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RESEARCH OF SOIL-CONCRETE MATERIAL AND ITS APPLICATION FOR THE PRODUCTION OF PILES AND SOIL STRENGTHENING

ABSTRACT

The results of the research of soil-concrete strength characteristics and frost resistance depending on cement gauging, mixture density, soil type etc. are presented in the article.

According to the results it has been stated that the rise of cement gauging from 5% to 30% leads to the compressive strength improvement Rсж of soil-concrete samples by 70-90%.

Thus the value of the indicator Rсж at the age of 90 days on average is 1,5-2,5 times higher of the value of the indicator Rсж at the age of 28 days. It's necessary to highlight that the samples, that have been preserved in water, show the most high value of the indicator Rсж.This leads to the conclusion that the arrangement of soil-concrete piles in water-deposited soils is favorable. The density of a sample has the essential influence on soil-concrete strength. Increasing density it is possible to reduce the expenditure of cement up to 50%. Soil-concrete density is the basic factor that influences the increase of frost-resistance of the material.

The value of the indicator Rсж depends mostly on soil characteristics, in particular – on grain size composition. For example, under equal initial conditions (expenditure of cement, water, mixture density and so on) the strength of soil-concrete made on the basis of sandy silt is 1,5 times lower than the one made on the basis of medium coarse sand or sandy clay.

The soil-concrete made on the basis of sand, clay-bearing soil (sandy soil, sandy clay) is a frost resistant material. Frost resistance as well as density increases through time and depends on cement expenditure. 35 cycles of "frosting-defrosting" for all types of the soils under research are provided with the cement expenditure at the amount of no less than10% (to the weight of airy dry soil). No less than 50 cycles are achieved for the soil-concrete materials made of medium coarse sand, sandy soil and sandy clay with the cement gauging at the level of 15-20%, for the ones made of sandy silt – 25%.

With cement gauging lower than 15% the decrease of sample density by 5-10% and of compressive strength – by 20-40% (depending on the type of soil) was observed for all types of samples after 20-30 cycles.

In terms of the research carried out in laboratory and real-life conditions of testing on the factory floor during piles erection, technical, constructive and design requirements to soil-concrete used for piles production (strength, water resistance, frost resistance, expenditure of materials, methods of arrangement, quality and acceptance control) are elaborated. Economy up to 50%.

Keywords: soil-concrete, density, frost resistance, strength, foundations, recommendations, saving

INTRODUCTION

The matters of reduction of resource consumption in construction production are of key importance nowadays. Therefore, the work on the research and development of the technology for foundation making of in situ soil-concrete compaction piles (including punched, rammed, rolled ones etc.) for conditions of soils available in the Republic of Belarus has been carried out by specialists of the Department of Bases and Foundations of Institute BelNIIS RUE, because of the fact that currently the soil-concrete is one of the cheapest materials [1], and compaction piles are the most effective ones [2].

It is known that soil-concrete as a material is an artificial stone that is equivalent to concrete; cheap locally-available soil is used to prepare it, and it is applicable for foundations if its strength is within 5-10 MPa, its frost-resistance grade is C8/10 or better for soil strengthening and C12/15 or better for pile structures, with cement expenditure (due to economic reasons) not exceeding 0.15-0.30 tons per cubic meter.

According to the experimental data, the principal initial parameters of the soil-concrete production process that significantly affect the quality of piles are:

- initial soil characteristics (density, moisture, soil composition);
- gauging of soil-concrete mixture components (water, cement);
- technological mode of pile-making (mixer rotation frequency and immersion rate, number of passes and mixture compaction degree).

In the article provided below, the results are given for the researches and related tests carried out under industrial conditions in pile making and low-strength soil strengthening by reinforcing members made of compaction piles arranged in pierced wells (punched, rammed, rolled ones etc.).

