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Laboratory determination of cement consumption when using tube-a-manchette grouting

Détermination en laboratoire de la consommation de ciment lors de l'utilisation de coulis tube-a-manchette

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ABSTRACT: The tube-a-manchette (TAM) grouting technology is widely used in Bulgaria for strengthening soils under existing buildings and structures. For fine grained soils, the method is not always applicable. This paper presents a laboratory study using a device for determining cement consumption when grouting under low pressure. Some of the laboratory results are used for evaluation and comparison with the tube-a-manchette (TAM) grouting performed when strengthening a building in Sofia. A correlation was searched between groutability ratio and the soil properties of typical Bulgarian soils.

RÉSUMÉ : La technologie de TAM est largement utilisée en Bulgarie pour le renforcement du sol sous les bâtiments et constructions existants. Pour les sols à grain fin, la méthode n`est pas toujours applicable. L`article présente une étude laboratoire avec un appareil de détermination de la consommation du ciment en jointoiement à la pression basse. Une partie des résultats laboratoires est utilisée pour l'évaluation et la comparaison avec l`injection de TAM en renforçant les bâtiments existants à Sofia. Il a été déterminé aussi l'effet de la pression d'injection et de la taille des grains de ciment à la consommation. Il a été recherché la corrélation entre le coefficient d`injection et les paramètres du sol qui sont typiques pour la Bulgarie.

KEYWORDS: tube-a-manchette (TAM), grouting, strengthening

1 INTRODUCTION

The injection of cement grout under low pressure by means of the Tube-A-Manchette (TAM) grouting method is one of the most applicable, technologically accessible and efficient methods for strengthening the soil under existing structures in Bulgaria.

The main problem associated with the application of this method is determining the possibility of injecting the soil. Until now, the practice of determining and predicting the required amount of solution has relied on approximate methods and correlations (Totsev & Ruseva 2020).

In 2020, a device for determining the injectability of cement grout in a soil sample in laboratory conditions was developed and presented, and the "TAM groutability ratio" was defined (Totsev 2021).

The purpose of this paper is to present the results of the laboratory tests performed to determine the "TAM groutability ratio" and to classify various soils according to this coefficient.

A number of graphical dependences between the "TAM groutability ratio" and various soil properties are presented in search of a correlation.

A case study of a heavily cracked building in the city of Sofia is presented, where a complete strengthening of the sub-grade soil was subsequently carried out by the TAM grouting method. Test pits were also made. The samples taken from the test pits were examined in laboratory conditions, which guarantees successful injection and predicts the exact amount of cement grout required.

2 THE TUBE-A-MANCHETTE (TAM) GROUTING METHOD

The method itself is well known in practice. The grouting technology is shown schematically in Fig.1.

A metal or plastic pipe with holes is lowered into a pre-drilled borehole. The openings are covered with manchettes. The area between the pipe and the soil is filled with cement-bentonite grout. The grout is injected under low pressure using a packer. The cement grout enters through the pre-drilled holes in the pipe and penetrates the soil. In this way the stress and strain characteristics of the soil are significantly improved.

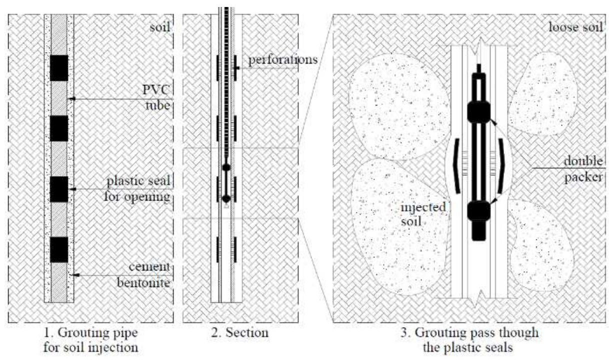

Figure 1. Tube-a-manchette grouting - typical scheme.

The disadvantage of this method is its inapplicability and lack of proof of effectiveness in some soil types such as very dense clays. Until now, an experimental section has been injected in order to prove the method's applicability.

