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IMPROVEMENT OF THE METHODOLOGY FOR EVALUATION OF INJECTION RADIUS DURING HIGH-PRESSURE CEMENTATION

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Abstract. The process of the soils strengthening with the development of modern constructional engineering becomes more complex because of territorial limitation for construction sides and ability of existing buildings to damage in the result of dynamic influence.

In recent years new more efficient combined methods for improving engineering properties of soil mass are being used. These methods integrate advantages of two, three or more technologies for transformation of the soils properties. High-pressure cementation is one of these combined methods for the soils strengthening under buildings and structures.

This paper discusses high-pressure cementation as one of the possible solution of the foundation problems and presents the results of theoretical and practical investigations made on the determination of the injection radius.

Keywords: high-pressure cementation, reduced injection radius, spherical coordinate system.

Introduction. It's a well known fact that the population of our planet is increasing and the soils suitable to sustain loading from buildings or structures are becoming scarce. Due to the scarcity of land and the development of the marshy areas, mountainsides and landfill areas begins to use as the alternative places for the people's living. Therefore, soil stabilization is one of the successful solutions of the soil treatment in such areas for achieving the required engineering properties and specifications so that structures can be placed safely without undergoing large settlements.

In some regions construction becomes complicated because of specific geological conditions connected with the powerful layers of loess soils, submergence territories and significant change of physical and mechanical properties of soils in the process of buildings exploitation. Sometimes construction has to be carried out in the construction site consisted of man-made ground and different anthropogenic soils, which have the low density and can be self-consolidated in the process of its exploitation.

Therefore development and application of new technologies which have combine influence on soils become very popular. One of these methods is high-pressure cementation. Unlike classical cementation, during high-pressure cementation water-cement or water-cement-silicate solutions pumped under high pressure into soil. As the result of the action of this pressure cavities and fissures were created in soil mass. Solution penetrates into these fissures and then will be come hard. High pressure creates additional compaction of surrounding ground. Consequently composite with high mechanical strength can be created by reinforced cement stone layers and by the vertical elements of injector in soil. Fig. 1 shows scheme of soil mass strengthened by high-pressure cementation.

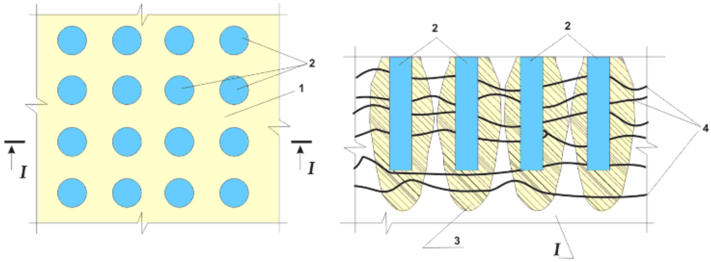

Fig. 1 Scheme of soil mass strengthened by high-pressure cementation: 1 – soil with natural structure; 2 – vertical reinforce elements; 3 – compacting zone; 4 – horizontal cement stone layers.

Advantages of high-pressure cementation:

1. absence of dynamic influences on a ground and therefore possibility of application during reconstruction of buildings and structures and in the conditions of territorial limitation.
2. combined action on the soil which include:
   - forming new and hardening old bonds between particles;
   - compaction of soil under improved pressure of injected solution;
   - creation space structure with ruggedness which include vertical elements of injector and cement stone layers.
3. elimination of the soils slumping properties;
4. opportunity to bury of radioactive and toxic waste;
5. high strength characteristics of soil composite reinforced by this method;
6. ability to use higher or lower than the level of ground waters.

Methodology for determination the characteristics of high-pressure cementation process was studied and developed not long ago [2, 3]. Empirical approaches which based on the pressure monitoring and consumption of the solution during the injection were used previously [1, 4 – 6]. Therefore the analysis of existing design-theoretical solutions and investigations of methods for determination of radius of injection are very actual problem.

The main purpose of this research is improvement of the methodology for evaluation of injection radius during high-pressure cementation.

