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Micro-Cement for Injection Consolidation of Base Soils

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Abstract*: Issues of development of compositions of injectable materials on inorganic basis for underground and transport construction are considered in the paper. Inorganic binders for aqueous suspensions for strengthening of low-strength sandy and debris soils by injection into the fortified massif are proposed. The use of silica gel in combination with hydrated lime for injectable aqueous suspensions is justified. The influence of superplasticizer on the technological properties of suspensions is shown. The properties of micro-cement of different compositions are presented. Optimal ratios of components were determined. The following properties of aqueous suspensions have been studied: viscosity, sedimentation and penetrating power. The viscosity was up to 40 s, sedimentation up to 1.4%. Soil-concrete obtained by injecting the aqueous suspension based on composite binders has the compressive strength in the range of 3.3-6.2MPa.

Keywords*: Micro-Cement, Injection, Suspension, Silica Gel, Lime, By-Product Of Industry, Superplasticizer, Soil Consolidation, Ecology, Environmental Construction.

I. INTRODUCTION

Development of underground space and development of transport network is a distinctive feature of modern urban construction [1-3]. Currently, the problem of soil consolidation in new construction, reconstruction and repair of existing buildings and structures is relevant [1,4-8]. Violation of integrity of structure of consolidated massif of soil is inadmissible in the conditions of dense city building at technological production. Injection technologies meet this requirement. Issues of selection of the composition of injection material for soil cementation by injection technology are of interest to researchers. The influence of the type and dispersion of mineral additives on the technological properties of aqueous suspensions (conditional viscosity, sedimentation and penetration) has been studied in many papers [9-12]. It should be noted that uniform bulk impregnation of the soil massif is possible in the case of using the micro-cement with a particle size up to 10-16μm for the preparation of an aqueous suspension [9,10].

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The technology of manufacturing micro-cement due to grinding is energy-intensive one [10]. This leads to the cost rise of materials for injection technology. Thus, the issue of application of by-products of industry with the required dispersion is relevant. Silica gel formed in the production of aluminium fluoride by the interaction of hydrofluosilicic acid with aluminium hydroxide can be such a secondary raw material. The exclusion of grinding operation in the manufacture of micro-cement for injections also leads to significant reduction in the cost of soil consolidating technology.

Technologies of water suspensions of micro-cements for impregnation of loose or low-strength porous soils are actively developing in recent years. Currently, effective micro-cements are produced in the world [10]. However, the cost of micro-cements is higher than the cost of Portland cement of ordinary strength class.

Micro-cement is obtained by grinding Portland cement with a superplasticizer in grinding units. Micro-cement with the grain size greater than 16μm is obtained in the case of insufficient grinding. The grains with size greater than 16μm clog capillaries and pores in the process of injecting the suspension into the soil. This slows or stops the injection process. It is possible to use an additional operation to separate fine fractions with grains of the required size in the air flow as shown in the study of fine-ground quartz sand [13,14]. Thus, micro-cement that is produced by the technology of grinding the original cement with subsequent separation into fractions is an expensive material. The use of such micro-cement for the preparation of injection materials significantly increases the cost of the fixed soil array, i.e. soil-concrete. Soil consolidation consists in artificial transformation of soil properties under conditions of their natural occurrence by different chemical methods [15-19]. This allows increasing the strength and reducing the deformability of soils by providing adhesion among soil particles. It should be noted that soils that are permeable and filter water well are most susceptible to intensive consolidation. The main methods of solidification are cementation, silicification, electrochemical binding, heat roasting, solitary, clay alteration and bituminous grouting, etc. Injection technologies without structural damage of soil are the most common ways of soil consolidation of bases (Fig. 1). Injection suspensions based on micro-cements are used to secure the foundations and to strengthen the masonry or rubble concrete in the reconstruction or repair of buildings [20-27].

Cementation of coarse and sandy soils can be used to create anti-filtration curtains that prevent the removal of small particles from the foundation base of nearby buildings in the case of pumping water from the excavation pit [28-31].

The solution of the problem of increasing the strength and anti-filtration properties of consolidated massifs, their resistance to various aggressive influences while maintaining a low cost of work is possible by using injections based on micro-cement that consists of silica gel and hydrated lime. Silica gel is a waste product. This solves the environmental problem. In addition silica gel is a ready-made raw material that can be used without further processing to prepare a mineral aqueous suspension for injection into the soil. Silica gel in aqueous suspension with superplasticizer has fine particles smaller than 10 microns.

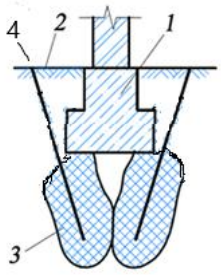

Figure 1. Scheme of soil consolidation under foundation: 1-foundation; 2-soil; 3-consolidated soil zone; 4-injector

Superplasticizers play an important role in injection suspensions [32-35]. The use of superplasticizers allows regulating the technological properties of aqueous suspensions: conditional viscosity, sedimentation and penetration. It is necessary to take into account the interaction of superplasticizer with mineral micro-particles in order to select the quantity of superplasticizer [36-42].

The aim of the paper is to study the technological properties of injection suspensions based on silica gel, hydrate lime and superplasticizer.