The use of the device for determining the "TAM groutability ratio" in laboratory conditions makes it possible to assess the applicability of the TAM grouting method in the research phase and, if necessary, to move to an alternative approach such as jet grouting, pile foundation, etc

3 A DEVICE FOR DETERMINING THE "TAM GROUTABILITY RATIO

As shown in Fig. 2 the device for determining the "TAM groutability ratio" includes an air compressor (1), a control panel (2), a pneumatic cylinder with a piston (3), a metal tank for injection grout (4), a transparent polymer tank for embedding soil samples (5).

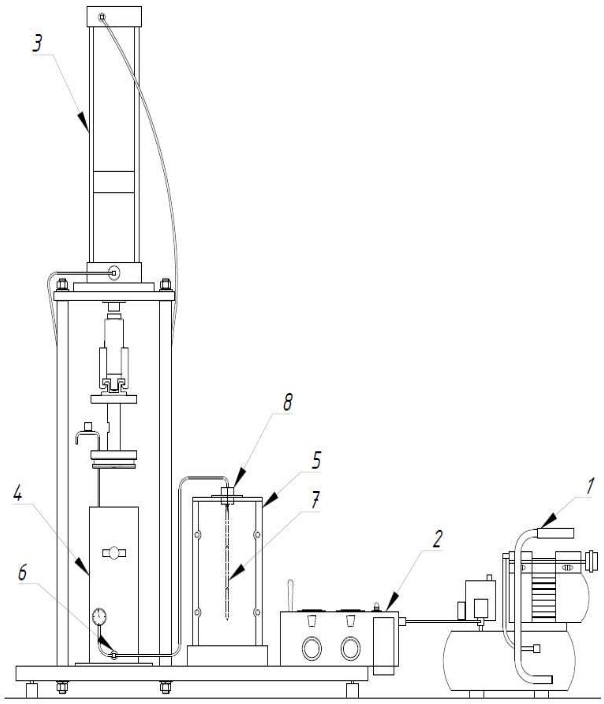

Figure 2. Schematic diagram of a Device for determining the "TAM groutability ratio" (Totsev 2021).

The device works in the following way: the air compressor activates the piston of the pneumatic cylinder and creates a constant pressure in the injection grout tank. The injection process begins with the opening of the shut-off valve (6), which feeds the grout into the injector and then to the soil sample. The injector (7) is firmly attached to the soil sample tank with a screw-in nozzle (8). On Figure 3 we can see the device construction and how the grout pass through the injector and enter the soil.

When working with the device, first the soil sample tank, which has a cylindrical shape and a central hole, is opened and a pre-drilled soil sample is placed into it. If necessary, the joint between the soil and the container can be sealed with silicone. After closing the tank, the injector is inserted into the pre-drilled hole.

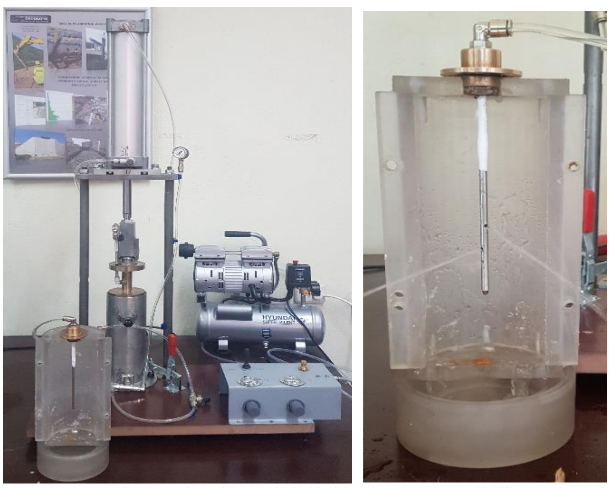

Figure 3. A device for determining the "TAM groutability ratio" (a), transparent polymer tank, screw-in nozzle and injector (b).

The tank is weighed together with the sample and the injector in order to determine its weight before injection. Cement grout is placed in the grout tank according to a pre-selected and prepared recipe. The injection process begins when constant pressure is created in the system.

