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Experimental research of ground improvement using dry concrete columns

Recherche expérimentale d'amélioration du sol à l'aide de colonnes en béton sec

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ABSTRACT: Ground improvement is a challenging task for Belarus due to load increment on the soil base and large thickness of soft soils at the surface of the base at many construction sites. One of the effective ground improvement methods used in Belarus for water-saturated soft clayey soils is the reinforcing with dry concrete columns. The method allows the soils to be compacted and drained at the same time. As a result, strength and deformation properties of natural soils improve. A series of laboratory and field investigations were carried out in order to show the efficiency of dry concrete columns. The results showed a significant increase in the bearing capacity and a considerable decrease in deformations as well as the improvement of soil properties due to compaction and dewatering thanks to using dry concrete columns.

RÉSUMÉ: L'amélioration des sols est une tâche difficile pour la Biélorussie en raison de l'augmentation de la charge sur la base du sol et de la grande épaisseur des sols meubles à la surface de la base sur de nombreux chantiers de construction. L'une des méthodes efficaces d'amélioration des sols utilisées en Biélorussie pour les sols argileux tendres et saturés d'eau est le renforcement avec des colonnes en béton sec. La méthode permet de compacter et d'assécher les sols en même temps. En conséquence, les propriétés de résistance et de déformation des sols naturels s'améliorent. Les séries d'enquêtes en laboratoire et sur le terrain ont été menées afin de démontrer l'efficacité des colonnes en béton sec. Les résultats ont montré une augmentation significative de la capacité portante et une diminution considérable des déformations, ainsi que l'amélioration des propriétés du sol dues au compactage et à la déshydratation, grâce à l'utilisation de colonnes en béton sec.

Keywords: Dry concrete columns; soft clayey soils; soil properties; bearing capacity; deformations

1 INTRODUCTION

Ground improvement is a challenging task for Belarus due to load increment on the soil base and large thickness of soft soils at the surface of the base at many construction sites. Often pile foundations are applied in comparatively favourable ground conditions. However, soft soils such as soft clayey soils, peat soils and peat can lie at the surface and reach tens of meters in depth. Therefore the application of piles and other conventional foundations can be rather difficult and expensive, especially in the presence of water-saturated soft clayey soils that need in the consolidation of pore water before to be compacted and the improvement of its properties. A rational solution in such conditions is an application of the ground improvement methods for upper soft soils to increase the bearing capacity and reduce deformations of the base. It allows the loads to be transferred on upper ground layers and the stresses to be dissipated considerably before reaching underlying soft ground layers.

One of the effective ground improvement methods for water-saturated soft clayey soils is the reinforcing with dry concrete columns (dry concrete piles/pillars, vertical reinforcing drain elements), which are used in Belarus. The method allows the soils to be compacted and drained at the same time. As a result, strength and deformation properties of natural soils improve (Tronda 2016, Никитенко 2014, Тронда 2013).

The dry concrete columns consist of compacted dry concrete and they are arranged by a vibro-hammer using a casing pipe according to vibro-stamped pile technology.

For the first time to use dry concrete for ground improvement of soft clayey soils was proposed by Prof. Nikitenko from Belarus (Никитенко et al. 2002). Nevertheless, this method did not receive a considerable attention in further research as well as regulations and national technical codes for design and construction of reinforced soils and man-made geo-massifs.

Therefore, a number of laboratory and field investigations were carried out and analysed in order to show the efficiency of dry concrete columns and develop design methods in the future.

2 MODEL TESTS

Model tests of dry concrete columns were carried out at the laboratory of the Department of Geotechnics and Ecology in Civil Engineering and the Research and Testing Laboratory of Concrete and Building Materials at Belarusian National Technical University.

Model investigations were divided into three groups. The aim of each series of the laboratory tests was to:

1) show the efficiency of dry concrete columns during the model tests in the soft water-saturated clayey soil;

2) study the process of strength set with dry concrete mix under conditions of water-saturated clayey sand and determine the strength of the models;

3) determine the change in water content and liquid index of clayey sand during the application of dry concrete columns.

2.1 The efficiency of dry concrete columns

The effectiveness of dry concrete columns was determined according to the results of bearing capacity and soil deformations under a slab.

At first, models of the square slabs (140x140x27 mm) were tested in the rig filled with the soft water-saturated clayey soil. The load was applied with a leverage and weights. Settlements of the slab were fixed by dial indicators. Then dry concrete columns were installed into the soil, the additional sand layer (10 mm) was used on the surface of the soil as a transfer layer and the models of reinforced soil were subjected to static load after 28 days. The models consist of square slabs (140x140x27 mm) and dry concrete columns with the diameter of 16 mm and the length of 100, 150, 200 mm (Figure 1), the volume of the reinforced soil is 1960, 2940 and 3920 sm^3 respectively. The models were tested without contact between the slab bed and the columns. The load was applied with a leverage and weights and settlements were fixed by dial indicators as well.

