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Orginal Article

The sands of medium density and sandy loam density differences investigation while cement injection and pressuremetry crimping

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Abstract: The article focuses on the study of medium density sand and sandy loam density changes during water-cement solute injection and pressiometer expansion. Cement mortar injection is performed into boreholes under small pressure of up to 300 KPa resulting in radial well expansion. This expansion process also takes place during pressiometer studies. A cavity of compacted soil is formed around the expended boreholes in radial direction; the anchor and pile load determine field studies of the load, which they can perceive along lateral surface. It is worth noting that they frequently do not coincide with the calculated values. Following field anchor excavations, it was observed that root shearing can occur both directly at the contact between the cement root and the soil and at some distance from it. Subsequent laboratory studies revealed that when the soil is pressed, its density can change along a sinusoid, comprising pressed zones and decompaction zones. This gives rise to the displacement of the shear zone at the contact between the root and the soil.

Keywords: ground characteristic change, pressure, injection moulding, displacement, unit weight

1. Introduction

The soil injection method has become a widespread way of strengthening buildings and structures' foundations in Belarus. This method is used for making anchor and the pile for new buildings and during reconstruction and modernization of existing buildings and structures. This technology is currently used to increase the ground bearing capacity of plate foundations, anchors and piles, and also to prevent dangerous geological processes such as settlements, subsidence and suffusion.

The unit weight, angle of internal friction, and cohesion change take place when cement mortar is injected under small pressure of up to 300 kPa into boreholes; when anchors and piles are erected, and ground well expands. The same processes of well expansion and compaction of the surrounding soil also takes place during ground pressuremeter tests for determining the total deformation modulus. The value of the additional expansion of the well and dimensions of the compacted soil zone depend on the depth below the day surface, compressibility of the soil, and technological features of the injection. The well walls displacement determination can be attributed to the classical Lame solution of the thick-walled vessel walls stresses and displacements determination.

2. Justification of research objectives

Only a small number of works have been devoted to a purposeful study of the variability of soil properties around boreholes and wells expended by cement mortar injection. This is due to the technical impossibility of digging out natural anchors and piles in various soils in field, as opposed to the high accuracy experimental work performed in natural conditions, and the methodological functionality of modeling in laboratory conditions of the physical processes that occur during the introduction of cement mortar into soils.

The analysis of the studies of A. Cambefort [1], L. Hobst [2], V.A. Mishakov [3], M. Al Masri [4], A.A. Petukhov [5], M.I. Nikitenko [6], K.E. Povkolas [7], J. Warmer [11] and others helps us to determine:

– the ground (non-rocky soils) property change occurs to ground pressing and watering while cement mortar injection mainly due to ground pressing and watering (P) M.I. Nikitenko [6]). The compacted zone is equal to 3.1-3.2 of the initial diameter of the borehole ore well in the plane;
– the soil strength characteristics decrease with distance from the borehole Smorodinov [8];
– there are ground compaction and decompaction zone tracks (M. Hello Moussa [9]);
– borehole diameter increased due to the injection pressure (P) M.I. Nikitenko [6]);
– the waterproof soil quality does not depend on the pressure value, but on the time of injection (P) M.I. Nikitenko [6]);
– the injected can be characterize as an outflow along microfractures while injection with pressure of more than 0.4 MPa;
– penetration into the contact layer of up to 7-10 mm thickness and cementation of soil particles around the injection material are possible in loose, coarse, and gravel sands;
– excess moisture is drained from the water-cement mixture, which may be characterized by the W/C = 0.23-0.27 in the sands;
– they is no cement mortar impregnation in cohesive soils;
– high injection pressure adducts to hydraulic cracks around wells in clays;
– water is taken from the cement mortar into the surrounding soil, therefore, the clay soil plasticity increases and friction falls down in the first time after the mortar injection. At the same time, the resistance of the lateral surface increases with the soil strength increase and the plasticity decreases. [2, 6, 9] ;
– there is an increase in contact shear resistance in cylinders in 1.5-2.0 times compared to cement mortar injection and cement mortar filling holes [9]).

3. The description of the experiment and applied soils

3.1. The ground description

For laboratory experiments we used soils commonly found on the territory of Belarus – sands of medium density (γ = 16.5-16.7 kN / m^3, W = 0.7%, Pdmin = 1.5 MPa) and lean clay (γ = 19.1-19.2 kN/m^3, W = 12.7-13.0%, Pdmin = 3.5 MPa) (further in the article – clay).

3.2. The description of the experiment

Our research was carried out in the laboratories of the department of Geotechnics and Ecology in Construction of BNTU, using two methods:

– pressuremeter expansion,

– extension by injection of cement mortar.

