GEEG
GEOTECHNICAL & ENVIRONMENTAL ENGINEERING GROUP

Startup di

SAPIENZA
UNIVERSITÀ DI ROMA

Effectiveness study of Porous Alpha product for soils and rocks from mechanized tunnelling applications

Summary of the laboratory activities

Final report

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Index

Figures

Tables

1 Introduction

GEEG (Geotechnical and Environmental Engineering Group) is a Startup Company of “Sapienza" University of Rome. The company aims to actively contribute to the scientific progress in the world of tunnels and underground excavation by developing innovative experimental procedures, to verify the properties of materials and chemical products, to monitor the technical performances and reduce the environmental impact of the works.

GEEG is a reference structure on the experimental tests on materials and products, on the chemical treatment of soil, on the environmental studies and in the monitoring activities in the world of tunnelling.

This document is the report of the effectiveness study of the Porous Alpha product, proposed as a water retainer to be mixed with soil.

The study conducted by GEEG includes an experimental activity, carried out in the Geotechnical Laboratory of the Department of Structural and Geotechnical Engineering of Sapienza University of Rome (DISG) which is equipped to develop specific tests to verify the effectiveness of the product in modifying the characteristics of soils and to make them suitable for the tunnelling operations.

2 Experimental program

2.1 Aims

EPB-TBM technology can rightly considered one of the latest innovations in terms of automation, performances and safety and certainly one of the most widespread methodologies in the word of tunnels excavation.

Through this technology, pressure is applied to the front face using excavated soil mixed with water and chemicals. The injection of chemicals, defined soil conditioning process, is performed to the front-face and in the working chamber of the TMB.

After the excavation, the soil, temporary placed in an area outside the tunnel, presents unsuitable characteristics:

- liquid consistency;
- not proper workability due to excess water, and thus it is difficult to transport;
- poor mechanical strength characteristics;
- variable chemicals inside.

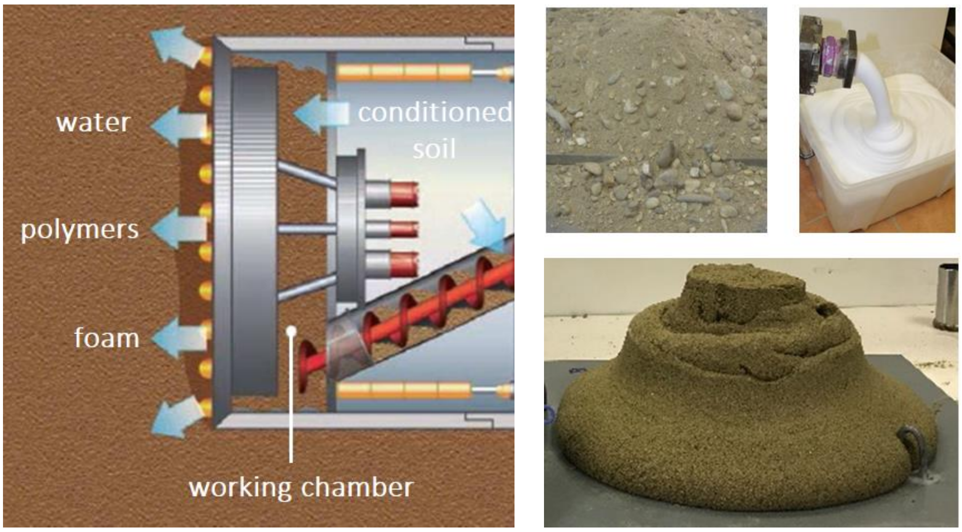

Figure 1. EPB-TBM scheme on the left and laboratory soil conditioning process on the right.

To remedy this, typically chemical additives (as superabsorbent polymers) are mixed with the soil.

In the experimental activity here reported, GEEG would like to verify the possibility of using Porous Alpha product mixed with conditioned soil, in substitution of chemical additives, to:

- absorb part of the excess water present into the soil and thus improving its overall behaviour and increasing its workability, starting from the same water content;
- introduce, at least partially, a solid skeleton and consequently increasing the mechanical characteristics and reducing compressibility;
- increase the amount of air present in the soil and consequently increase the evaporation rate of excess water;
- increase the amount of air present in the soil and consequently increase the biodegradation rate of the conditioning agents injected during tunnelling operations.