RESEARCH PROCEDURE AND RESULTS

The soil-concrete research was primarily focused on studying its mechanical strength characteristics and frost-resistance as major parameters predetermining the quality of piles. The research was carried out with mixtures differing in cement content, with its variable density and moisture, using the standard procedure with 100x100 mm cubic samples.

As a raw material for making soil-concrete samples, sand from Gomel, Mogilev and Minsk, differing in coarseness, as well as sandy soil and sandy clay (from Minsk District) was used. As a binder, M400-500 Portland cement from Volkovysk Cement Plant was used, with the initial setting time over 2 hours, the activity 528 kg/cm^2, and the grinding fineness 0.008 (12%).

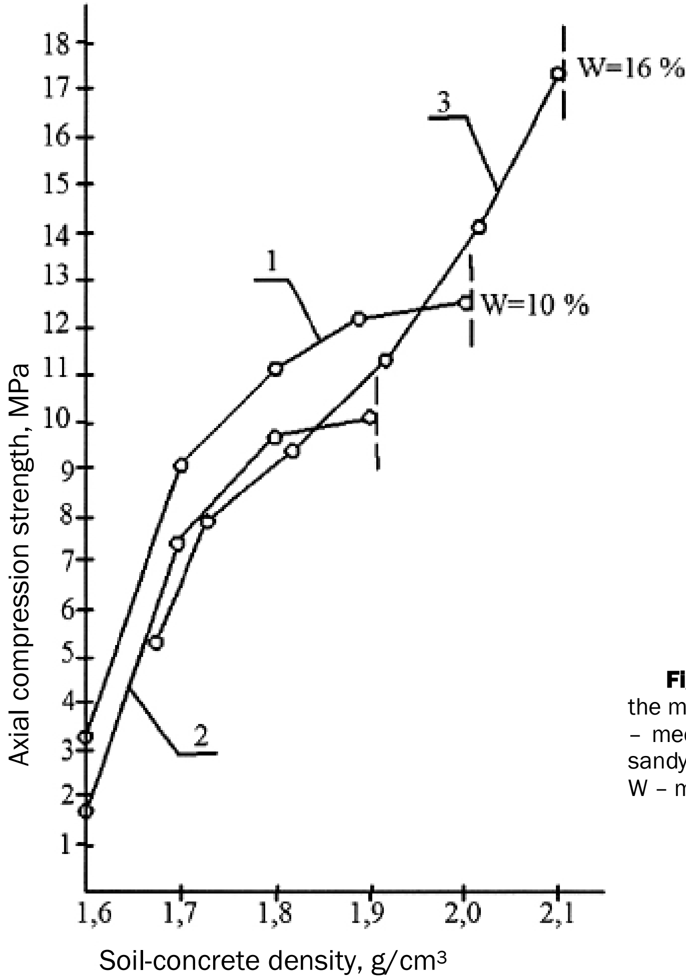

Figure 1. Soil-concrete strength (at 90 days) versus the material density (M400 cement, expenditure 20%): 1 – medium-coarse sand, d_{60} = 0.35; 2 – fine sand; 3 – sandy clay (particles < 0.5: 35 – 50%; I_p = 0.11; pH = 8); W – moisture

The influence of the amount of cement on the soil-concrete strength was studied within the range of additives in soil mass from 5 to 40%, with water adding from 5 to 30

Cement was added in dry condition into the soil mass and then mixed with it. After water adding, mixture was again mixed thoroughly and laid into standard molds according to the procedure specified in GOST 10180, with the varying degree of compaction.

Strength and frost-resistance of samples was estimated after 28 and 90 days of normal-moisture storage (wet sawdust) and water storage, using the sample test data in accordance with the instructions given in GOST 10180 and GOST 10060.

See Figures 1-4 for the results of research of soil-concrete made of locally-available soils, such as variation of their strength and frost resistance as a function of cement gauging, mixture density and soil type.

