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NON-CRACKING TECHNIQUES FOR GROUTING

MIROSLAV TODOROV

Structural Design Ltd., Sofia, Bulgaria

Techniques for improving the ground base have been used since ancient times. The need of the geotechnical engineer to use zones with weak (cracked or high porosity) soil poses new, increasingly complicated problems. The solutions must consider requirements for the materials used and restrictions over the invasion. The use of natural (inorganic) materials is an approach resulting from the low speed of the change of the properties. The insignificant effect of the environment on the properties of the materials to be grouted is unquestionable. Here we should consider a number of factors connected with the anthropogenic conditions. An important aspect in the choice of materials is the expected positive changes in the structure and properties of the natural materials - improvement of soil skeleton structure, preservation of the migration of water, filling saturation, decreasing the consolidation deformability and others. The use of techniques for grouting with relatively small influence over the structure and properties of the natural materials requires certain basic mechanical parameters. Here we should pay attention to the scale of the interventions as a whole, the effect of which is considerably smaller than in usual techniques for different deep foundations. Another important aspect of these techniques is the economic effect, which creates conditions for a number of optimizations concerning the use of small-scale resources, by-products (colloidal clay, flay ash, lime, gypsum), small quantities of waste products, short periods for realization and others.

Keywords: Soil, Material characteristics, Specific parameters, Grouting techniques.

1 INTRODUCTION

A number of projects in the foundation construction of buildings and facilities use territories with not suitable geotechnical conditions. These zones have been used since ancient times and what makes them valuable is that they are situated in lowland areas around big rivers, lakes and seas. Such massifs offer a wide range of young soil varieties, some of which are not suitable for the foundation of heavy buildings and facilities. The well-known practices of increasing the depth of the foundation and the use of different kind of deep foundations do not always solve the structural problems that rice up. After a clear evaluation of the conditions in such situations grouting techniques can be used for strengthening and preventing damages and settlements in the natural structure of the soil massif.

Here the emphasis falls on the grouting technique, which may well be called saturation technique (non- cracking destructive grouting).

What does that mean and what is the difference between this method and the usual one, in which the compaction and strengthening effects are achieved through the induced high external pressure? The major approach of the non-destructive for the soil skeleton technique is in the balance between the properties of the soil, the permeability properties of the grouting materials, the technology of the process and the pressure applied for grouting.

2 CRITERIA FOR THE APPLICATION OF THE METHOD

The set of conditions, which influence the soil structure, should be identified early in the stage of research. The research of the soil formation may include the following major elements:

- Stratigraphy and structure of the Lithological varieties
- Physical properties with the emphasis on the grain size distribution, density, permeability and the overall quantity of pores (open and closed)
- Defining the over consolidation pressure of the material through tests (e.g., oedometer test) as a main criterion for flaws in the soil skeleton
- Research and quantitative analyses of the macro-cracking of the material
- Selection of grouting mixture regarding their permeability, long life, diagenesis effects, etc.
- Selection of grouting pressures and estimation of the duration of the grouting process (time for filling), monitoring and control of the grouting effects

The choice of intervention techniques requires the answer to a number of technological questions, evaluating at the same time the overall effect on the environment - natural and anthropogenic.

Here we should pay attention to the following aspects:

- Accessibility of the site. Usually these techniques allow the use of small-size equipment (naturally compared to the one using in deep excavations and pile foundations)
- Duration of the technological processes and their dependence on the climatic conditions allowing the application of acceptable results of the intervention
- The effect of the process on the long-time deformability of the soil massif, as a main design criterion for the serviceability capabilities of the foundation
- Expected change in the deformation (through compaction and destruction) and strength parameters of the materials

We can expect negative effects such as decreased water permeability of the strata, formation of local ponds or an overall change in the migration of the ground water; non-homogeneous penetration of the grouting mix and as a result non-homogeneous mechanical properties of the massif.

While meeting the criteria for the application of this method we should attempt to use materials of non-organic origin, the main argument in favor of that being the comparatively small change in their properties over time (Todorov 2016). When preparing the grouting material we can use natural (usually silicate materials), as well as industrial waste products.