The main goal of this activity is to study the effectiveness of the Porous Alpha product in order to use it in substitutions of chemical additives typically used during the tunnel excavation in order to achieve many advantages on different point of views, such as:

- logistical aspects, as the possibility to quickly transport and or reuse the excavated material out of the construction site;
- economic point of view, as the reduction of the use of chemical agents and thus the increased possibilities of reusing the excavated soil with neglectable risks for the environment;
- environmental point of view, as the enhancement of the natural biodegradation due to the high presence of air into the soil and the enhancement of the reuse of soils and rocks as a non-renewable natural resource;

- circular economy processes, i.e. lower impact in terms of transport (vehicles, pollutions, noise impact, etc…), lower impact in terms of reduction of extraction activities from underground (quarriers for building materials, quarriers for coating road pavements, etc…).

2.2 Materials and dosages

In this research activity, the effectiveness of the Porous Alpha product developed by Better2Earth has been studied using three soils come from real EPB-TBM tunneling projects: one coarse-grained soil named hereafter Rome sand A and two fine-grained soil named Rome clay A and Rome clay B.

In order to verify the efficacy of this product, the results obtained through the tests performed on the conditioned samples treated with Porous Alpha were compared with those obtained from conditioned soils. To better understand the potential beneficial effect of the product against possible excess of water, the conditioning process was performed by reaching water contents higher than those usually used during the excavation phase.

In Rome sand A the product was used in his coarse-grained configuration (called hereafter "*granules*") with a percentage by weight equal to 42%; in Rome clay A, instead, the Porous Alpha was used as a "*powder*" with particles size less than 1 mm in two different percentages, equal to 5% and 27% by weight. Finally, in Rome clay B a mixture composed by 30% granules and 70% powder was used at 15, 25, 30 and 35% by weight.

2.3 Laboratory tests

In this experimental activity, the test described in the following paragraphs was performed on soils described in detail in chapter 3. As previously specified, the tests were conducted first on conditioned soils and then on conditioned soils treated with different percentages of Porous Alpha. Since during this activity the first results obtained led to think that the effectiveness of the product is influenced by the time, some of the tests were conducted not only right after the treatment (about 10 minutes later) but also after 48 hours, to highlight any differences.

Some of the tests entailed by this experimental program are well known and defined by ASTM standards, such as the grading curve and the Atterberg's limits. Another test that may be less common is described hereafter.

2.3.1 Flow table test

The flow table test or flow test is a method to determine the consistency of specimens. This parameter is determined by the increase in the mean diameter of a conically-moulded specimens which has been placed on the flow table (Figure 2) and received a defined number of vertical drops by lifting the flow table and letting it fall freely through a given height.

Any changes on the consistency of the soil induced by the addition of the Porous Alpha product, eventually in different concentrations, can be determined through this test.

Figure 2. Flow table test apparatus.

3 Soil samples characterization

As previously specified, in this study the Porous Alpha product has been used in one coarse-grained soil named Rome sand A and in two fine-grained soil named Rome clay A and Rome clay B. All three soils come from real EPB-TBM tunneling projects.

As reported in the following Table 1, Rome sand A is made up of 66.8% sand and the remaining 33.2% gravel. Rome clay A and Rome clay B, being fine-grained soil, have lower percentages of gravel and sand and high levels of silt and clay: the first soil is made up of 37.8% clay, 32% silt, 28.6% sand and 1.5% gravel, while Rome clay B is made up of 43.8% silt, 38.2% sand, 17.7% clay and the remaining 0.3% gravel.

Table 1. Granulometric ranges of Rome sand A, Rome clay A and Rome clay B.

	clay (%)	silt (%)	sand (%)	gravel (%)
Rome sand A	0.0	0.0	66.8	33.2
Rome clay A	37.8	32.0	28.6	1.5
Rome clay B	17.7	43.8	38.2	0.3