Pressure-settlement diagram $S = f(P)$ (Figure 2) received according to the results of the test shows a significant increase in the bearing capacity and a considerable decrease in deformations when applying the dry concrete columns. The bearing capacity of the base increases in 7.2-10.8 times by the settlement of 8 mm that was taken as a criterion for comparison, and deformations decrease significantly, in 12.6-23.7 times by $P \in [0; 15]$ kPa depending on the reinforced soil volume.

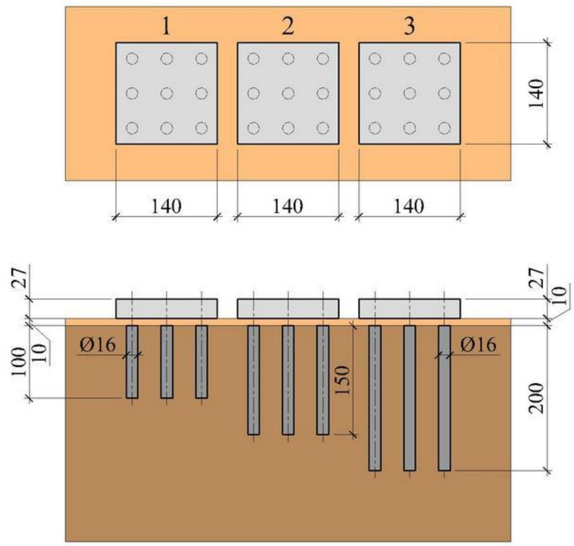

Figure 1. The experimental models of reinforced soil with dry concrete columns

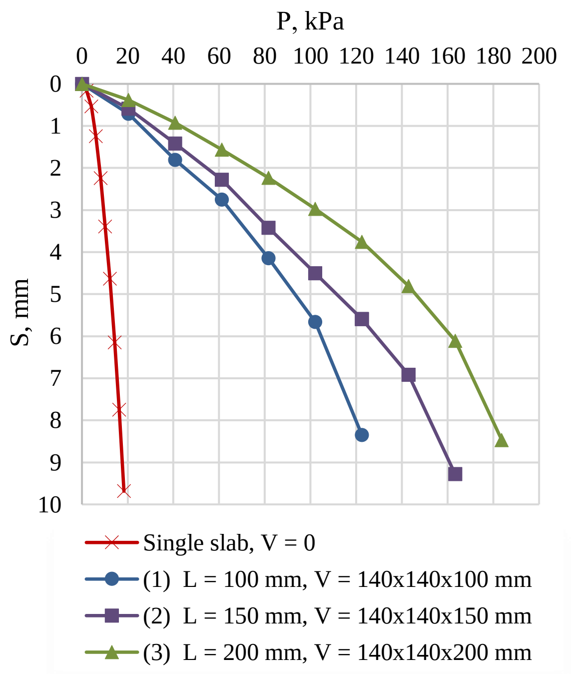

Figure 2. The results of the static load model test – soil deformations under the slab

2.2 *The strength of dry concrete column models*

The study of the strength set by dry concrete mix was performed under conditions of water-saturated clayey sand (w = 13.7 and 15.4%, w_L = 15.7%, w_P = 9.1%, I_P=6.6%, I_L = 0.70 and 0.95). The models of dry concrete columns were installed into two cylindrical test boxes with variable inner diameter from 500 mm to 580 mm and with the height of 350 mm (Figure 3). The cylindrical box represents the required area of a unit cell around a column. The models with the diameter of 160 mm and length of 270 and 250 mm were made using a dry concrete mix of two classes by replacement method. 10 and 8 kg of the dry mix were used for the models under the standard proportion for concrete classes of C8/10 (Model 1) and C12/15 (Model 2). Dry mix consisted of 0.8 kg of Portland cement, 3.7 and 2.8 kg of sand, 5.5 and 4.4 kg of gravel for the Model 1 and Model 2 respectively.

Figure 3. The test box filled with soft water-saturated clayey sand and installed model of dry concrete column

The experiment lasted 56 days. On the 56th day, the models were pulled out and tested for the determination of the compressive strength on a hydraulic press (Figure 4) according to the national technical codes (ГОСТ 10180-2012). The compressive strength was 1.2 and 1.5 MPa at a failure loads F = 20 and 25 kN respectively.

Figure 4. Testing model of dry concrete column under the hydraulic press

Although the standard value $f_{ck} = 8$ and 12 MPa was not achieved for concrete classes of C8/10 and C12/15, the strength and pressure that the models withstand exceed the strength of soft soils and the average pressure that is commonly transmitted to the ground base from buildings. This is one of the main principles when using reinforcement.

2.3 The change in water content and liquid index of clayey soil

The change in water content and liquid index was determined in two experiments. The first results were received from the test described in Subsection 2.2.

During the experiment, the water content was determined on 7th, 14th, 21st, 28th, 42nd and 56th days (Table 1). The boxes were properly covered to prevent the additional surface water evaporation during the lasting experiment.

