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THE INFLUENCE OF THE EXTRACTION SPEED IN PULL-OUT TEST FOR CLOGGING RISK EVALUATION

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ABSTRACT. During mechanical tunnelling in fine-grained soils a common problem is that the excavated soil tends to stick to the metallic parts of the Tunnel Boring Machines (TBMs). Despite this troubling behaviour, known as clogging phenomena, strongly affects the profitability of a tunnelling project in fine-grained soils, a precise and reliable prediction method of the clogging potential is not available yet. One of the most widespread tests used to evaluate this phenomenon is the pull-out test, proposed in literature in different configurations. The experimental activity presented was aimed at studying the influence of the extraction speed on the results of plate pull-out tests carried out on two different fine-grained soils. An overall view of the results suggests that the maximum pull-out force registered for each soil sample increases as the speed increases: deriving the equations that links these data was possible to correlate, for each speed tested, the gaussian trends that discribe the clogging behaviour of fine-grained soils as the water content varies.

1. INTRODUCTION

Mechanical tunnelling in fine-grained soils is often affected by clogging phenomena and thus, as it is well known, the excavated soil tends to stick to the metallic parts of the Tunnel Boring Machines (TBMs). This means that this dangerous behaviour may occur at the cutting wheel, in the excavation chamber or in the conveyor belt of TBMs and, in the most serious cases, can also cause damages to internal components and the blocking of the machines.

The extent of the problem depends on many factors, among which:
- geological and geotechnical conditions: grain size distribution, mineralogy, plasticity, water content, ...;
- technical specifics of the TBM: cutting wheel design, pump capacity, …;
- construction operations: drive mode, downtime, ….

Despite the profitability of a tunnelling project in fine-grained soils is strongly influenced by the clogging potential of the materials involved (Thewes & Burger, 2005), a precise and reliable prediction of clogging behaviour is not yet possible. Among the different laboratory tests proposed in literature to evaluate this phenomenon, such as mixing test and modified direct shear test, and thus to assess the need for appropriate mitigation actions, the pull-out test (Thewes & Burger 2005; Khabbazi et al. 2019) is one of the most widespread and it is used in many different configurations, among which the plate pull-out test (Sebastiani et al. 2019).

This paper presents the results of an experimental activity developed in the geotechnical laboratory of Sapienza University of Rome, aimed at deepening the understanding of the plate pull-out tests, verifying any influences of the extraction speed on the results of this test and at correlating, for each speed tested, the gaussian trends that discribe the clogging behaviour of fine-grained soils as the water content varies. In fact, by varying the extraction speed of the test, it is possible to highlight and better understand the clays behaviour during the excavation through TBM when the cutting wheel advances at different rotation speeds, thus influencing the extent of the clogging risk.

A brief description of the main characteristics of two natural fine-grained soils (London and Viterbo clays) selected for this study and the results of the experimental campaign will be presented.

2. MATERIALS AND METHODS

The experimental study was focused on two fine grained soils: London and Viterbo clays, which differ mainly in terms of grain size distribution (performed following the ASTM D7928), plasticity (the determination of Atterberg limits was carried out following the ASTM D4318) and mineralogical composition (UNI EN 13925-2). The geotechnical characterization of these clays (described in detail by Sebastiani et al., 2022a, which also contains some information about the mineralogy of the two clays) is briefly reported in Table 1, where w_L and w_P represent liquid and plastic limits, I_P plasticity index, A activity and G_s specific gravity of the two clays.

Table 1. Geotechnical characteristics of the two soils tested.

soil sample	clay (%)	silt (%)	sand (%)	gravel (%)	w_L (%)	w_P (%)	I_P (%)	A (-)	G_s (-)
London	18	48	27	7	54	28	26	1.43	2.55
Viterbo	25	69	6	0	38	21	17	0.68	2.70

Samples at a fixed water content for each soil were prepared and plate pull-out tests at different speeds were carried out.

The pull-out test, even if still not included in international standards, is proposed in literature (Feinendegen et al., 2011; Zumsteg & Puzrin, 2012) and it is currently performed (Sebastiani et al. 2019) for clogging potential evaluations, as it provides information about the adhesion between a metallic element and the soil. Different authors, as Thewes & Burger (2005), Sass & Burbaum (2008) and Khabbazi et al. (2019), with different approaches, used this test to measure the clogging tendency of a soil. The test is performed by placing a metal tool in contact with the soil sample and then measuring the force necessary to separate the tool from the soil, extracting it vertically. The modified version of the pull-out test performed at the Sapienza University geotechnical laboratory, named plate pull-out test, was set up applying the same principle using a convex surface plate (curvature radius equal to 11 cm) instead of the conical or flat tool. This configuration was studied to improve the homogeneity of the contact between the steel tool and the soil: the plate, in fact, is pushed directly on the other half of the spherical joint leaving a thin layer of soil in between and thus eliminating possible unevenness or air bubbles, which can be created pre-drilling the cavity for the cone insertion in the cone pull-out test.

