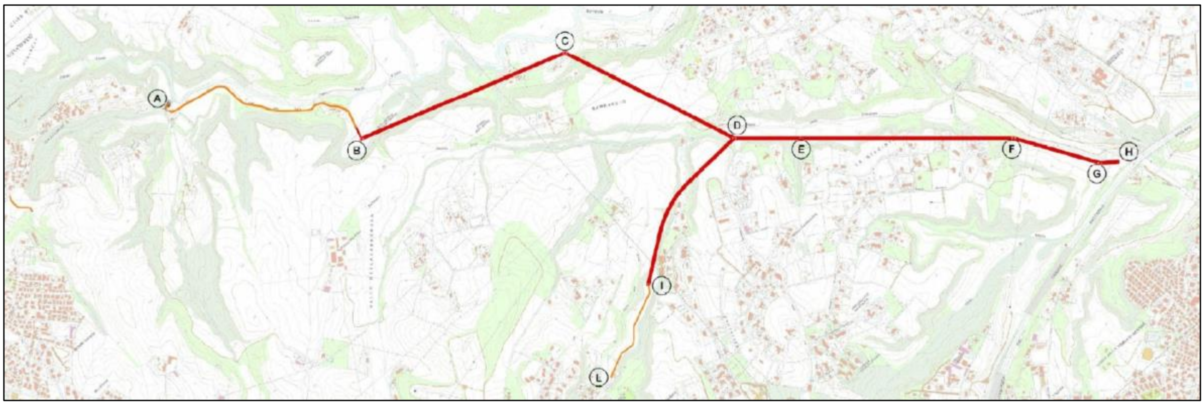


Figure 1 – General project chorography

The works fall under the area of competence of the Veio Park Authority, i.e. a protected area of high landscape and historical value. The choice to install the pipes by microtunnelling was key to solving critical disruptions and minimising the impact of the works on the sites.

Figure 2 – Top view of the construction site area of Section B-C

The works were contracted out to the joint venture Mario Cipriani – I.CO.P. by Acea ATO 2 S.p.A. Within the project, I.CO.P. was entrusted with the construction of 6 microtunnels for a total length of almost 5 km, and the corresponding launch and reception shafts having a depth down to 25 m and retained by a secant pile walls.

Figure 3 – Top view of shaft D, depth 25m (left), and archaeological excavation at shaft C (right)

Glass-reinforced polyethylene (GRP) jacking pipes with lengths of 6 meters each were used for the main sewer line. This material has been chosen due to the need to guarantee high water tightness, given the presence of groundwater in the subsoil where the pipes should be installed.

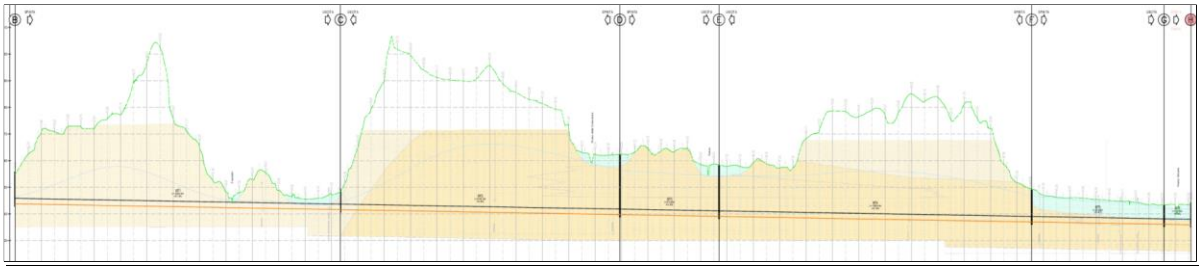
The table below summarises the main features of the microtunnels that were built:

Table 1 – Summary of crossings and corresponding features

Section	Length (m)	Pipe type	External Diameter (mm)	Maximum Coverage (m)	Soil type* crossed	Drilling Starting Date	Drilling Ending Date
A-B	90	GRP	1200	10.3	1, 2	17/08/2020	27/08/2020
B-C	1235	GRP	2047	60	2	10/10/2020	16/01/2020
D-C	1069	GRP	2047	60	2, 3	06/03/2021	16/07/2021
D-E	376	GRP	2047	25	3	26/08/2021	18/09/2021
F-E	1150	GRP	2047	45	3	01/11/2021	19/12/2021
F-G	501	GRP	2047	6	3	26/05/2022	28/06/2022
D-I	970	RC	2120	10	3, 1	16/08/2022	01/10/2022

2.1 Description of the project Crescenza Lot III

From a geological point of view, the area subject to intervention is characterized by the outcrop of formations of pyroclastic origin, widely deposited above clayey and sandy-gravelly sediments of marine and continental origin. The stratigraphic section below shows the expected lithological units along the sewer drilling axis.



*	Symbol	Soil Description
1		**Alluvial and eluvial deposits of the valley floor:** silty-sandy and silty-clay soil, from slightly to moderately consistent
2		**Sacrofano stratified tuffs:** slightly coherent fallout pyroclasts, with sandy-silty granulometry and pedogenised levels
3		**Fosso della Crescenza formation:** deposits of fluvial and fluvial-lacustrine environment in silty-sandy and sandy-silty facies, moderately thick (s), with thick clay intercalations (a)

Figure 4 – Stratigraphic column of the area affected by the microtunnel crossings

As can be seen in Figure 3, the *Fosso della Crescenza Formation* is predominant in the general geological structure of the area subject to intervention. This is a typical geological unit of the area, having known characteristics and consisting of gravels, fine silty sands, and greenish-grey clays of fluvial and fluvial-lacustrine environments.
Almost all the crossings in this kind of soil did not present particular execution difficulties, as the geological conditions found corresponded to those expected from project predictions and validated by a geognostic survey.
The greatest execution issues were found only where the overburden heights were such as to make impossible an in-depth investigation of the lithological and granulometric variability that this formation may present, as in the case of section D-C.

Another critical geological issue was represented by the hydrogeological structure of the area, due to the presence of a continuous aquifer along the entire sewer route, with piezometric heights in the microtunnel sections creating water heads up to about 25 m, with respect to the depth of the excavation bottom.

In addition to these complexities (heterogeneity of geolithological formations, drive lengths, presence of groundwater and excavation depths down to over 60 m), during the execution of the works, further technical challenges arose from the presence of soils that were partly different from those expected, including clays with high cohesion and plasticity. In fact, at the design stage, the possibility of carrying out deep survey was limited due to important access restrictions to the protected area.

2.2 Specific features

The following chapters highlight the distinctive features of the project.

2.2.1 Section B-C

Main features:

- length: 1235 meters. It has been recognised as the longest drive ever made in the world with GRP pipes;
- overfill: 59 meters at the chainage of 530m;

geology: with the exception of a first section of approx. 100 meters in alluvial soil and deposits, most of the drilling was expected to cross the "Sacrofano stratified tuffs".

2.2.2 Section D-C

Main features:

- length: 1069 meters;
- maximum overfill: 63 meters;
- complex geology: based on project documentation, the entire crossing was predicted through sandy silt and silty sand facies of the Fosso della Crescenza formation (s). In reality, consistent clays (a) were found along most of the drive length, which were absolutely unforeseen at these depths. In addition, the repeated vertical alternation of different materials worsened the situation.

2.2.3 Section D-I

Main features:

- length: 970 meters;
- maximum overfill: 36 meters;
- planimetric development: the distinctive feature of this crossing is represented by its approximately 970m long, non-straight route (Figure 6). In fact, in addition to a straight section, its planimetric development presents a 350m long section with a circular curve of 600m radius. This particular curved section required the use of reinforced concrete pipes having a length of 3 meters and a diameter DI1700/DE2120.