The experiment is performed for 10 minutes. At the second and fifth minute the control amount of the injection solution that has been injected into the soil is measured. In different soil types, the saturation with grout occurs at different durations, for example as early as 2 minutes, and sometimes even 30 seconds are sufficient.

In the process of adapting and refining the device it was found that rather adequate results are obtained even without embedding the soil sample in the transparent polymer tank. When the soil sample has a stable shape, it can be covered with fine gauze and placed on a base of transparent polymer.

In case of non-injectable or poorly injectable soils, there is no visual change during injecting the grout. In medium, well and strongly injectable soils, the grout passes through the soil and flows into a larger container. Subsequently, the weight of the soil before and after the injection is determined again and thus the water remaining in the soil sample is determined exactly.

Despite the possible leakage of fine soil particles, the results of the defined "TAM groutability ratio" remain close to those of the embedded soil samples. A huge advantage of the non-embedded injection is the opportunity to monitor the process visually as well as the way the grout enters the volume of the tested sample. The obtained data are compared with field experiments and show good overlap of the results.

To determine the ability of a soil to be injected or, respectively, what will be the effectiveness of the TAM grouting method in a particular geology be, the authors propose a classification table (see Table 1) of soil injectability depending on the laboratory-obtained "TAM groutability ratio" $k_{inj,2}$

The conclusions were made after grouting many soil samples.

Table 1. Soil classification depending on the "TAM groutability ratio" $k_{inj,2}$

Soil type	$k_{inj,2}$
Non-injectable soil	$0 \leq k_{inj,2} \leq 3$
Poorly injectable soil	$3 < k_{inj,2} \leq 6$
Medium injectable soil	$6 < k_{inj,2} \leq 12$
Well injectable soil	$12< k_{inj,2} \leq 16$
Strongly injectable soil	>16

The "TAM groutability ratio" is the ratio of the injected solution for a period of 2, 5 or 10 minutes to the actual void ratio. The shown Equation 1 is a example how receive the result for 2 minutes.

$$k_{inj,2} = \frac{V_{inj}}{V_{ss}.n} \quad (1)$$

4 DETERMINING THE "TAM GROUTABILITY RATIO" OF VARIOUS BULGARIAN SOILS

110 experiments with various soil samples were conducted at the laboratory of the Department of Geotechnics of the University of architecture, civil engineering and geodesy in Sofia, which determined the physical characteristics, grain size distribution and "TAM groutability ratio".

Some of the obtained results are shown in Table 2. The data in the table are taken from different sites and soil samples in order to show the variety of results

Table 2. Some results of experiments conducted at the laboratory of the Department of Geotechnics at the UACEG

	Sample No	Soil classification according to BDS EN ISO 14688-2	$k_{inj,2}$
1	Dimovo, No 515	csa FGr	11
2	Dimovo, No 310	Cl Sa	3
3	Dimovo, No 496	gr cl Sa	5
4	Lyaskovets, No 4-1	Cl	8
5	Sofia, No 577	sa si Cl	7
6	Sadievo, No 528	sa Cl	2
7	Shumen, No 190	si Cl	16
8	Bankya, No 1	csa MGr	31
9	Razgrad, No 455	sa si Cl	12
10	Tolstoy, No 1	si Cl	45
11	Tolstoy, No 7	Cl	18
12	Stara Zagora, No 89	gr sa cl S	11
13	Stara Zagora, No 101	gr sa Cl	24
14	Graf Ignatievo, No 207	sa si Cl	8

Samples numbers 10 and 11 were taken from the Tolstoy site in Sofia, which was subsequently injected using the TAM grouting method and the obtained laboratory results were compared with the actual injected amounts of grout.

5 DEPENDENCIES BETWEEN THE “TAM GROUTABILITY RATIO” AND SOME SOIL PROPERTIES

In search of a correlation between some basic soil properties and the “TAM groutability ratio”, the results of the experiments performed are summarised in Figures 4, 5, 6, 7, 8, 9 and 10.