3.3. The description of cement mortar injection expansion method

Cement mortar injection expansion experiment was carried out in cylindrical tanks with a diameter of 750 mm and a height of 0.9 meters (Fig. 1). The excess moisture from the injected cement slurry was released into the soil during experiment. The body of the well was formed by a pipe with a diameter of 110 mm, around which the soil was laid and compacted.

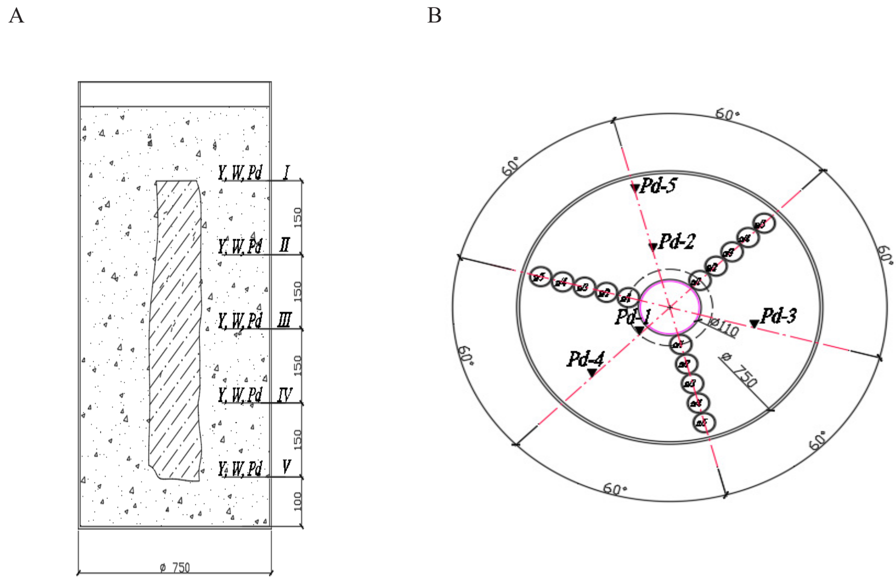

Fig. 1. The places of the selected soil samples (A – in height, B – in plan; I...V – sample place level; n/1...5 – sampling sites for determining soil moisture and density; Pd-1...5 – dynamic sounding locations).
Source: own study

The well former was removed and injection of cement mortar was pumped under the pressure of 150 kPa, after placing the soil into the cylindrical tanks. M 400 cement grade was used in the experiments, the water-cement ratio of the poured solution equalled 0.5.

The initial diameter of the wells increased in sandy loam by 1.24-1.27 times, in sand by 1.19-1.23 times as the result of the injection.

After technological breaks lasting 7, 14, and 28 days, the excavation of injected bodies was carried out. A number of test samples were selected to determine the density and moisture content of the soil, and dynamic probing of the soil around the injection body and below it was also performed at 5 levels (with a step of 150 mm). In radial direction, soil density and moisture were determined with a step of 50 mm.

3.4. Pressiometer tests

The initial diameter of a borehole expanded by pressiometry methods was taken in the range from 130 to 140 mm based on the assumption that the soil properties around boreholes and cavities expanded by pressiometry method changes at a distance of up to 2.5-3 of bore-hole diameter.

The experiment was carried out in a metal tray of plan dimensions of 910 x 930 mm and the hight of 200 mm. The tray cover was made of transparent plexiglass. The rigidity of the tray cover and tray bottom was of a magnitude greater than that the soil, so the wells could expand only in radial direction with a corresponding change in soil properties.

The tray was filled with compacted soil by layers of 50 mm. Soil compaction was carried out by a dynamic density meter by dropping a weight of 30 kN from a height of 300 mm onto a stamp with a diameter of 100 mm. After that, a well was made in the centre of the tray and an expanding chamber was installed. Wire ground marks were dipped into the ground in radial directions in three quadrants of the tray at distances of 18-22 mm.

The wells formed in the soil mass expanded only in radial direction. The pressure created in the pneumatic chamber was up to 150 kPa. Prior to pressuremeter reaming of the well, measurements and binding of the locations of the marks were performed relative to the centre of the well, and the diameter between equidistant marks was also determined. After air was pumped into the chamber, the movement of the marks was determined by measuring their new location (Fig. 2). During the pressuremeter test, the initial radius of the well increased by 20-40%.

A *B*

Fig. 2. Carrying out laboratory pressuremeter tests, A) – location of the top cover and soil marks in sandy soil; B) – bursting cracks in the soil after an increase in the initial diameter of more than 40%. *Source:* own study

4. The results of laboratory tests

4.1. Pressiometer expansion

Based on the condition of constancy of the soil mass between two grades, the change in the density of the soil composition was determined.