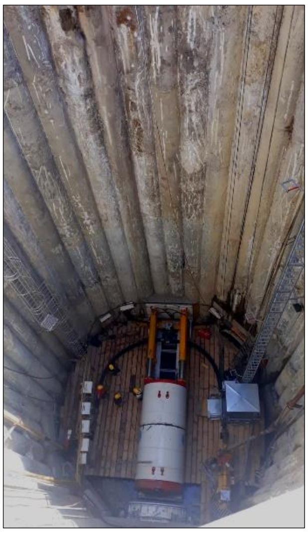


Figure 5 – Top view of shaft D, depth 22m

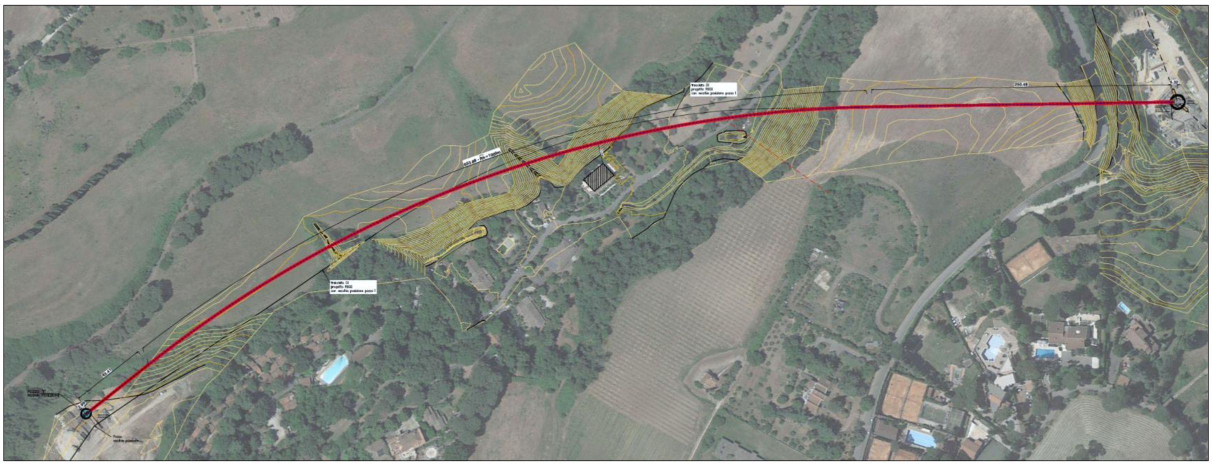


Figure 6 – Orthophoto of the section D-I with curvilinear planimetric development

2.2.4 Type of pipes chosen to be laid by microtunnelling method

Centrifugal cast GRP pipes were used for the main sewer line, with the aim of guaranteeing high water tightness.

In order to ensure the performance required under design conditions, before starting the works, the supplier (AMIBLU) carried out specific official laboratory tests to test the actual compliance of the joint tightness with the requirements of the Technical Specifications (PN6 lining both inside and outside).

2.2.5 Design of the Intermediate Jacking Stations

Due to the length of the single drives and the particular geological features of the soils to be crossed, it was necessary to provide for the installation of a suitable number of intermediate jacking stations.

As GRP pipes are not standard products, a specific and articulate study was necessary. The intermediate jacking stations were designed in cooperation with the pipe manufacturer, in order to combine the very limited permissible tolerances and the use of an elastic material such as the GRP, with the need to actuate the IJS for many cycles because of the lengths of some microtunnels.

Therefore, the following elements were manufactured:

1. Lead Pipe: element connecting to the front of the metal piece;
2. Lag Pipe: male element inserted after the intermediate jacking station, which remains steady during jack extension and retraction and seals to the IJS thanks to its head gasket on which the metal casing slides;
3. Interjack Adaptor: adapter ring intended to transfer the jacking force from the jacks to the pipe, and compensate for the dimensional differences between the two;
4. Interjack Active Seal: ring provided with gasket, intended as an additional measure to prevent any leakage from the gasket of the Lag Pipe;
5. Steel cylinder: a metal piece which is the mobile part of the IJS. A metal cross is installed to avoid deformation during transport.