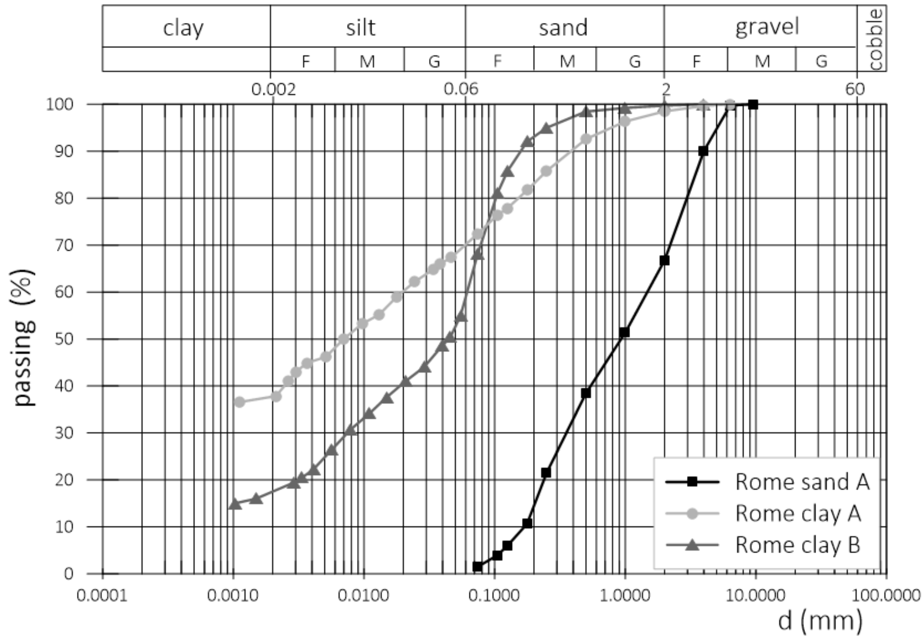

Figure 3. Grain size distribution of Rome sand A, Rome clay A and Rome clay B.

In Table 2 and in the Casagrande plasticity chart (Figure 4) the Atterberg limits obtained for the two fine-grained soils are reported: liquid limit w_L, plastic limit w_P, plasticity index I_P and activity *A*. From these results it can be seen that Rome clay A shows a higher plasticity due to its particles size composition, i.e. higher percentage of silt and lower percentage of sand. These differences could highlight different behaviours of the soils after the addition of the Porous Alpha product.

Table 2. Atterberg limits of Rome clay A and Rome clay B.

	w_L (%)	w_P (%)	I_P (%)	A (-)
Rome clay A	66.5	32	34.8	0.92
Rome clay B	27.6	18	9.3	0.52

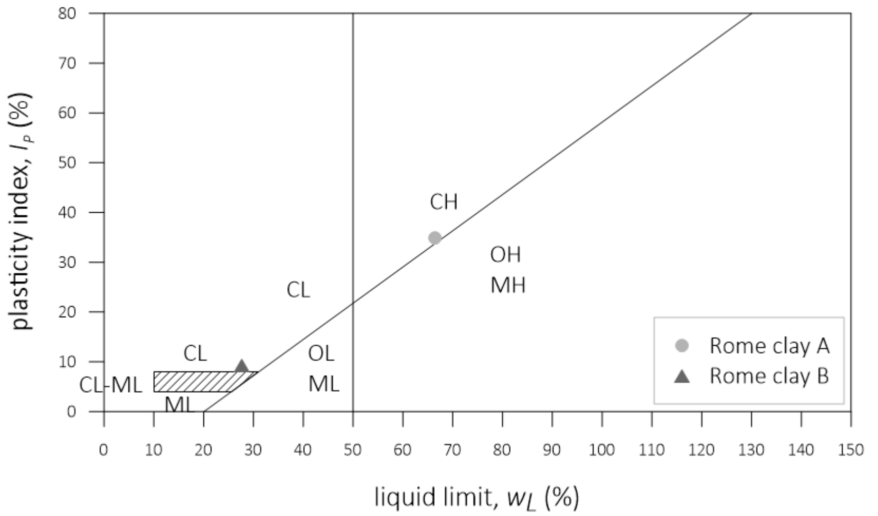

Figure 4. Casagrande plasticity chart of Rome clay A and Rome clay B.

4 Results

In this chapter all the results obtained through the aforementioned test, on samples treated with different concentrations of Porous Alpha product, are reported in order to verify the effectiveness of the product itself on coarse- and fine-grained soils.

The main aspect investigated is the possible change in consistency of soils come from real EPB-TBM tunneling projects.

