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Improvement of soft clay soils with vertical reinforcing drain elements

Amélioration des sols argileux mous avec éléments verticaux de renforcement et drainage

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ABSTRACT: Ground reinforcement is one of the effective soil improvement methods. In the case of large thickness of soft soils under the base, the cost of ground reinforcement is lower than the cost of pile foundation. Considering soft water-saturated clay soils, it is necessary to consolidate soils to reach the improvement of their properties. In Belarusian practice vertical reinforcing drain elements in the form of dry concrete columns are used. Application of vertical reinforcing drain elements allows compacting and draining water-saturated clay soils at the same time that leads to improvement of physical and mechanical characteristics. Laboratory experiment of clayey sand reinforced by dry concrete element was carried out and is described in the paper. The characteristic compressive strength of the element and the water-cement ratio were determined. Change in time of water content, changes of physical and mechanical properties were received and compared with the results of in situ tests.

1 INTRODUCTION

There are many methods of ground improvement using various materials and structures (Mangushev 2012, Ilyichev and Mangushev 2014), but all methods have limited sphere of use and need special equipment and machines. Soil compaction can improve properties of soils, but it is also necessary to press pore water out for water-saturated soils. Therefore, sand and lime piles, vertical sand and wick drains with drainage blankets are used (Abelev 1983, Korobova 2008, Fellenius 2009). However, in the presence of thick layers of soft water-saturated clay soils at the top the conventional methods may be not suitable or have high labor inputs and cost.

One of the new effective methods of ground improvement for soft water-saturated clayey soils is vertical reinforcing drain elements (or dry concrete columns) that make it possible to compact and drain soils at the same time. Installation technology according to vibro-stamping piles using casing pipes with the closed remaining end promotes compaction and speeds up consolidation process, and dry concrete mix absorbs water necessary for hydration of cement. As a result, physical and mechanical properties improve (Tronda 2016a and 2016b).

This study is focused on a comparison of laboratory experiment and in situ tests to estimate the changings of physical and mechanical properties for clay soils improved with the vertical reinforcing drain elements.

1.1 Laboratory experiment

The laboratory experiment was performed with water-saturated clayey sand ($w=13.7\%$, $w_L=15.7\%$, $w_P=9.1\%$, $I_P=6.6\%$, $I_L=0.70$, $e=0.5$, $S_r=0.74$, $\phi=21^\circ$, $c=21$ kPa, $E=4.3$ MPa) reinforced with the vertical reinforcing drain element in the cylindrical test box with height of 350 mm and with variable inner diameter from 500 mm to 580 mm (see Figure 1). The cylindrical box represents the required area of a unit cell around a vertical reinforcing drain element. The vertical element with diameter of about 160 mm and length of about 270 mm using dry concrete mix was prepared by vibro replacement method. Under the standard proportion for concrete with class of C8/10, 0.8 kg of Portland cement, 3.7 kg of sand and 5.5 kg of gravel were used for the vertical reinforcing drain element.

The experiment length was 56 days. The water content was determined on 7th, 14th, 21st, 28th, 42nd and 56th days (see Table 1). The box was properly covered with polyethylene film to prevent the additional surface evaporation of water.

On 56th day the vertical reinforcing drain element was pulled out (see Figure 2) and tested for the compressive strength of

concrete on a hydraulic press according to the national technical codes (GOST 10180-2012). The characteristic compressive strength f_{ck} was 1,2 MPa at a failure load $F=20$ kN. Although the standard value $f_{ck}=8$ MPa was not achieved for concrete C8/10, the strength and pressure that the element can withstand exceed the strength of soft soils and the average pressure that is commonly transmitted to the ground base from buildings. That is the main principle when using reinforcement.



Figure 1. The vertical reinforcing drain element from dry concrete mix installed into soft water-saturated clayey sand.



Figure 2. The vertical reinforcing drain element pulled out of the soil after 56 days.