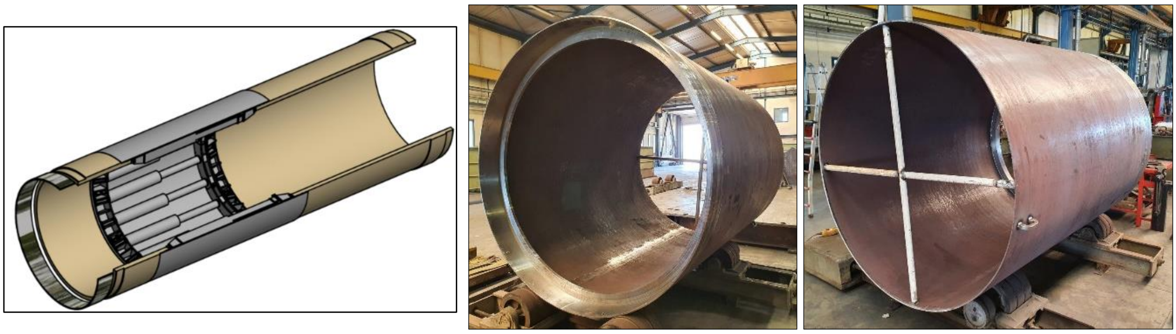


Figure 7 - 3D view of an IJS (left), coupling side of the steel cylinder (centre) and detail of the metal cross (right)

The design and manufacturing of the steel cylinder was particularly critical, as this element should both ensure water tightness, because of the high hydraulic pressure at the joint, and allow operational activities.

Therefore, the metallic piece should:

- take into account the reduced construction tolerances for coupling when assembling and using the piece on site (risk of coupling difficulties or damage to the gasket due to the slight clearance tolerances between the metal piece and the GRP pipe);
- be technically feasible using machining technologies, to guarantee a high degree of precision;
  comply with the design requirements of the manufacturer Amiblu, in order to ensure the movement of the IJSs and their hydraulic tightness.

A prototype was therefore manufactured and tested for the assembly of an IJS in order to check the functionality of the elements and establish the correct on-site assembly method. The resulting operating procedure provided for the use of a base frame on which the elements (lead pipe, steel cylinder and lag pipe) should be positioned; after assembling the adapter rings, they were connected by sliding them on the track by means of jacks and dywidag bars.

Figure 8 – View of the jacks and dywidag bars (left) and IJS assembled laying on the tracks (right)

3. ISSUES AROSE AT EXECUTION STAGE

3.1 Drilling in consolidated, high-plasticity and swelling clays

One of the main criticalities arisen during drilling, especially in Section B-C and Section D-C, was the presence of layers of compact clay, which was sometimes swelling and pushing.

The geological profiles shown below superimpose the geology predicted in the project with the soils actually crossed during both drives. Soil evaluation resulted from the analysis of the excavated material leaving the separation plant.

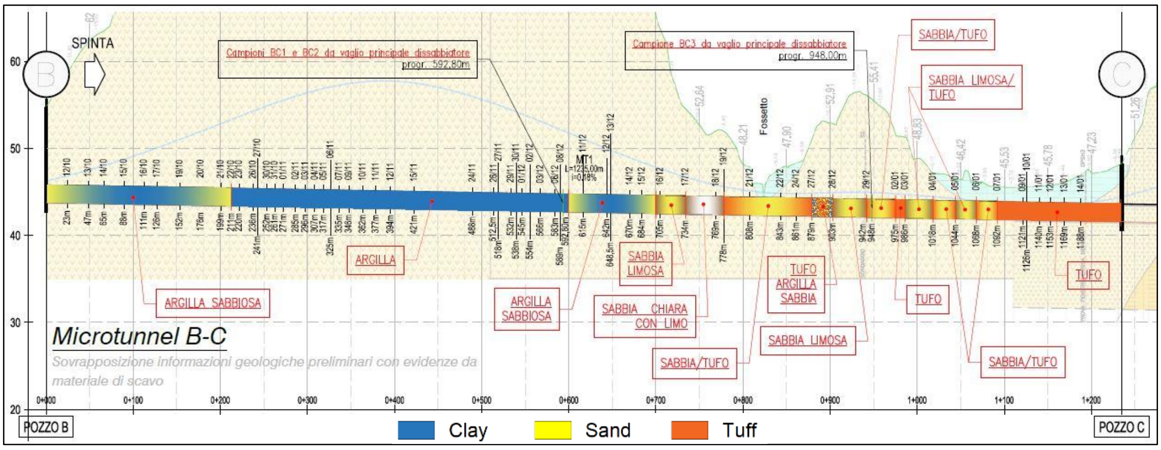


Figure 9 - Superposition of the geology predicted in the project with the soils actually crossed (Sec. B-C)