4.1 Results for Rome sand A

The flow table test was performed, as above described, first on the Rome sand A samples conditioned with the dosages reported below in Table 3 and then on the samples conditioned and treated with 42% by weight of Porous Alpha granules:

Table 3. Conditioning dosages for Rome sand A.

soil	w_n (%)	WIR (%) by volume	C_f (%)	FER (xx:1)	FIR (%)	TR (l/m^3)
Rome sand A	10	10.0	2.0	10	40	0.8

As already mentioned, these conditioning dosages lead to water contents higher than those usually used during the excavation phase: in this way it is easier to highlight any changes induced by the Porous Alpha.

The flow table test was carried out to determine the consistency of specimens. In this case the parameter is determined by the increase in the mean diameter *d* of a conically moulded specimens subjected to 15 vertical impacts.

The results in Table 4 and the pictures here below show a great increase in the consistency of the specimens after the addition of Porous Alpha, i.e. a considerable decrease in the mean diameter of the samples after 15 drops if compared to the conditioned untreated sample. As shown in the following table, in fact, after the treatment the water content *w* of the sample is reduced by about 6%.

Table 4. Results of flow table tests for Rome sand A.

	Porous Alpha (% by weight)	w (%)	d (cm)
Rome sand A	0	20.28	24.50
Rome sand A	42	14.46	15.75

1)

2)

Figure 5. Pictures of: 1) over-conditioned Rome sand A; 2) over-conditioned Rome sand A treated with 42% of Porous Alpha.

4.2 Results for Rome clay A

For Rome clay A the flow table test was performed, as above described, first on the soil samples conditioned with the dosages reported below in Table 5 and then on the samples conditioned and treated with 5% and 27% by weight of Porous Alpha powder.

Table 5. Conditioning dosages for Rome clay A.

soil	w_n (%)	WIR (%) by volume	C_f (%)	FER (xx:1)	FIR (%)	TR (l/m^3)
Rome clay A	30	5.0	2.0	10	50	1.0

Even for this soil, these conditioning dosages lead to water contents higher than those usually used during the excavation phase.

In this case the consistency of specimens is determined by the increase in the mean diameter *d* of a conically moulded specimens subjected to 15 vertical impacts, then 25 and at the end 40.

The results in Table 6 and the pictures here below show a slight increase in the consistency of the specimens after the addition of 5% Porous Alpha, i.e. a decrease after 40 drops of about 40% in the mean diameter d_{40} of the samples if compare to the same parameter obtained for the conditioned untreated sample. When the soil is treated with higher percentages of Porous Alpha, as expected the improvement of the consistency is more evident: the decrease in the mean diameter at the end of the test (40 drops) after the treatment with 27% of product is about 85% if compared to the conditioned untreated sample and about 50% compared to the specimen treated with 5% of product.

Even in this case by adding Porous Alpha into the samples the water content *w* is reduced: for the dosage equal to 5% the reduction is about 1.5%, for 27% of product the reduction is higher than 10%.

Table 6. Results of flow table tests for Rome clay A.

	Porous Alpha (% by weight)	w (%)	d_{15} (cm)	d_{25} (cm)	d_{40} (cm)
Rome clay A	0	55.21	18.55	19.50	20.95
Rome clay A	5	53.58	15.20	15.85	17.20
Rome clay A	27	42.97	11.10	11.70	12.30

1) 2) 3)

Figure 6. Results after 40 drops for: 1) over-conditioned Rome clay A, 2) over-conditioned Rome clay A treated with 5% of Porous Alpha; 3) over-conditioned Rome clay A treated with 27% of Porous Alpha.

4.3 Results for Rome clay B

Flow table test was performed, as above described, first on the Rome clay B samples conditioned with the dosages reported below in Table 7 and then on the samples conditioned and treated with a mixture of Porous Alpha composed by 30% granules and 70% powder and used at 15, 25, 30 and 35% by weight.

Table 7. Conditioning dosages for Rome clay B.

soil	w_n (%)	WIR (%) by volume	C_f (%)	FER (xx:1)	FIR (%)	TR (l/m^3)
Rome clay B	17	12.5	2.0	10	70	1.4

Even for Rome clay B, to highlight any changes induced by the Porous Alpha the conditioning dosages chosen lead to water contents higher than those usually used during the excavation phase.