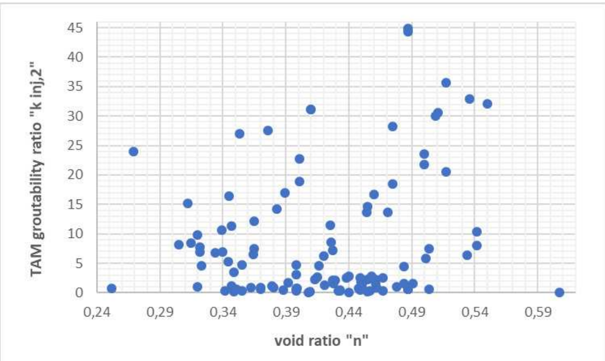

Figure 4. “TAM groutability ratio” K_{inj} / void ratio n chart.

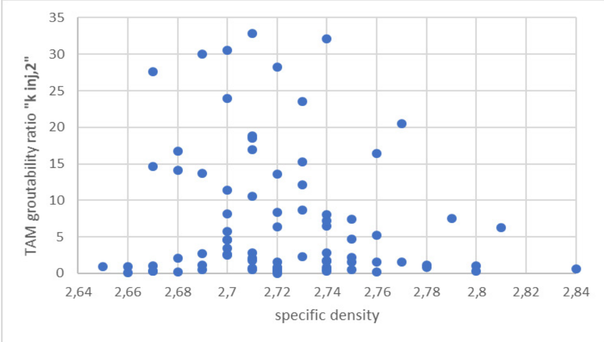

Figure 5. “TAM groutability ratio” K_{inj} /Specific density chart.

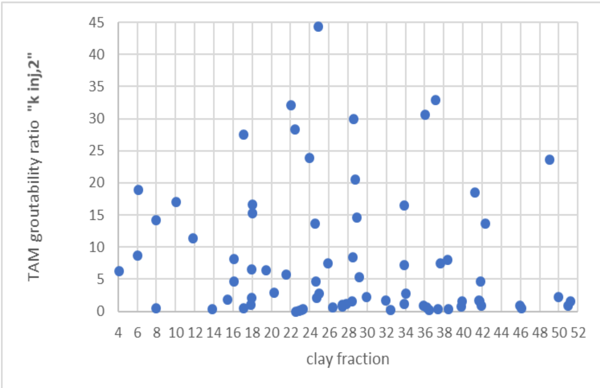

Figure 6. “TAM groutability ratio” K_{inj} /Clay fraction content.

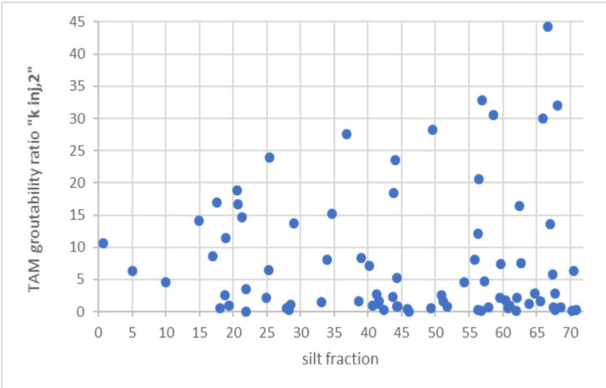

Figure 7. “TAM groutability ratio” K_{inj} /Silt fraction content chart.

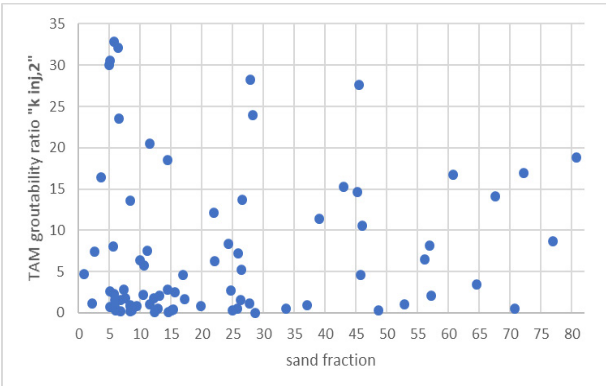

Figure 8. “TAM groutability ratio” K_{inj} /Sand fraction content chart.