Methodology. The most correct theoretical approach for determination the characteristics of high-pressure cementation process was find in spherical coordinate system allow central symmetry of problem. For calculation it was took into account that the form of injection zone is hollow sphere that is situated sufficiently far from day surface. Fig. 2 shows the geometrical parameters of model for determination the characteristics of high-pressure cementation process.

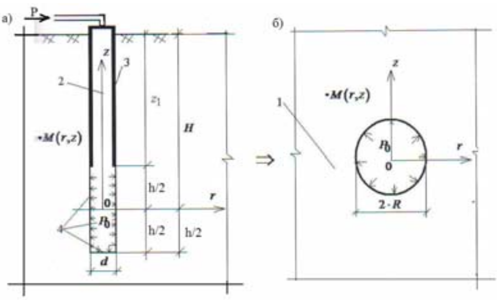

Fig. 2. Geometrical parameters of model for determination the characteristics of high-pressure cementation process: a – real scheme, b – approximate scheme; 1 – subsoil; 2 – borehole; 3 – casing; 4 – zone of injection.

Relationship between radius of injection and pressure of injection was obtained:

$$r = R\left(\frac{P}{k_1}\cdot\frac{3-\sin\varphi_I}{\gamma_I\cdot H\cdot\sin\varphi_I + c_I\cdot\cos\varphi_I}\right)^{1/n} \tag{1}$$

where k_1 and n are empirical coefficients; φ is friction angle; c is specific coupling; R is reduced injection radius.

Values of empirical coefficients:

- for clay soils: $n = (1{,}58 \pm 0{,}48) + (0{,}59 \pm 0{,}21)\cdot I_L$; $k_1 = 1{,}01 \pm 0{,}12$;
- for sand soils: $n = (3{,}61 \pm 1{,}08) + (1{,}64 \pm 0{,}57)\cdot e$; $k_1 = 1{,}02 \pm 0{,}08$,

where I_L is consistency index; e is void ratio.

Reduced injection radius was obtained from the equality of volumes of cylinder and sphere:

$$R_{vol} = \sqrt[3]{\frac{3\cdot d^2\cdot h}{16}} \tag{2}$$

The solution is injected into soil through the surface of injector. For this reason, the reduced injection radius was obtained from the equality of surface areas of cylinder and sphere:

$$R_{surf} = \sqrt{\frac{2\cdot d\cdot h + d^2}{8}} \tag{3}$$

where d and h are diameter and height of cylinder accordingly; R is radius of sphere.

For investigation the relations of injection radius from operation factors of injection process and engineering properties of soil with R_{vol} and R_{surf} the next basic data were used: cementation depth *4,0…10,0 m,* pressure of cementation *0,5…4,5 Mpa,* height of zone of injection – *1,5 m,* soil mass is sandy-loam; void ratio *e=0,96;* specific coupling *c=7 kPa;* consistency index $I_L=0$, friction angle $\varphi=23^0$, specific weight *1,59 kH/m*^{3}.

Results of calculation are presented in fig. 3 – 5.