The execution modality of this modified configuration consists in the progressive approach of the tool to the soil sample, until they adhere completely causing the partial spill of the material from the gap, and the subsequent extraction of the tool at a constant speed of 5 mm/min (equal to extraction rate of the cone pull-out test) measuring the force at regular intervals. The maximum measured extraction force is the plate pull-out force, *PF*.

In this activity four different speeds (equal to 0.5, 1, 5 and 9 mm/min) were tested, in order to verify if and how the results of plate pull-out test are influenced by this parameter.

In order to evaluate how the extraction speed alone affects the maximum pull-out force registered for each clay, based on results of previous tests (Sebastiani et al. 2022b), it was decided to perform the laboratory tests fixing the water content at 42% for London clay and 28% for Viterbo clay.

3. RESULTS

The results obtained in this experimental activity through the plate pull-out test carried out at an extraction speed v equal to 0.5, 1, 5 and 9 mm/min are reported below, together with the water content w and the contistency index I_c.

Table 2. Results obtained through the plate pull-out tests carried out at different speed for the two clays.

soil sample	v (mm/min)	w (%)	I_C (-)	PF (N)
London clay	9.0	43	0.42	49.34
	5.0	42	0.44	40.52
	1.0	42	0.45	42.67
	0.5	42	0.45	36.98
Viterbo clay	9.0	28	0.58	97.41
	5.0	28	0.57	96.63
	1.0	28	0.56	83.97
	0.5	29	0.53	71.12

From these results it can be noted an overall increasing trend of the pull-out force as the speed increases: by interpolating these data with a linear equation (Figure 1) the results obtained at different speeds can be correlated. In particular, it is possible to calculate the difference *Δ* (%) between the *PF* values estimated at the standard speed of 5 mm/min and those estimated at differend speeds through the linear interpolation.

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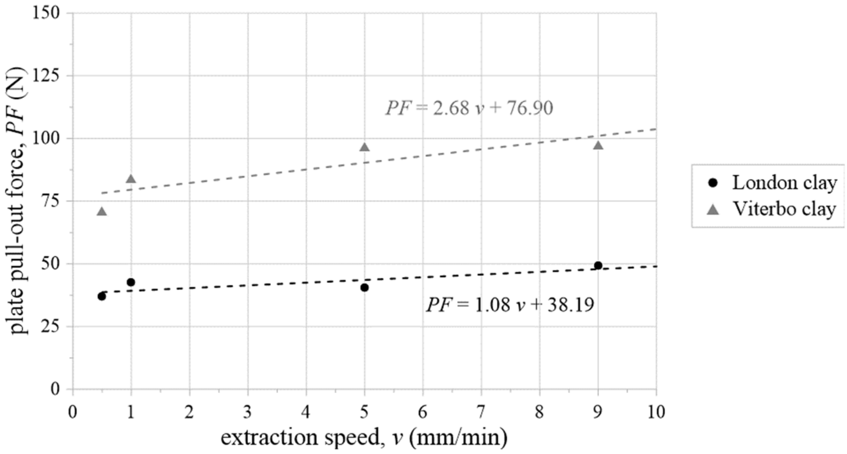


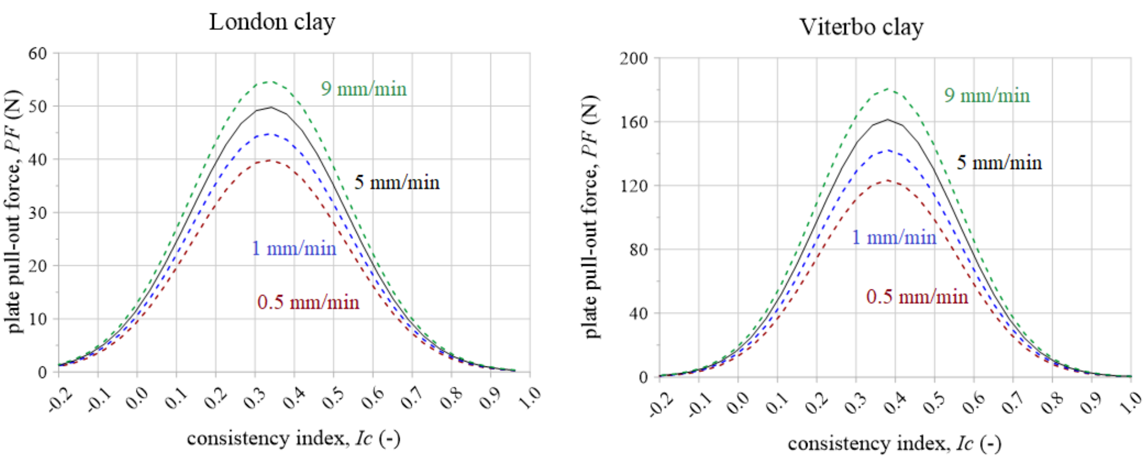
Figure 1. Trends obtained through the plate pull-out tests carried out at different speeds for the two clays.