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

w , %	Days						
	0	7	14	21	28	42	56
Clayey sand (experiment)	13.7	13.0	12.8	12.8	12.5	12.5	12.5

The greatest decrease of water content occurs in the first 7 days. Then the water content decreases more slowly but continues after 28 days to a lesser degree. Based on the data obtained it can be concluded that the required amount of water for cement hydration enters the reinforcing drain element for the first 28 days. It was found that 0.65 liters of pore water from clayey sand was consumed for 0.8 kg of cement in the dry concrete mix. The water-cement ratio was 0.8, when in standard conditions the water-cement ratio is taken equal to 0.5.

The physical and mechanical properties such as 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 modulus E , MPa were determined at the beginning and the end of the experiment (see Tables 2, 3 and 4). Determination of properties was carried out according to the national technical codes (GOST 12248-2010).

1.2 In situ tests

Vertical reinforcing drain elements with diameter of 426 mm and length of 4...7 m using dry concrete with class of C8/10 were installed at the site in Kolodischi according vibro displacement method for improvement soft water-saturated clay soils at the top. Ground conditions and technology are described in earlier papers more detailed (see Tronda 2016a and 2016b). Static penetration tests were carried out before and after installation of elements and results are shown in Tables 2, 3 and 4. Determination of properties was carried out according to the national technical codes (TKP 45-5.01-15-2005).

1.3 Laboratory and in situ results

The results of the laboratory experiment and the in situ tests are shown in Tables 2, 3 and 4.

Table 2. Liquid limit w_L , %, plastic limit w_P , %, plasticity index I_P , % and change of liquid index I_L .

Soil	w_L , %	w_P , %	I_P , %	I_L	
				before	after
Clayey sand (experiment)	15.7	9.1	6.6	0.70	0.51
Clayey sand (in situ)	18.2	14.3	3.9	0.31	0.08
Sandy clay (in situ)	25.2	17.2	8.0	0.59	0.14

Table 3. Change of water content w , %, void ratio e and saturation S_r .

Soil	w , %		e		S_r	
	before	after	before	after	before	after
Clayey sand (experiment)	13.7	12.5	0.501	0.502	0.74	0.67
Clayey sand (in situ)	15.5	14.6	0.49	0.47	0.90	0.81
Sandy clay (in situ)	21.9	18.3	0.65	0.56	0.92	0.86

Table 4. Change of friction angle ϕ , °, cohesion c , kPa and Young modulus E , MPa.

Soil	ϕ , °		c , kPa		E , MPa	
	before	after	before	after	before	after
Clayey sand (experiment)	21	27	21	29.6	4.3	4.8
Clayey sand (in situ)	19	26	12	17	8.0	37.3
Sandy clay (in situ)	15	21	15	31	4.9	29.6

2 CONCLUSION

The laboratory experiment and the in situ tests showed the possibility and efficiency of improving the properties of soft water-saturated clay soils with the vertical reinforcing drain elements.

The application of dry concrete mix as material makes possible the drainage of water saturated clay soils and reduces the water content w on average 1.9%, saturation S_r by 0.07 units and liquid index I_L by 0.29 units that changes the consistence of clay soils. The absorption of water lasts essentially 28 days but most intensively in the first 7 days and that is about 58% of all absorbed water. Then on 14th day the amount of absorbed water is about 75%. The water-cement ratio received in the laboratory experiment is 0.8 that is more than standard water-cement ratio equal 0.5. Moreover, the vertical reinforcing drain element gains strength more than the strength of soft soils and withstands the pressure commonly transmitted to the ground base.

The vibro displacement method for installation of elements helps to compact soils therefore the results of laboratory experiment differ from the results of the in situ tests. Void ratio e remained practically unchanged in the laboratory experiment due to the use of the vibro replacement method but reduced by 0.06 units in the in situ tests.

Analysis of mechanical properties showed the increase of friction angle ϕ by 6°, cohesion c in 1.6 times and Young modulus E in 1.1 times for the laboratory experiment and 5.4 times for the in situ tests that can also be explained by the use of different methods of installation.

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