3 NECESSARY RESEARCH FOR EVALUATING THE APPLICABILITY OF THE METHOD

When defining the scope of research we should consider the two groups of methods for examining the ground base:

- Laboratory methods including: physical properties tests - grain size distribution, indicators of the density of the material; mechanical properties - deformability (oedometer test, triaxial tests etc.), permeability and strength parameters.

- The field methods can be used in the first place as a means of evaluating the initial state of the material and secondly as an estimate of the effects after grouting. These means should be set as one of the elements of the monitoring project program.

The laboratory methods, despite their drawbacks, are cheap and make possible the creation of a large database. They can serve the purpose of initial evaluation of the properties of the material.

The first well-known criterion for the applicability of the method is based on the grain size distribution of the material. Here we should pay attention to the fact that the testing is applied on material with a totally distorted structure and this changes the natural permeability of the material. A number of authors point out criteria with data from the grain size analyses for the evaluation of the applicability of the grouting mixture.

Based on practical experience we can conclude that with finer grain size ($D < 0.063$ mm), less than 10-15%, and organic materials should be applied. Here we should also consider the structure of the materials, which changes with the advanced geological age due to colmatation substances, which in itself leads to change in the porosity. Thus the grain structure criterion can be considered universally valid for non- cohesive materials. A solution to this problem can be found only in testing in natural conditions.

The second criterion is connected with research on modified cement compositions, which require a dual approach. On one hand our aim is to increase the permeability of the compounds and on the other - to control the pressure in grouting so as to prevent damage of the material structure of the soil. The balance between the two factors has a considerable influence on the results. This makes it possible to influence the macrostructure of the soil, mainly in the open pores, cracks in the process of drying (characteristic of the swelling materials from the Paleogene and the Neogene) and other weak zones, shaped as a result of changeable sedimentary processes. A summary for these criteria can be found in Table 1.

The results from the research of the permeability of the soil are another element of the evaluation of the efficiency of the process. The permeability can easily be evaluated by measuring the quantity of the grout mixture in natural conditions, which is a more reliable criterion compared to the laboratory tests. In test areas and in the whole process of strengthening it is possible to take corrective measures at each stage. They can be implemented on all of the above-mentioned elements of the process.

As a result of studying the experience of applying the method in natural conditions we come to the conclusion that very often the laboratory research of the water permeability of the soil leads to poor results. For instance laboratory results show lower permeability for materials with a larger content of fines ($d < 0.063$ mm) as compared to in situ tests. This is mainly due to the macrostructure of the material, which receives adequate saturation in testing.

Table 1. Criteria for the applicability of the grout.

Grouting ratio	Grouting possible	Grouting not possible
$N = \frac{D_{15,soil}}{D_{85,grout}}$ (Sherard *et al.* 1984, Perbix and Teichert 1995)	>24	<11
$N = \frac{D_{10,soil}}{D_{95,grout}}$	>11	<6
D_{15} is the 15 percent finer grain size of the medium to be grouted and D_{85} is the 85 percent finer grain size of the grout		

The choice of grouting pressure also has to be subjected to testing procedures. From the point of view of long-term deformability this parameter needs to be examined in detail, because inappropriate choice may lead to escalation of the deformations. The aim (applying the optimal pressure in this case) can be achieved by means of methodology based on one major condition-preserving the structure of the material. The destruction of the natural structure means initiation of deformations.

In defining the parameters of the grouting pressures we can use the results of the well-known oedometer test. The defined preconsolidation stress σ'_{pc} can be fixed as a limiting parameter for the estimate of the grouting pressures. This testing has to be carried out in laboratory conditions with intact samples. Other parameters, which have to be observed and used in the choice of pressure, are the geological load and the horizontal stress in the soil massif using the Pressuremeter test.

By using this set of parameters and the limitations on the procedure that they impose, we can preserve the natural structure of the soil and limit the areas with escalation of the soil deformation over time.