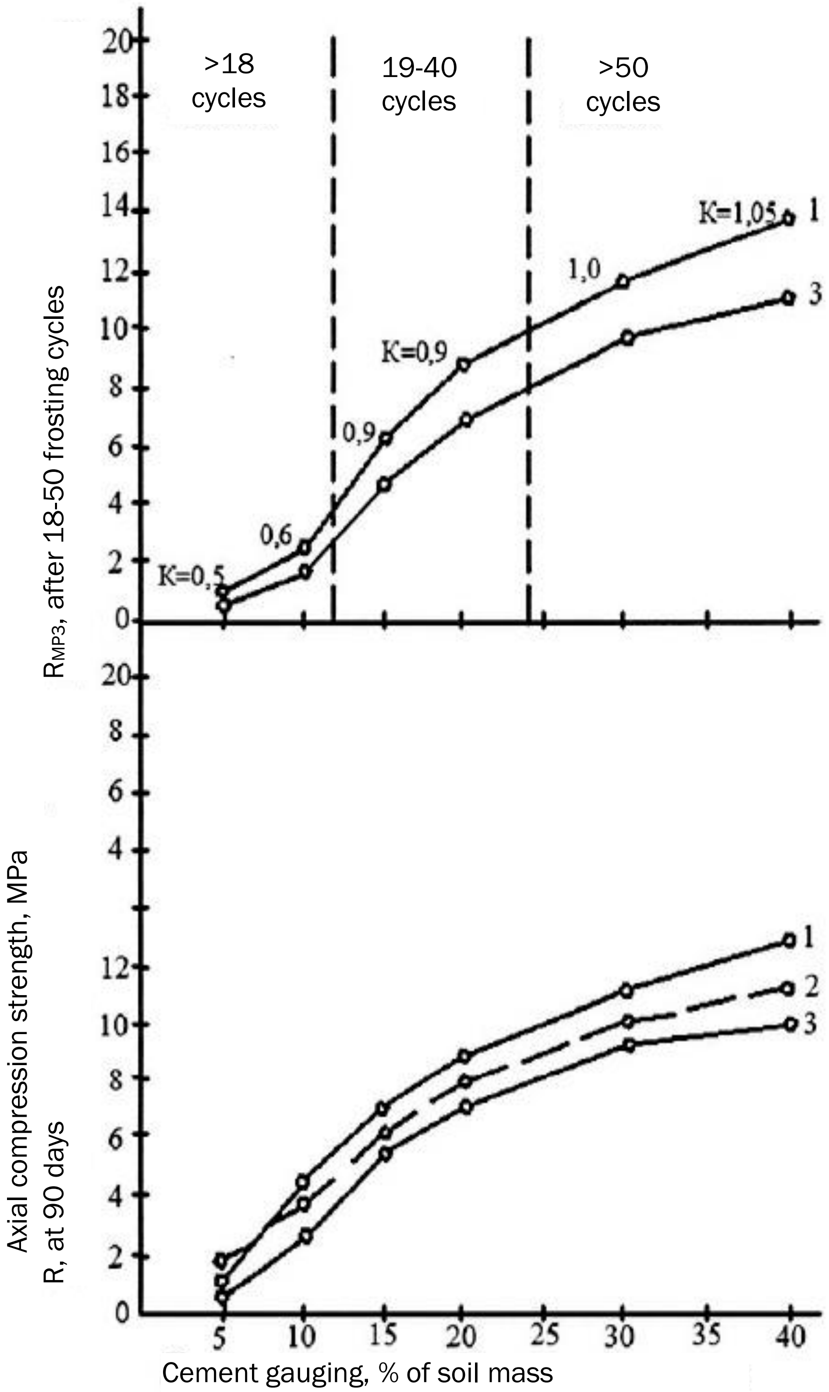

Figure 2. Variation of strength of soil-concrete (ρ=1.8 g/cm³) made of homogeneous fine sand and sandy silt, at 90 days, as a function of cement and water gauging and during the frosting: 1 – fine sand, water content 10% of soil mass; 2 – water content, the same, 15%; 3 – sandy silt, water content 10-12%; K – frost-resistance factor, ratio