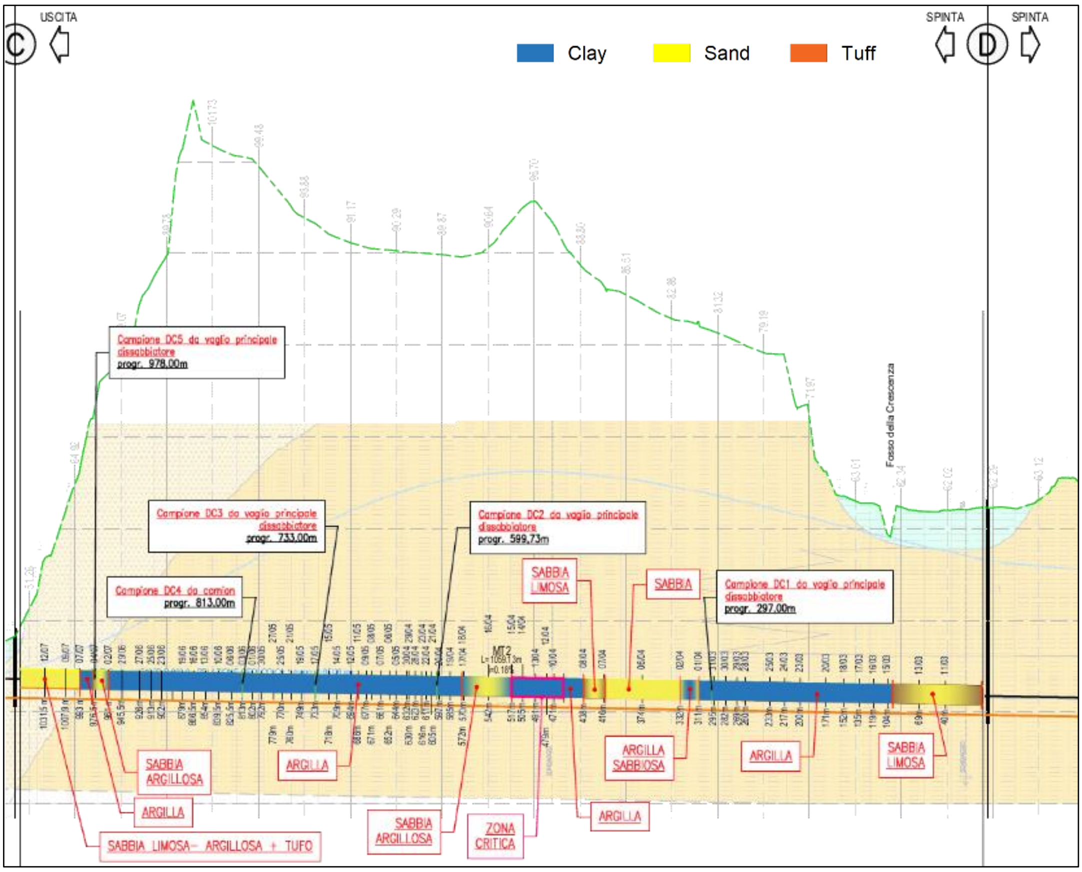


Figure 10 – Superposition of the geology predicted in the project with the soils actually crossed (Sec. D-C)

As a first consequence, there was a significant decrease in drilling speed during both drives. This in itself is an important aspect, especially if we consider that the length of these two drives is over a kilometre. The reduced drilling speed inevitably caused a series of problems due to wear and the difficulty of intervening in such long pipes.