4 RESULTS

The above-mentioned approach has been applied in a number of projects with existing facilities. The procedure is in accordance with the discussed criteria and the results are acceptable. The figure below shows a common view of the materials from the areas of grouting. Figure 1 distinctly differentiates the coloration of the natural zones and those of the grouting materials. These materials are beyond the boundaries of the fine grain criteria for the application of silicate compounds. The results achieved through full-scale tests are representative.

As part of the procedures for control research through conventional laboratory techniques and in situ tests of the physical and mechanical parameters of the area of grouting has been done. The results of the tests to establish the parameters in natural conditions, carried out at different periods are presented in Table 2 and 3.

In examining the properties of the ground base a series of researches over a relatively long period have been done. This to some extent makes it possible to outline some changes, which are caused by the conditions in the environment, as well as by the impact of human activity.

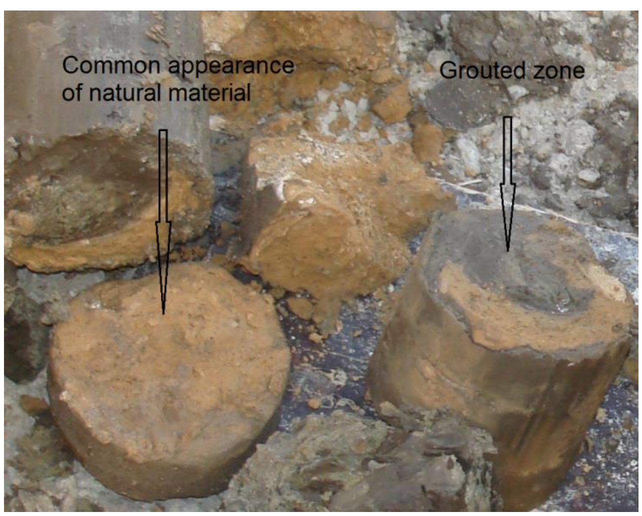

Figure 1. Common view of the materials from the areas of grouting.

Table 2. Physical parameters before and after grouting.

Bore Hole №	Soil specimen	Depth	Void ratio	Dry density	Natural density	Plastic limit [PL]	Liquid limit [LL]	Plastic index [PI]
	№	h	e	ρ_d	ρ_n	w_p	w_l	I_p
		m		g/cm^3	g/cm^3	%	%	
Physical parameters before grouting								
1/08.2015	5491	2.00	1.02	1.36	1.85	23.40	62.90	39.50
2/08.2015	5493	1.90	1.37	1.16	1.68	22.12	59.74	-
9/08.2015	5496	1.90	1.12	1.29	1.79	19.20	58.70	39.50
2/08.2009	8838	5.80	1.56	1.03	1.56	19.20	58.70	39.50
2013	314-4	6.10	0.77	1.51	1.92	19.20	58.70	39.50
Average value			**1.17**	**1.27**	**1.76**	**20.25**	**59.75**	**39.50**
Standard deviation			0.31	0.18	0.14	2.10	2.10	0.00
Physical parameters after grouting								
BH 1 / 12.2015	418-1	3.90	0.92	1.39	1.86	-	-	-
BH 1 / 12.2015	418-2	6.65	0.96	1.38	1.84	-	-	-
BH 2 / 12.2015	418-3	2.60	0.96	1.38	1.83	-	-	-
BH 2 / 12.2015	418-4	6.60	0.92	1.39	1.85	-	-	-
BH 3 / 12.2015	418-5	3.35	1.00	1.35	1.86	-	-	-
BH 3 / 12.2015	418-6	4.30	1.00	1.36	1.85	-	-	-
BH 3 / 12.2015	418-7	5.20	1.04	1.33	1.84	-	-	-
BH 2 / 12.2015	418-8	3.60	0.85	1.48	1.86	-	-	-
BH 2 / 12.2015	418-10	4.15	0.79	1.53	1.87	-	-	-
BH 2 / 12.2015	418-11	6.35	0.75	1.58	1.92	-	-	-
Average value			**0.92**	**1.42**	**1.86**	-	-	-
Standard deviation			0.09	0.08	0.02	-	-	-

5 CONCLUSIONS

Grouting at low pressures with the aim of saturating the soil materials is a process, which can be applied in conditions, for which the initial criteria for applicability show mixed results. Like all geotechnical solutions here, too, the theoretical-experimental approach is with a major means. The level of knowledge about the environment and the processes to unfold in the future are the main evaluation set of data.