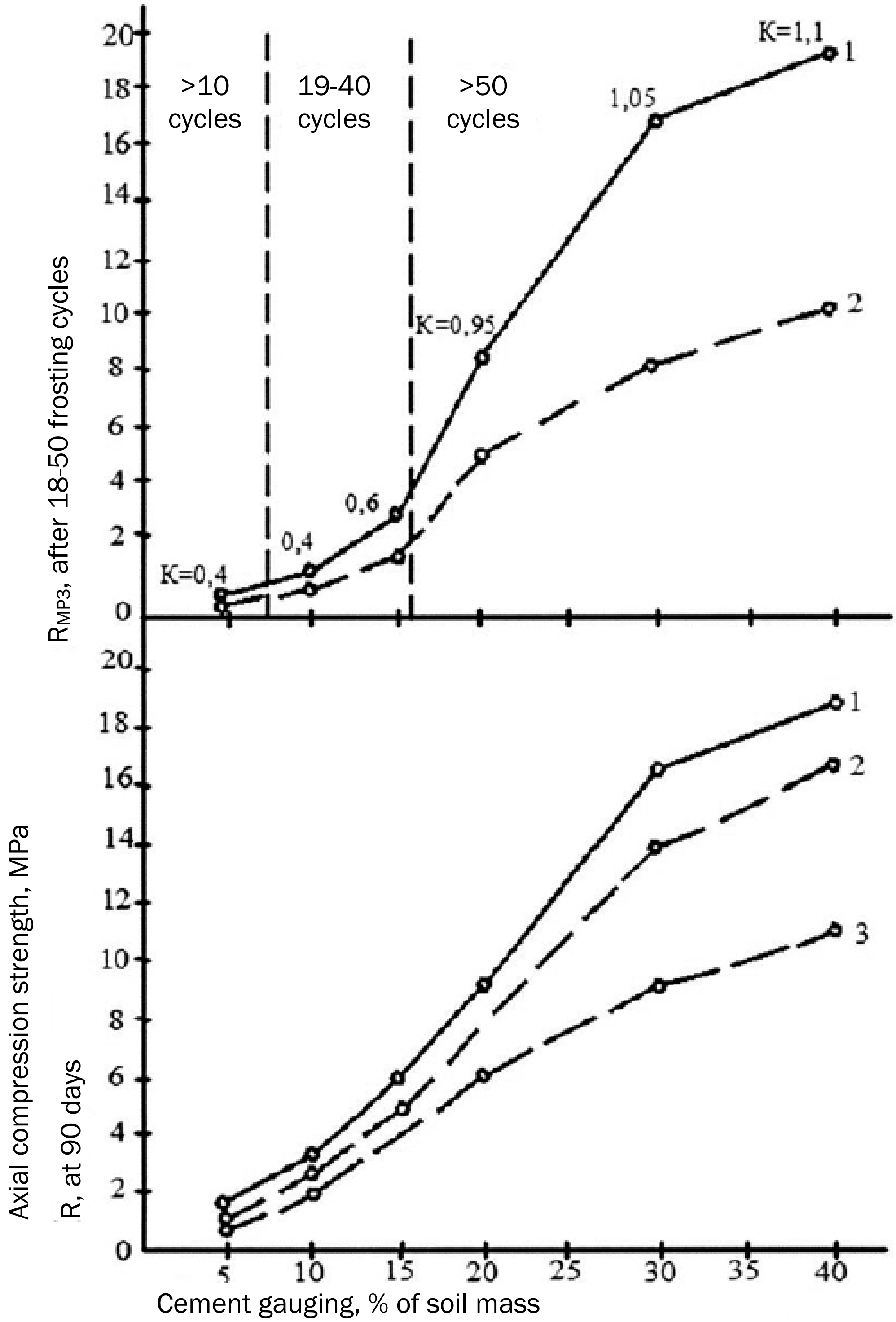

Figure 3. Variation of strength of soil-concrete (ρ=1.8 g/cm³) made of homogeneous medium-coarse sand, at 90 days, as a function of cement (M400) and water gauging and during the frosting: 1 – fine sand, water content 10% of soil mass; 2 – water content, the same 15%; 3 – the same, 20%; K – frost-resistance factor, ratio