II. MATERIALS AND METHODS OF RESEARCH

Hydrate lime for construction of JSC "Uglovsky Lime Plant"; silica gel formed in the production of aluminum fluoride by the interaction of hydrofluosilicic acid with aluminium hydroxide; polycarboxylate-based superplasticizer Stachement 2000 were used as the main components for injectable suspensions.

Compressive strength was determined according to standard 30744-2011, conditional viscosity was determined according to standard 33762-2016, sedimentation according to normative document 39-2-645-81, suspension density was determined according to standard 5802-86.

Water was pumped through a sample of compacted sandy soil and then the aqueous suspension of the calculated composition at the pressure of 0.4 MPa was pumped. The permeation capacity of the aqueous suspension was assessed by the nature of the suspension propagation that could be observed through a transparent mold during testing. Samples of suspension-rich soil hardened under normal conditions and were tested at the age of 2 months.

III. RESEARCH RESULTS AND DISCUSSION

Aqueous suspensions with different ratios of silica gel, lime and superplasticizer Stachement were prepared with forced mixer "Digi Mortar Mixer". The water-to-binder ratio was equal to 2.0.

The requirements for particle size (up to 10μm) as well as the requirements for the technological properties of aqueous suspension are mandatory criteria for the applicability of micro-cement in injection technology. This is the viscosity and sedimentation of the suspension particles for 90 minutes. Viscosity is characterized by the rate of discharge of the suspension from the standard funnel of one litre volume (conditional viscosity). It is usually believed that the viscosity should not exceed 40 s. The permissible sedimentation of particles in the suspension for 90 minutes should not exceed 2% of the suspension volume.

All studied suspensions had sedimentation up to 1.4% within 90 min as shown in Table 1. This is less than the maximum permissible value and indicates a high dispersion and water-holding capacity of the studied micro-cement.

The conditional viscosity of suspensions is presented in Table 2. The results showed that suspensions without superplasticizer do not meet the requirements for conditional viscosity that should be up to 40 s. Consequently, the suspensions were prepared in further studies with the addition of the superplasticizer in the amount of 0.6% and 1.2% by weight of the micro-cement. At the same time, their conditional viscosity was in the range of 36-37 s. This is not much higher than the water conditional viscosity that is equal to 32 s. Such suspensions have a good penetrating ability and allow obtaining soil-concrete when injected into sandy soil.

Table 1. Sedimentation of suspensions

Composition		Sedimentation of suspensions, %			
Ratio of silica gel to lime	Superplas-ticizer,%	Duration of observations, min.			
		0	30	60	90
1:2	0	0	0	1.2	1.3
1:1	0	0	0	1.2	1.2
1:2	0.6	0	0.5	1	1.2
1:1	0.6	0	0.5	0.8	1.0
1:2	1.2	0	0.8	1.2	1.4
1:1	1.2	0	0.8	0.8	1.2

Table 2. Conditional viscosity of suspensions

Composition		Viscosity, sec.				Compres-sive strength, MPa
Ratio of silica gel to lime	Superplas-ticizer,%	Duration of observations, min.				
		0	30	60	90	
1:2	0	64	64	62	60	-
1:1	0	68	66	66	64	-
1:2	0.6	44	44	42	42	3.5
1:1	0.6	46	46	46	44	3.3
1:2	1.2	36	36	37	36	6.2
1:1	1.2	36	37	37	37	6.0

Low-base calcium hydrosilicates are formed by reaction of silica gel with lime [43]. Silica gel contains silica in the active form that is able to interact with $Ca(OH)_2$ at room temperature to form calcium hydrosilicates by reaction:

$SiO_2 + Ca(OH)_2 + n(H_2O) \rightarrow$ H-S-C.

Calcium hydrosilicates are the main hydration product of the studied micro-cement. Calcium hydrosilicates bind sandy soil into soil-concrete.

Consolidation of soils has different purposes: consolidation of unstable soils, construction of ground water cutoffs and increase of bearing capacity of the soil for the foundation bases [44-50]. The bases under the foundations should have increased compressive strength.

As a rule the consolidated soil under the foundations must have strength up to 3-6 MPa and at concentrated load - up to 9 MPa. The results of tests of soil-concrete samples for determining the compressive strength show that the developed micro-cement provides the required values of the compressive strength according to Table 2. Strength value of 6.2 MPa for samples based on silica gel and lime with the ratio of 1:1 was achieved. The cost per $1m^3$ of consolidated soil is determined by the high cost of micro-cements for injection technology that are obtained by additional grinding. In this case the cost of silica-based micro-cement will be lower since silica gel is a by-product of industry. It is necessary to take into account the environmental effect of its use as a secondary resource [51-56].

IV. CONCLUSIONS

The use of micro-cement based on silica gel and hydrate lime for injection technology of soil consolidation is studied in the paper. Technological properties of aqueous suspensions with good penetration capability have been obtained. The need to select the quantity of superplasticizer to obtain the required conditional viscosity and sedimentation was shown. Aqueous suspensions based on silica gel and hydrated lime had the required technological properties namely low conditional viscosity up to 40 s and sedimentation up to 1.4 %. Soil-concrete obtained by injecting the aqueous suspension based on proposed binder had the compressive strength in the range of 3.3-6.2 MPa. The developed binder has the necessary compressive strength and technological parameters and can be used for soil consolidation. Also, the use of silica gel solves the problem of environmental protection as it is a by-product of industry.

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