Table 1. Change in water content w, % of clayey sand during 56 days

Model	0	7	14	21	28	42	56
1	13.7	13.0	12.8	12.8	12.5	12.5	12.5
2	15.4	13.1	13.1	13.0	12.7	12.6	12.6

As we can see the greatest decrease in water content occurs in the first 7 days. Then the water content decreases more slowly but continues after 28 days. Liquid index I_L changed from 0.70 to 0.51 for Model 1 and from 0.95 to 0.53 for Model 2.

It was found that 1.3 and 2.75 l of pore water from the soil was absorbed for 0.8 kg of cement in the dry concrete mix. The water-cement ratio was 1.6 and 3.4 when in standard conditions the water-cement ratio is taken equal to 0.5.

Also other physical and mechanical properties were determined at the beginning and the end of the experiment and water content w, %, liquid limit w_L, %, plastic limit w_P, %, plasticity index I_P, %, liquid index I_L, void ratio e, saturation S_r, friction angle φ, °, cohesion c, kPa and Young's modulus E, MPa were compared with the results of field tests (see Tronda 2017). Determination of properties was carried out according to the national technical codes (ГОСТ 12248-2010).

The second results for the change in water content and liquid index were received after statistical analysis of additional experimental data.

Six cylindrical boxes filled with clayey sand of different initial water content and liquid index (Table 2) were used for the test. Dry concrete mix was prepared for the models under the standard proportion for concrete classes of C8/10. The models of dry concrete columns with the diameter of 80 mm and the length of 100 mm were installed into the boxes with the diameter of 250 mm and the height of 300 mm.

The experiment lasted 28 days. The models were pulled out at the expiration (Figure 5) and water content and liquid index were determined again. The results are shown in Table 2.

Figure 5. Testing models of dry concrete columns after 28 days

Table 2. Change in water content w, % and liquid index I_L of clayey sand after 28 days

Model	***w*, %**		**Δ*w*, %**	**I_L**		**ΔI_L**
	before	**after**		**before**	**after**	
1	11.3	10.2	1.1	0.33	0.16	0.17
2	11.7	9.6	2.1	0.40	0.07	0.33
3	12.6	11.3	1.3	0.53	0.33	0.20
4	13.0	10.4	2.6	0.59	0.20	0.39
5	13.4	11.0	2.4	0.65	0.29	0.36
6	14.5	12.5	2.0	0.82	0.51	0.30

The statistical analysis was performed according to the test results and the national technical codes (ГОСТ 20522-2012). The change in water content and liquid index is Δw = 1.41% and ΔI_L = 0.21 with the confidence probability α = 0.95.

Moreover, all models gained strength after 28 days.

3 FIELD TESTS

Dry concrete columns were adopted in Belarus at two construction sites with complicated ground conditions. The complications were connected with the occurrence of soft clayey soils, soils with organic inclusions and peat. According to a comparative analysis of several options as a foundation, it was decided to apply dry concrete columns for ground improvement of upper layers as more suitable because of ground conditions and construction cost. Application of dry concrete columns reduced the cost of foundations by 32-75%. Ground conditions, technology and some tests are described in earlier papers more detailed (Tronda 2016, Никитенко 2014, Тронда 2013 and 2016).

Field tests were provided to check the technology on an availability. Series of cone penetration and static load tests before and after the application of the method was carried out according to the national technical codes (ТКП 45-5.01-15-2005).

Physical and mechanical properties improved for soft sandy clay and clayey sand within the length of columns. For sandy clay, moisture content was reduced by 3.2%, void ratio in 1.14 times, saturation by 0.06, and friction angle was increased by 6°, cohesion in 2.1 times, Young‘s modulus in 9.8 times. For clayey sand, moisture content was reduced by 0.9%, void ratio in 1.04 times, saturation by 0.09, and friction angle was increased by 7°, cohesion in 1.4 times, Young‘s modulus in 4.7 times (Tronda 2016).

4 CONCLUSIONS

The model and field tests showed the efficiency of dry concrete columns using for ground improvement of soft water-saturated clayey soils:

1. The bearing capacity of the base increases and deformations decrease significantly depending on the reinforced soil volume.
2. Dry concrete mix gains the strength under conditions of water-saturated clayey sand and the strength exceeds the strength of soft soils.
3. The greatest decrease in water content occurs in the first 7 days. During 28 days the change in water content and liquid index is Δw = 1.41% and ΔI_L = 0.21 with the confidence probability α = 0.95.
4. Application of dry concrete columns is effective in complicated ground conditions caused by soft clayey souls. The method allows physical and mechanical properties to be improved significantly and it can reduce the cost of foundations by 32-75% in certain cases.

In view of the above, dry concrete columns may be widespread as a ground improvement method for soft water-saturated clayey soils. It is necessary to provide additional experiments to develop the method, design and production guidelines in the future.

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