Experimental processing of statistical data was performed in order for systematic errors and the measurement errors of the instruments and tools to be used as exception [3, 9]: the thesis was suggested that the relative deformation of each *i + 1st* layer should be less than that of the *i-th* layer; and also the total displacement of the borehole wall should be equal to the compression of all layers within the active deformable annular zone (Fig. 3).

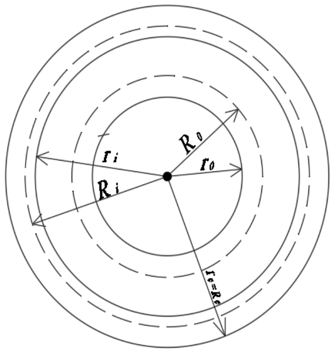

Fig. 3. Soil density change calculation scheme in the radial direction due to the well expansion (r_o is the initial radius of the well before expansion; R_0 is the radius of the well after its expansion; r_i is the radius up to the *i-th* mark before the well expansion; R_i – radius up to the *i-th* mark after the well expansion; r_e is the radius to the last mark before the well expansion; R_e is the radius to the last grade after the well expansion). *Source:* [4, 6]

Marks movement graphs were constructed relative to the zero point in sands and clays.

In this case, the condition must be observed that if

$$R_{i+1}-r_{i+1}<R_i-r_i \quad (1)$$

is taken into account, the amount of displacement should decrease with a growth of the distance from the borehole axis (Fig. 4).

The graph above shows that the boundaries were moving both in sandy and clay soils, which was accompanied by soil compaction in the volume of an elementary selected layer between the marks. The weight of the soil between adjacent marks *(M*) is a constant value, because within the corresponding i-th annular volumes of soil with the same heights *h*, only soil compression occurs. To compare the soils weight changes, the author proposed to use the soil compaction coefficient (K_{comp}). The soil compaction coefficient is the ratio of the weight of the soil after pressiometer expansion Y_i to the weight of the soil before expansion y_i and found the following expression:

$$K_{comp}=Y_i/y_i=\left(h\left(r_i^2-r_{i-1}^2\right)\cdot 3.14M\right)\Big/\left(h\left(R_i^2-R_{i-1}^2\right)\cdot 3.14M\right)=\left(r_i^2-r_{i-1}^2\right)\Big/\left(R_i^2-R_{i-1}^2\right) \quad (2)$$

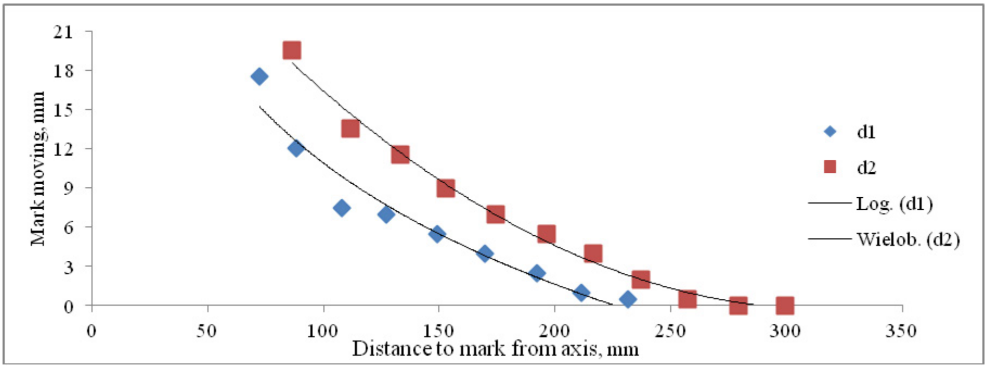

Fig. 4. Graphs of grades movement ΔR, mm with an initial radius of 80 mm. (d1 – sand; d2 – clay; Log(d1) – logarithmic trendline for sand data: wielob. (d2) – multinominal trendline for clay data). Source: own study

Based on the results of the experiments, it was revealed that the compaction coefficient K_{comp} takes values both greater than unity and less. When $K_{comp} > 1$, the soil is compacted; when $K_{comp} < 1$, the soil is decompacted (Fig. 5).