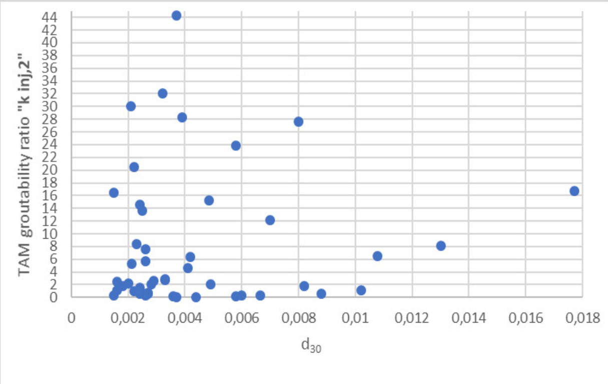

Figure 9. “TAM groutability ratio” K_{inj} / d_{30} chart.

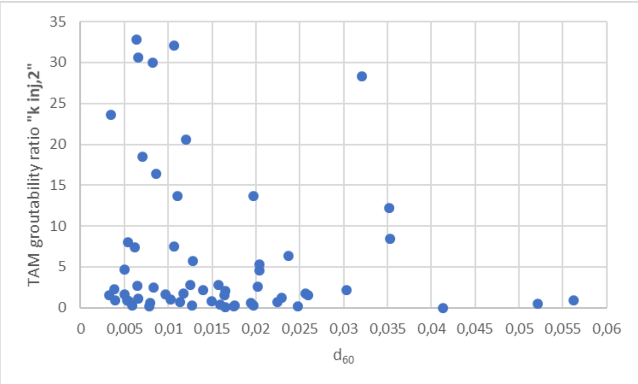

Figure 10. “TAM groutability ratio” K_{inj} / d_{60} chart.

The correlation between the “TAM groutability ratio” and the void ratio, the specific density, the clay fraction content, silt fraction content and the sand fraction content in the soil as well as d30 и d60 are shown.

The summarised results in the figures above show there is no correlation between the individual physical soil parameters and the “TAM groutability ratio” of the various examined soils on the territory of Bulgaria, respectively the injection rate of cement grout into the soil.

This justifies the effectiveness and applicability of the proposed methodology for determining the “TAM groutability ratio”.

6 STRENGTHENING OF A BUILDING IN SOFIA

The site is a block of flats in Tolstoy district built in the 1960s. On Figure 11 we can see the building itself. The building has three sections and four storeys. It is a frameless structure made of precast reinforced concrete panels. The development of uneven subsidence over time was established. In 2000, cracks, opening of joints, curved openings, "detachment" and deformation of members, which violates the serviceability of the premises, began to be observed in the basement. The building is based on strip reinforced concrete foundations laid in a layer of clay of hard plastic consistency, which implies a high deformation modulus, respectively minor subsidence. The silt fraction content makes soils sensitive to changes in water content, as a result of which their strength decreases and they become highly deformable, as a result of which additional, uneven subsidence occurs. In recent geological surveys, the ground has been identified as swollen soil. The change in the water content most often occurs as a result of leaks in the water supply network or penetration of rainwater.


Figure 11. Cracks on the facade of a building in Sofia.

Despite the measures taken over the years to strengthen and reinforce the structure, such as the construction of corner fastening plates between wall and floor panels, construction of a suspended type of sewer, construction of a sidewalk with a slope pointing outside the perimeter of the building, adverse processes have not subsided.

In 2020, Prof. Mihova prepared a project for strengthening the soil under the strip foundations by injecting cement mortar with additives of lime, bentonite and Mapei Viscofluid Jet 500. 150 injection pipes with a total length of 5,0 m were provided and laid every 0.8 m along the entire perimeter of the building (Fig. 12).


Figure 12. Reinforcement of the soil under the strip foundations by the TAM grouting method along the entire perimeter of the building.