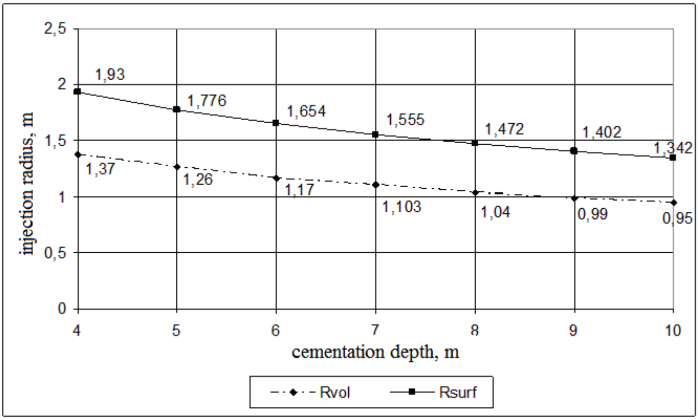

Fig. 3. Change of the injection radius with the increasing of cementation depth

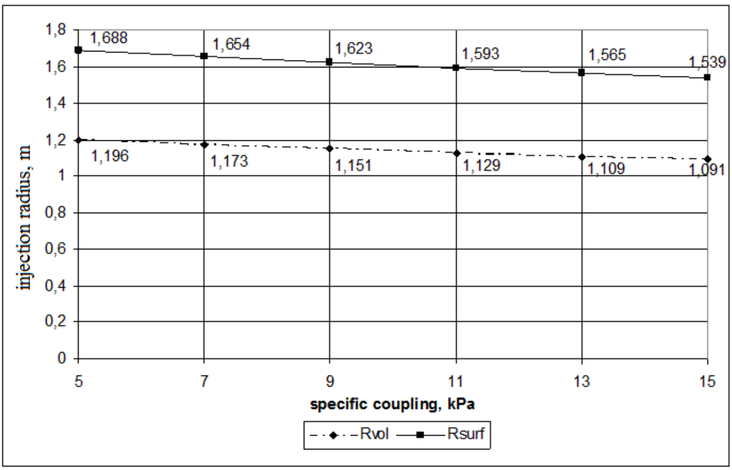

Fig. 4. Change of the injection radius with the increasing of specific coupling

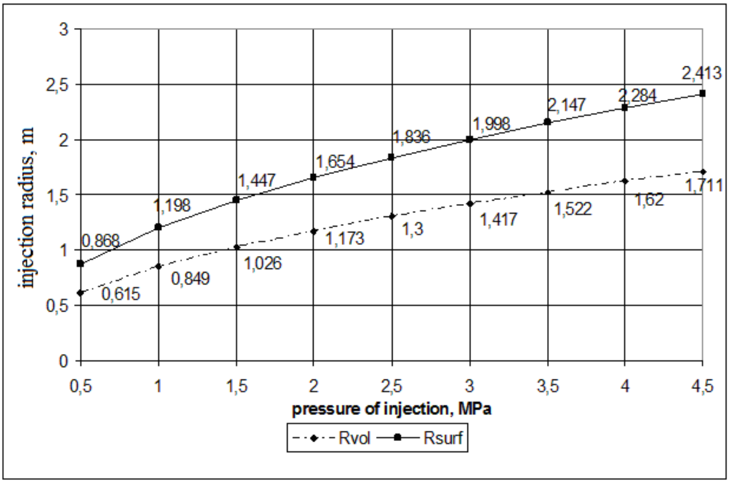

Fig. 5. Change of the injection radius with the increasing of pressure of cementation

Results of calculation of the injection radius with R_{vol} and R_{surf} are presented in table 1.

Table 1

Relation the injection radius from the reduced injection radius

Diameter of the borehole, m	Method of calculation of reduced injection radius *R, m*	
	R_{vol}	$R_{surfв}$
0,093	1,173	1,654
0,127	1,448	1,95

It is apparent from fig. 3 – 5 and table 1 that injection radius significantly depends on the pressure of cementation and reduced injection radius. Injection radius changed from 0,3 to 0,5 m with different volumes of the reduced injection radius.

Experimental investigation was carried out for verification of received theoretical results. Subject of research – foundation base of four-storey building on Kirova street, 91 in Dnipropetrovsk.

*S*oil mass is sandy-loam; void ratio $e=0,96;$ specific coupling $c=7\ kPa;$ consistency index $I_L=0,$ friction angle $\varphi=23^0,$ specific weight $1,59\ kH/m^3$. Pressure of cementation *0,45…4,7 Mpa*, diameter of borehole *0,093 m*, height of zone of injection *0,87…1,84 m*, cementation depth *4,0…10,0 m*.

Real and calculated values of radius of injection are presented in table 2.

Table 2

Injection radius

Real values	Calculated values	
	R_{vol}	R_{surf}
0,58…1,29	0,526…1,53	0,685…2,23

From the Table 2 it can be seen that the results of calculation the injection radius with R_{vol} are more equivalent to the real values then with R_{surf}.

Conclusion. The theoretical investigations of injection radius calculation methods were carried out. The dependence of reduced injection radius on the equality of volumes and surface areas of cylinder and sphere was found. The equation for reduced injection radius calculation was obtained from the equality of volumes of cylinder and sphere. This equation can be effective used for calculation the characteristics of high-pressure cementation process.

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