The results presented in table 2 and 3 distinctly show positive changes in the physical, as well as in the mechanical properties of the soil. The increase in density and the decrease of the pore parameters are important perimeters for forecasting of the consolidation phenomena. Alongside with these figures are established the increase of the module of deformations and the characteristics of the shear strength. This expected positive change in the properties is observed in the process of grouting and through controlling the amount of grout compound. The amount of grout compound, together with the control of the grouting pressure, are the major monitoring parameters in the process of implementation of the measure.

Here the emphasis falls on the conventional methods of testing the ground base, which are cost-efficient, and are sufficient and justifiable. Despite that it is important to pay attention to the study of the following main groups of parameters: (i) Type, physical, and mechanical properties of the soil strata; (ii) type and characteristics of the grout compounds by means of proving their qualities in in situ conditions; (iii) size and duration of impact of the grout; (iv) study of the results of the grouting as well as prospective analysis of the deformations (consolidation) in future periods.

All direct and indirect methods can be used to control the results of these interventions in the soil environment. Major advantages of this approach are the following:

- Relatively low cost as compared to the conventional approaches of deep foundation,
- Use of small- scale equipment and easy access
- Possibilities for corrective action during the process
- When using inorganic compositions containing calcium compounds, we can expect their migration over time to lead to improvement of the new structure of the massif.

All these characteristics make the technology applicable for existing facilities, as well as facilities under construction, in a wide range of geological conditions.

Table 3. Mechanical parameters before and after grouting.

BH№/data	Soil specimen	Depth	Oedometer modulus with respect of vertical effective stresses - E_{oed}			Compr. index	Swelling index	Characteristics of the peak shear strength/ (DST)	
	№		σ'v =100	σ'v =200	σ'v =300	C_c	C_r	c'	φ'
		m	kPa	kPa	kPa			kPa	deg
Mechanical parameters before grouting									
1.8.2015	5491	2	3500	4700	7900	0.18	0.07	10	15
2.8.2015	5493	1.9	2600	3100	4050	0.32	0.04	19	12
9.8.2015	5496	1.9	1250	2300	7100	0.41	0.03	15	16
2.8.2009	8838	5.8	2150	3255	6950	0.4	0.06	22	19.5
2013	314-4	6.1	2830	3750	5670	0.12	0.02	22.3	18.5
Average value			**2466**	**3421**	**6334**	**0.286**	**0.044**	**18**	**16**
Standard deviation						0.131	0.021	5.2	3.0
Mechanical parameters after grouting									
BH 1 / 12.2015	418-1	3.9	9000	6500	9200	0.09	0.02	31	22
BH 2 / 12.2015	418-4	6.6	14200	7000	8100	0.09	0.02	41	12
BH 3 / 12.2015	418-5	3.35	2100	3800	6000	0.12	0.02	22	17
BH 3 / 12.2015	418-6	4.3	3250	2780	7200	0.11	0.015	35	16
BH 3 / 12.2015	418-7	5.2	3350	6120	8450	0.092	0.009	24	16
BH 2 / 12.2015	418-8	3.6	4100	5800	8200	0.09	0.01	27	19
BH 2 / 12.2015	418-10	4.15	2300	5400	9500	0.09	0.01	22	22
BH 2 / 12.2015	418-11	6.35	4100	7500	11500	0.08	0.02	29	21
Average value			**5300**	**5613**	**8519**	**0.095**	**0.016**	**29**	**18**
Standard deviation						0.013	0.005	6.7	3.6

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