During the drilling of Section D-C, from chainage 420m there was a strong increase in resistance during the jacking process, which required an intensive use of the intermediate jacking stations. However, this was not sufficient to prevent the blockage of the drive progress at chainage 460m. In researching the causes that led to the stoppage of drilling operations, it appeared clear that the same was due to the clay swelling which completely clogged the over-excavation, thus exerting a strong direct soil pressure on the surface of the pipes.

The data obtained from the subsequent laboratory tests and from evidence found on site showed that the presence of pressurized groundwater in the section under investigation caused a quick and progressive swelling of the clays.

Therefore, it was envisaged to intervene inside the pipe in order to:

- reduce the external pressure on the area subject to the greatest load;
- re-feed the lubrication outside the pipes in the areas relieved from the external overpressure that caused the stop.

The reduction of local pressure was obtained installing relief valves on all the pipes crossing the section where the blockage occurred. The valves were installed in specific points, which were identified after a check and analysis of the relevant data available. The effect of these valves was to drastically decrease the confinement pressure on the pipe (with consequent reflux of material inside the pipe – see Figure 11). To complete the intervention, additional injection valves were installed to restore lubrication in the contact area between the pipe and the soil.

Once the drilling restarted, this operation was systematically repeated until the end of the drilling, depending on the specific needs.
The Intermediate Jacking Stations was installed as per operational practice, with a distance of 100m from each other. So, during these operations, the reliability of the IJSs proved to be essential. Indeed, some of them were actuated over 3000 times during the drilling, without any malfunction.

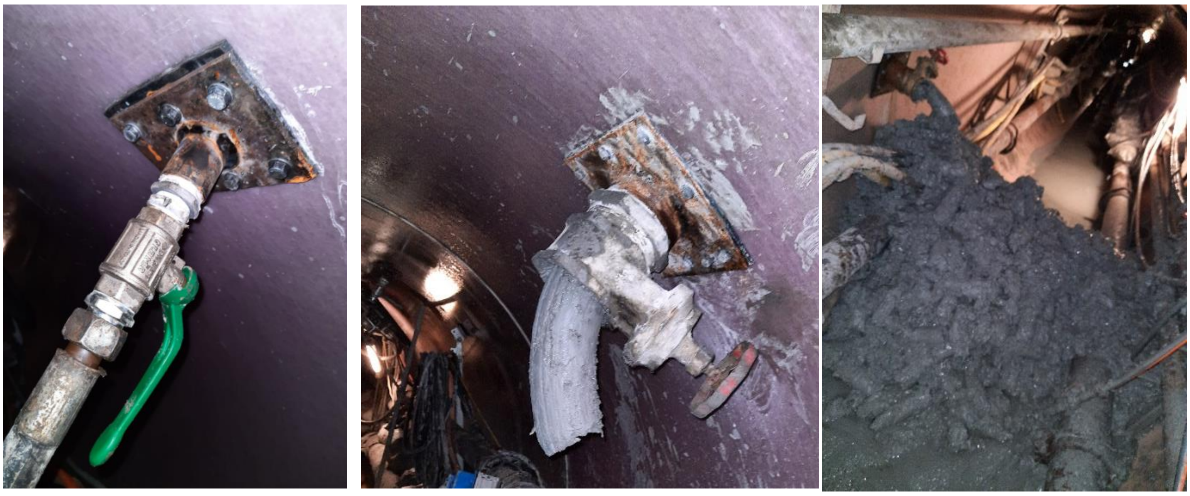


Figure 11 - Additional lubrication (left) and purge (centre) valves with backflow of plastic clay from the outside. On the right, detail of the accumulation of extruded material inside the tunnel.

In order to understand the causes that led to the blockage and how to intervene, it was of key importance to try to identify the rheology of the soils crossed, by analysing the results of the classification tests on the samples taken:

- during project surveys;
- in the relief valves installed on the pipes between chainage 420 and 560 of section D-C;
- in the excavated material from section D-C;
- in the material found in the plant at the end of section B-C.