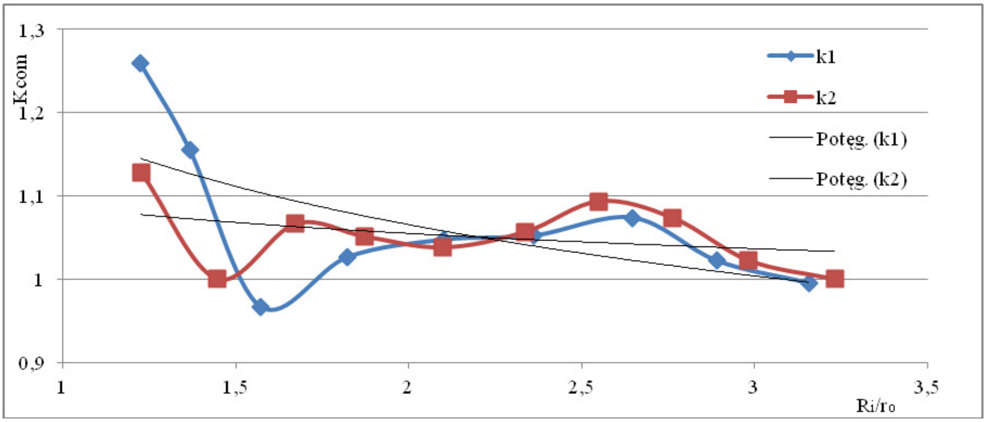

Fig. 5. The well pressiometer extension (k1 – sand compaction coefficient change; k2 – clay compaction coefficient change; Poteg (k1) – exponential trendline for sand compaction coefficient change; Poteg (k2) – exponential trendline for clay compaction coefficient change). *Source:* own study

The soil gravity changes graphs show the presence of zones of ground decompaction during pressiometer extension at a distance of 1.4-1,8 r_0 from the well wall. Such deconsolidation indicates the possibility of soil displacement at a similar distance from the side surfaces of the pile or anchor.

It should be noted that the increase in the initial diameter of the well r_0/R_0 more then 1.4 corresponds to the maximum density of soil composition and the minimum porosity coefficient. As a result of the performed laboratory experiments and statistical processing of the obtained data, the minimum possible soil porosity coefficients were determined, after which the processes of ruptures begin in the soils and contraction occurs. This coefficient is equal 0.33 for the medium sands and sandy loam.

4.2. Soil density change during cement mortar injection

The study of cement mortar injection to medium sand and sandy loam density changes was carried out during large-scale laboratory experiments. According to our research, the characteristics of the massif are constant and unchanged after 14 days from the injection of cement mortar into the sands, and after 28 days into clay.

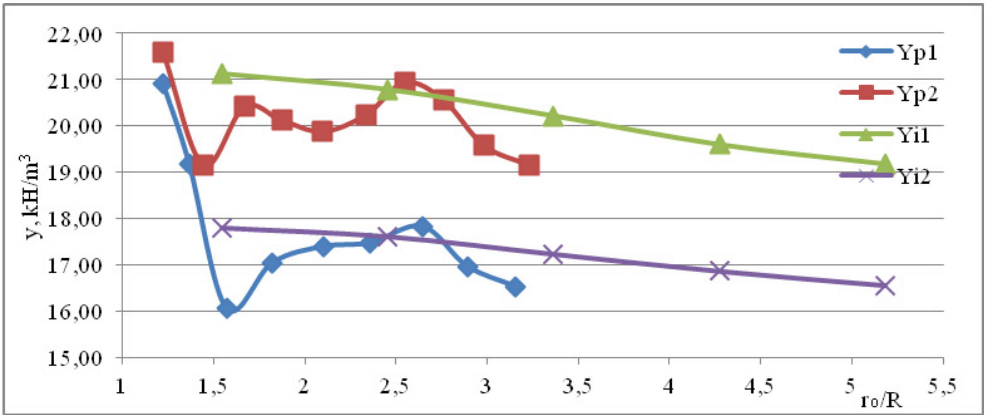

Fig. 6. Sand and sandy loam unit weight characteristics change in radial description (Yp1 – sand unit weight change after pressiometer extension; Yp2 – sandy loam unit weight change after pressiometer extension; Yi1 – sandy loam unit weight change on the 28th day after injection; Yi2 – sand unit weight change on the 14th day after injection). *Source:* own study

5. Conclusion

Based on the results of the laboratory experiment, it can be concluded that the soil area softening occurs during the pressiometer extension, and it also appears during cement mortar injection. The presence of softening zones can explain the occurrence of anchor and pile failure, also through the contact of the concrete body and the soil directly and through the softened soil. Furthermore, the pressiometer extension changes the unit weight of the sand in diapasons of 16.5-21.0 kH/m^3, and sandy loam 19.0-21.7 kH/m^3. The minimum porosity coefficients for these grounds equals 0.33.

According to our borehole injection expansion experiment, it was determined that the increase in the initial diameter of the well r_0/R_0 was more than 1.4, which corresponds to the maximum density of soil composition and the minimum porosity coefficient. After an increase in the initial diameter of more than 40%, discontinuous processes begin in soils.

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