The project was implemented in 2021. In addition to the planned measures for strengthening the soil, three test pits were made from which soil samples were taken. They were tested at the laboratory of the Department of Geotechnics at the UACEG and in addition to the basic soil properties, the “TAM groutability ratio” was determined.

To assess the effect of the strengthening, a dynamic penetration test with a DPM of medium type was performed (Fig. 13) before the strengthening, on the 7th and 21st day after injecting the grout into the soil. The obtained results are shown in Fig. 14.

Figure 13. Dynamic penetration tests performed with a DPM (dynamic penetrometer of medium type).

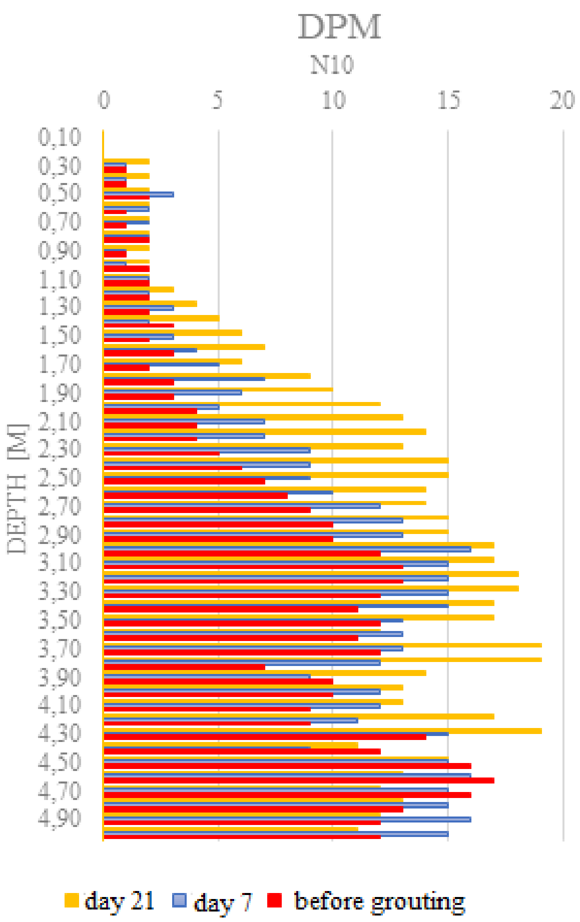

Figure 14. Dynamic penetration tests performed with a DPM.

Laboratory experiments to determine the "TAM groutability ratio" show that for soil varieties between 2,0 and 5,0 m (classified according to EN ISO 14688-2 as siCl and Cl), they have an arithmetic mean value of $k_{inj,2}$=14,4.

According to Table 1 this implies a classification of the soils as well injectable soils. There are layers of different boreholes with low values of "TAM groutability ratio", but in summary, over 40% of the samples tested at the site in the area of the planned strengthening are highly injectable.

During the actual implementation of the strengthening using the TAM grouting method, 59 m^3 of grout were injected on the site in all 150 injectors at a pressure of 7-8 bar. This makes an average of 390 litres of grout per injector.

After estimating the in situ amounts, it was found that the amounts actually injected correspond to the laboratory results.

It can be seen that on the 21st day in the area between 1,30 and 4, 40 m, the values of N_{10} are in total 71% higher than those reported before the injection. In some places they have increased up to 3 times.

7 CONCLUSIONS

This paper presents the results of laboratory tests on soils typical for the Republic of Bulgaria to determine their inje ctability with cement grout under low pressure.

Conducting the experiments is an alternative solution to the expensive and often difficult to implement test on the building site.

Demonstrating the effectiveness of the tube-a-manchette grouting method in specific engineering geological conditions becomes feasible in laboratory conditions as well.

The authors have not found a correlation between the physical soil properties or the content of the individual fractions in the soil and the "TAM groutability ratio" k_{inj}, therefore they recommend using the method during the research and design phase.

The obtained laboratory test results for determining the "TAM groutability ratio" by means of a device for determining the injectability of cement grout in soil samples for the presented site in Sofia show good overlap with the classification proposed by the authors and confirm the applicability of the method for laboratory determination of the injectability of soils.

8 REFERENCES

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