Classifica USCS	Indagine di progetto			Valvole sfogo Tratto D-C		Materiale rimaneggiato Tratto D-C				Materiale da vaglio Tratto B-C		
Descrizione campione	S5C3	S5C4	S5C5	C1/V tubo 49	C1/V tubo 87	DC1	DC2	DC3	DC4	BC1	BC2	BC3
	ML	CL	CH	CH	CH					CH	MH	MH
Limite liquido WL (%) =	37,10	45,00	53,30	53,60	57,00	59,20	69,10	59,90	64,60	55,20	59,30	69,40
Limite Plastico WP (%) =	27,80	22,70	26,90	19,30	19,00	28,80	32,90	29,30	30,30	28,10	35,50	47,10
Indice Plastico Ip (%) =	9,30	22,30	26,40	34,30	38,00	30,40	36,20	30,60	34,30	27,10	23,80	22,30
Frazione argillosa (%) =	31,10	62,90	57,10	51,00	51,10	58,20	52,80	65,90	48,90	41,20	38,40	17,00
Attività =	0,30	0,35	0,46	0,67	0,74	0,52	0,69	0,46	0,70	0,66	0,62	1,31

Figure 12 – Atterberg Limits related to the different samples considered

The Liquid Limit and the Plasticity Index were used to identify (in a simplified way) the presence of active clayey minerals and possible similar mineralogy in the two clayey soils.

Analysing the Casagrande Plasticity Chart (Figure 13), it has been shown that the samples taken during the geognostic survey showed low plasticity (S5C4-CL and S5C3-ML) or slight plasticity (S5C5-CH) and belonged to layers with very different mineralogy.

The samples of section B-C show a high plasticity, but are also different from each other (CH or MH)

The samples of section D-C show a high plasticity (CH) and are fairly clustered around the Line A.

The samples taken from the relief valves in the section where the pipes were subjected to compression phenomena and consequent blockage, are positioned in the area of high plasticity clays (CH), but in an area which is very distant from Line A, showing a behaviour attributable to more active and plastic clays even compared to the clayey layers of the same segment.

In short:

- C1/V pipe 49 and C1/V pipe 87 from relief valves were more plastic and with more swelling minerals;
- DC2 and DC4 were plastic and with similar mineralogy;
- DC1, DC3 were plastic and with similar mineralogy;
- BC1 and S5C5 were plastic and with similar mineralogy;
- BC2 and BC3 were high plasticity silts;
- S5C3 and S5C2 were clays and silts with low plasticity.

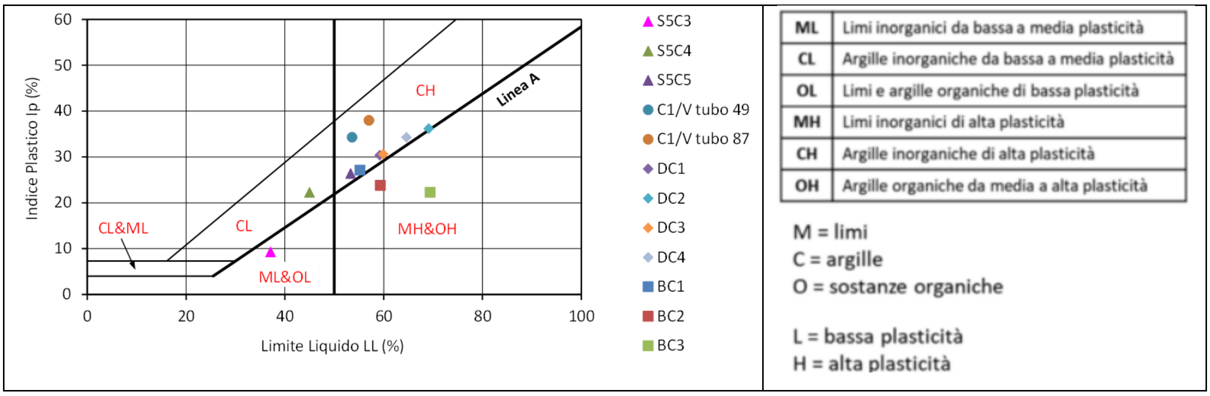
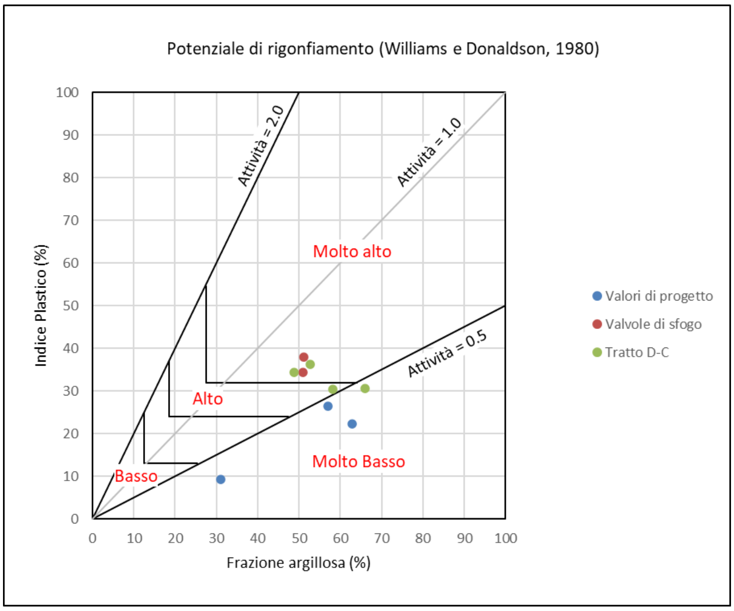