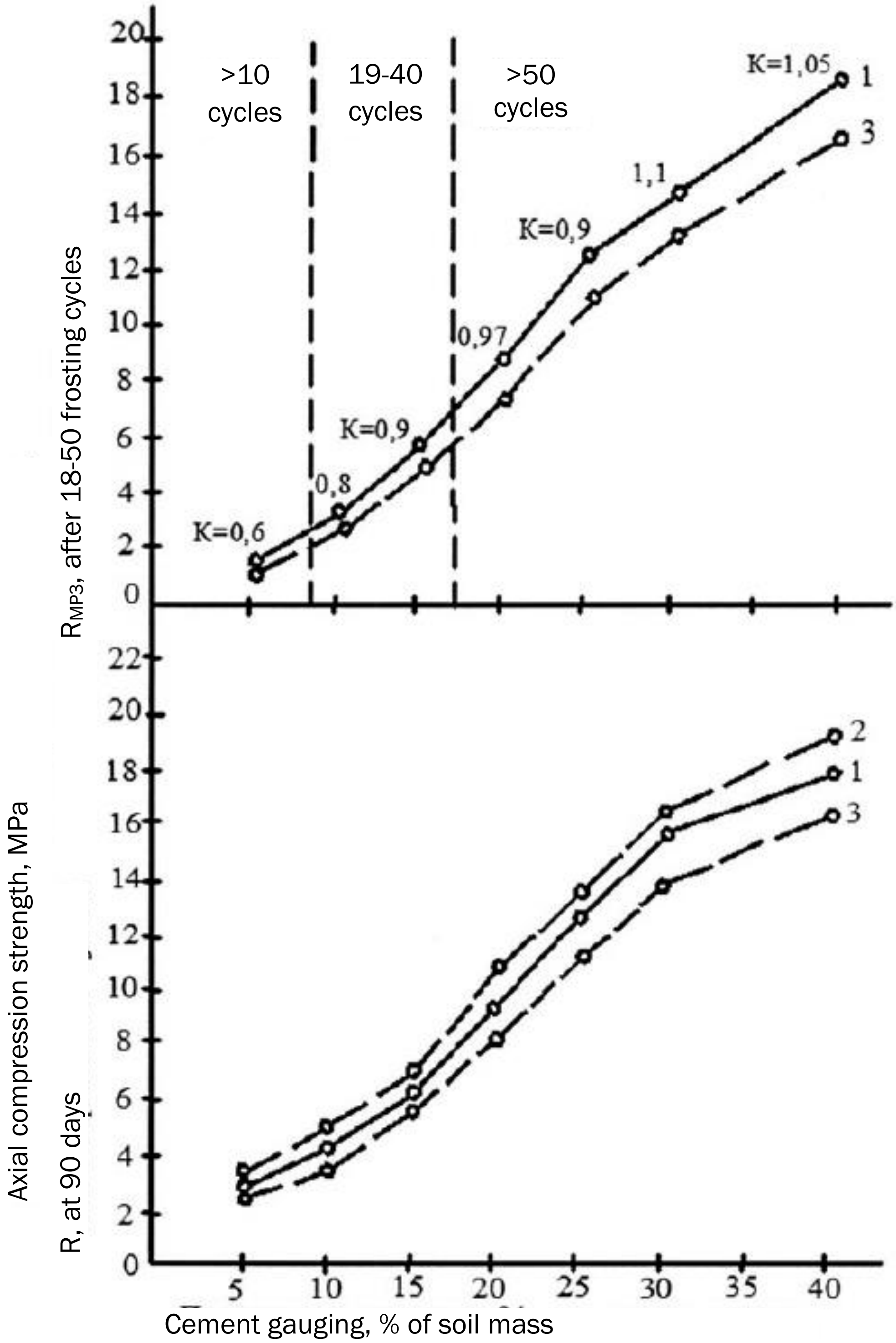

Figure 4. Variation of strength of soil-concrete (ρ=1.8 g/cm³) made of sandy clay, at 90 days, as a function of cement (M400) and water gauging and during the frosting: 1 – medium-coarse sand, d60 = 0.35; 2 – fine sand; 3 – sandy clay (particles < 0.5: 35 – 50%; IP = 0.11; pH = 8); K – frost-resistance factor, ratio

On the basis of the results obtained, the following was found:

1. The soil-concrete strength is significantly influenced by cement gauging (Figures 2-4). For example, rise of cement gauging from 5% to 30% results in rise of compressive strength of samples $R_{сж}$ by 70-90%.
2. The soil-concrete strength varies through time during water storage in normal-moisture mode. The values of $R_{сж}$ at 90 days are 1.5-2.5 times higher, on the average, than the values of $R_{сж}$ at the age of 28 days. It should be noted that the samples that were stored in water demonstrate the highest values of $R_{сж}$. This leads to the conclusion that the arrangement of soil-concrete piles in water-saturated soils is the most favorable.
3. The density of a sample has an essential influence on the strength of soil-concrete. Expenditure of cement can be reduced by the density rise, with the reduction up to 50%. Soil-concrete density is the key factor for the material frost-resistance rise.
4. Values of $R_{сж}$ depend significantly on properties of soil used, especially on its grain size distribution. For example, under equal initial conditions (such as expenditure of cement and water, mixture density etc.), strength of soil-concrete made on the basis of sandy silt is 1.5 times lower than that for medium coarse sand or sandy clay.
5. The soil-concrete under investigation in this research is a frost-resistant material. Frost-resistance, as well as density, becomes higher through time and depends on cement expenditure:
   a) 35 cycles of "frosting-defrosting" are provided by for all types of investigated soils when the cement expenditure is at least 10% (of the weight of airy dry soil);
   b) at least 50 cycles are reached for soil-concrete materials made of medium coarse sand, sandy soil and sandy clay with the cement gauging of 15-20%, or, for materials made of sandy silt, 25%.

For cement gauging less than 15%, the decrease of sample density by 5-10% and of compressive strength by 20-40% (depending on the soil type) was observed for all types of samples after 20-30 cycles.

As a result of experiments, the following optimal ratio of components in soil-concrete mixtures was found, providing the required quality of soil cement in bodies of piles for conditions of soils existing in the Republic of Belarus when the load from buildings is transmitted to these piles:

- cement gauging, tons per cubic meter:
  - for sand soils 0.15-0.25
  - for sandy soils and sandy clays 0.20-0.30
- water expenditure per 1 m^3 of mixture, m^3 0.15-0.18
- mixture density, t/m^3, at least 1.8

and the optimal soil mixture must have the properties as follows:

- grain size distribution:
  - clay and silt particles, % 20-40
  - sand particles (0.25-2 mm), % 30-40
  - sand particles (0.25-0.005 mm), % 20-40
- plasticity index 0.02-0.07

If soil-concrete is used as a filler for wells (reinforcing members) in strengthening of bases (for geomassives), it is reasonable to reduce concrete expenditure down to 0.05-0.1 tons per cubic meter of mixture, and to reduce strength of the material for compaction piles down to 0.5 MPa. Due to this circumstance, the task of provision of the equal strength of soil and piles can be solved, and the cost of foundations can be reduced 1.5-2 times when the strength and reliability conditions met in accordance with applicable regulations.