Being a fine-grained soil, as for Rome clay A even for Rome clay B the consistency of specimens is determined by the increase in the mean diameter *d* of a conically moulded specimens subjected to 15 vertical impacts, then 25 and at the end 40. Moreover, to evaluate if the product has a time-dependent behaviour when it comes in contact with the soil, the flow table tests are carried out not only on conditioned samples and about 10 minutes after treatment, but also after 48 hours.

The results in Table 8 and the pictures here below show, as expected, an increasing trend in terms of consistency as the percentage of the product increase, but for dosages up to 30-35% this trend seems to become constant.

It is also interesting to underline that 48 hours after treatment the effect of the product is more evident in the decrease of the mean diameter of the samples tested if compared to the results obtained after 10 minutes.

For what concern the water content *w* of the samples, as for the other soils tested, the results show that this parameter decreases after the addition of the product and this decrease is more evident for higher percentages. When the dosages of the product raise up to 30-35%, however, as for the consistency increase also the water content decreasing trend seems to become constant: the difference between the water content of Rome clay B treated with 30% and the same parameter of Rome clay B treated with 35% is neglectable.

Table 8. Results of flow table tests for Rome clay B.

	Porous Alpha (% by weight)	t	w (%)	d_{15} (cm)	d_{25} (cm)	d_{40} (cm)
Rome clay B	0	-	35.48	15.40	16.85	17.95
Rome clay B	15	10 min	31.29	14.45	15.35	16.25
Rome clay B	15	48 h	30.33	12.25	12.80	13.80
Rome clay B	0	-	34.66	15.40	16.85	17.95
Rome clay B	25	10 min	28.18	12.65	13.85	15.10
Rome clay B	25	48 h	27.70	11.70	12.35	13.05
Rome clay B	0	-	36.10	15.40	16.85	17.95
Rome clay B	30	10 min	26.81	12.75	13.80	14.90
Rome clay B	30	48 h	27.77	10.90	11.45	12.00
Rome clay B	0	-	36.17	15.40	16.85	17.95
Rome clay B	35	10 min	26.47	12.50	13.50	14.35
Rome clay B	35	48 h	28.38	11.20	11.95	12.70

1) 2) 3)

Figure 7. Example of results after 40 drops for: 1) conditioned Rome clay B, 2) conditioned Rome clay B treated with 15% of Porous Alpha after 10 minutes; 3) conditioned Rome clay B treated with 15% of Porous Alpha after 48 hours.

5 Conclusions and future developments

At the end of the experimental activities described in this document it was achieved a quite good knowledge, however preliminary, about the behaviour of the Porous Alpha product for soils and rocks from EPB-TBM mechanized tunnelling applications.

It is believed that the information acquired are enough to provide a general idea of the effectiveness of the product and it seems clear that it possesses all the features to be used after the mechanized excavation with EPB-TBM technology and particularly for soils with high water contents and thus low workability and poor mechanical strength characteristics in order to allow its proper management.

With reference to the performed tests, it is possible to list few conclusions:

- the Porous Alpha product can be proposed and used in place of synthetic or semi-synthetic polymers for specific tunnelling applications;
- through the soil treatment with Porous Alpha product, it is possible to absorb part of the excess water present into the soil and thus improving its overall behaviour and increasing its workability;
- on coarse-grained soils (sand and gravel) the use of Porous Alpha product in granules seems to be more appropriate considering the grain size distribution and the need to fill high volumes of voids;
- for fine-grained soils (silt and clay) the use of Porous Alpha product in powder or a combination of powder and granules seems to provide better results;
- the addition of Porous Alpha product, in fine grained soils, led to a time-dependent effect during the first 48 hours after the treatment which progressively increase consistency, mechanical strength and workability of soil;
- it is possible to reduce/optimize in a relevant way the amount of Porous Alpha required to obtain an increase in consistency, workability and mechanical strength of the soil.

Finally, it should be noted that the laboratory activities described in this document were aimed at testing the general effectiveness of the product tested in proper conditioning of some laboratory samples of natural soils and that therefore, in case of applications in a specific project, the dosage of the Porous Alpha product has to be determined by specific tests carried out using the soil coming from the real site.