Figure 13 - Casagrande Plasticity Chart with the samples considered. Classes above line A include inorganic clays, those below line A include silts and organic soils

From surveys and data available, we found that the swelling potential of clays (according to the Navfac DM7_01 design manual) is closely linked to their mineralogy and proportional to their ability to “activate” in the presence of water.

The graph below shows that the samples, taken in the segment where the pipes had most suffered the effects of swelling, have a very high swelling potential.



3.2 Management of the excavated material

Another consequent and not negligible aspect when crossing swelling clays was represented by the unexpected quantity of excavated material to manage.

The swelling of clays produced an important volume of material to be disposed, which, especially in some stretches of section D-C, recorded an increase of almost 100% compared to the initial predictions based on the theoretical excavation section.

The difference is due to two main causes, strongly linked to the swelling potential of the clay:

1. *Quantity of extruded soil resulting from the clogging of the over-excavation*

   Making a mass balance, the analysis of data collected from the samples of excavated soil shows that 50% of soil disposed consist of extruded material (highly swelling clays).

2. *Water content in the excavated material at the end of dehydration process*

   Drilling in mineralogically active and therefore highly swelling clays means considering the average water content of soil after dehydration process in the slurry treatment plant (desander + centrifuge units) in order to manage the spoil.

Based on typical data on these soils, the water content is estimated to be:

- 55% for the sandy facies;
- 75% for the clayey facies (which retains much more water in their lattice).

The greater quantities, in terms of weight and volume, of the materials to be disposed of have a big impact on logistics and transport costs, as well as on disposal costs, especially when the excavated material is classified as waste, such as in this case.

4. CONCLUSIONS

- NO DIG technologies allow operating in very critical environments, which have external constraints that would otherwise prevent the execution of important works due to their environmental impacts, such as sewage and wastewater management.
- Appropriate pipe strength and stress response during the jacking process, as well as a correct design and manufacturing of the intermediate jacking stations allow for drives of over 1,000 meters with GRP pipes even in very complex lithostratigraphic conditions.
- A prior risk assessment combined with adequate company know-how and careful management of drilling parameters and boundary conditions allows to promptly deal with anomalous situations that may arise at the operational stage, especially when preliminary geotechnical investigation cannot be performed at a sufficient level.
- The quantities of material to be treated and disposed, if appropriate, change not only depending on drilling diameters, but also on the types of soils crossed. In case of plastic and swelling clays, there may be a significant increase compared to other soils such as sands and silty sands.

Figure 14 – TBM recovery from the shaft E (left) and the arrival of the TBM in the archaeological excavation of shaft C, at the completion of the Section D-C drive (right)