For London clay the results of the pull-out test carried out at 0.5 mm/min are 11.1% lower than the one at 5 mm/min, while at 1 mm/min the difference decrease at -9.9%; at and 9 mm/min the results are about 9.9% higher. For Viterbo clay, instead, the differences are -13.4% at 0.5 mm/min and ±11.9% at 1 and 9 mm/min.

It can be noticed that for London clay, that presents a high percentage of sand (cfr. Chapter 2) and consequently low values of pull-out force (related to moderate clogging risk), the differences between the results obtained at various extraction speeds are less marked than the ones of Viterbo clay. The latter, in fact, presents higher percentages of fines and thus higher *PF* values and it can be noted that the calculated parameters *Δ* (%) are about 2% greater than those of London clay.

As already mentioned, clogging behaviour of fine-grained soils depends on many factors, among which the water content and consequently the consistency index: from literature (Feinendegen et al., 2011; Sebastiani et al., 2022a,b;) it is known that by varying this parameter for each soil clogging risk varies according to a normal distribution. This gaussian trends for London and Viterbo clays were already derived from punctual results obtained through the plate pull-out test carried out at 5 mm/min (Sebastiani et al., 2022b) therefore, through the just calculated parameter *Δ* (%), the clogging risk distributions of the two clays, associated with different test speeds, can be estimated. These correlations allow the understanding of the importance of the speed parameter in the pull-out test results and, moreover, can be used in similar works to compare the results of pull-out tests carried out at different speeds. It seems, in fact, that the gaussian curve that describe the clogging potential of a fine-grained soil when water content varies, depend not only on the geotechnical and mineralogical characteristics of the soil itself but also on the speed chosen for the test. By choosing 0.5 mm/min or 9 mm/min as test speed, for example, the same soil can be associated with a different clogging risk.

In Figure 2 the gaussian trends for London and Viterbo clays, already derived from punctual results obtained through the plate pull-out test carried out at 5 mm/min, are reported as a continuous line while the normal distributions derived from the linear interpolations proposed above are represented as dotted lines, together with the results obtained in this activity for each soil samples at different speeds.



a) b)

Figure 2. Normal distributions of clogging risk at different speeds for London (a) and Viterbo (b) clays.

4. CONCLUSIONS

The results of the experimental activity described in this paper provides some information about the influence of the extraction speed in the pull-out test, used to evaluate the clogging risk associated with fine-grained soils.

The main conclusions of this work can be summarised as follow:

1. as the extraction speed increases the pull-out values registered increase for both clays: the link between the data obtained can be approximated by a linear equation;
2. knowing the normal distribution that, for a certain extraction speed, describes the clogging behaviour of a fine-grained soil as the water content varies, it is possible to estimate the corresponding distribution related to different speeds;
3. it seems that for higher clogging potential, usually related to soil with higher percentages of fines, the difference between the *PF* measured at the standard extraction speed (equal to 5 mm/min) and the values measured at different velocities is grater.

It is important to underline that these are preliminary results, which require a deeper investigation. Several aspects can be explored in more detail, such as: repeating the plate pull-out tests on a larger number of fine-grained soils, with different geotechnical and mineralogical characteristics; varying the water content of the soil samples tested and decreasing the extraction speed even below 0.5 mm/min (paying particular attention to the possible drying of the sample for very long tests like these).

Nonetheless, this experimental activity shows that: during the excavation phase, different rotation speeds of the cutting wheel may influence the clogging behaviour of soil to be excavated; provides useful evaluations about the possibility of comparing the results obtained through various pull-out test modalities in different works and the results here proposed underline the need of a standardized methodology for the evaluation of clogging potential of a soil.

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