To make soil-concrete with the required strength and frost-resistance, Portland cement or Portland blast-furnace cement must be used with the grade M400 or better according to GOST 10178.

Water must contain at most 4% of chlorides and at most 2% of sulphates. Humus substances in soil must not exceed 6% of the mixture mass and silty-clayed substances must not exceed 15%.

The experience suggests that, in addition to the aforementioned parameters, the required values must also be specified for the degree of crushing (breaking) of soil aggregates. The total content of aggregates larger than 5 mm must not exceed 20% and the mixture must be completely free of aggregates larger than 20 mm. The experiments have demonstrated that if soil is not crushed properly the required strength of soil cement material cannot be provided.

The major task for this research during its 2nd stage was the testing of design-related and technological characteristics of the solutions developed, as well as the techniques for their implementation in industrial environment. At the same time, works were carried out to solve the tasks of retrofitting of the equipment and technologies for erection of piles and geomassives using soil-concrete for the purposes of large-scale implementation of the results of this work in construction practice, such as

- batching of optimal compositions of soil-concrete for load-bearing piles and non-load-bearing piles (reinforcing members), with the under-reaming technology used for pile arrangement;
- experimental works for optimization of designs of leader sinking machines (hereinafter referred to as "leaders") and techniques for well punching and, also, research of the behavior of piles under consideration in various soils;
- evaluation of the developed technologies of structures and equipment in industrial construction environment.

The works in the 2nd stage of the research were carried out jointly with the Centre for Bases and Foundations, Stroycomplex OJSC.

As a result of work evaluation in industrial environment, the following was found /1-3 etc./.

1. Soil-concrete made of optimal mixtures, used to make in situ load-bearing soil-concrete piles (hereinafter referred to as SCP) for the II criticality rating buildings in sand soils, shall demonstrate, after curing, the following (or better) characteristics in terms of compressive strength for cubes with the edge height 100 mm, MPa (min.):

after 7 days	3.0;
after 14 days	4.0;
after 28 days	6.0.

The minimal class in terms of compressive strength for geomassives shall be C_{TS}6/7.5 or better, and for load-bearing SCP, C_{TS}10/12 or better.

The average density for all types of load-bearing SCP shall be at least D_c 1800, and for geomassives, at least D_{TS} 1600.

2. In situ piles for low-load foundations (at most 300 kN) should be produced with the strength varying along the pile shaft; for example, in the top zone (over the middle), the strength class shall be C12/15, and in the bottom zone, C6/7.5.
3. The grades of soil-concrete in terms of their frost-resistance and water tightness for the II and III criticality rating buildings shall meet the requirements listed in Table 1, and the strength class, in Table 2.

Table 1

Grades of soil-concrete for load-bearing foundations, made of optimal mixtures, in terms of frost-resistance and water tightness, for various operation modes

Operation conditions		Soil-concrete grade, at least			
Mode description	Average outdoor air winter temperature, ºC	in terms of frost resistance		in terms of water tightness	
		for the criticality rating of a building or structure			
		II	III	II	III
Repeated frosting and defrosting for separate foundations (not in a building)	At least -10	75	35	No required values specified	
The same in a building in case of water saturation from time to time or in dry soils	At least -10	35	No required values specified		

Note. For foundations built in water-saturated soils, the soil-concrete class in terms of compressive strength and grades in terms of the average density and frost resistance shall be better than the recommended ones by one point.

Table 2

Design resistances of soil-concrete made of optimal mixtures

Resistance type	Design resistances of heavy (D_{TS} 18002000) soil-concrete for the specified class in terms of compressive strength, MPa (kg/cm²)					
	CTS 2/3.5	CTS 4/5	CTS 6/7.5	CTS 8/10	CTS 12/15	CTS 16/20
Axial compression (cube strength), $f^{k}_{cd,r}$	1.90 19.30	2.70 27.50	4.00 40.80	5.00 51.00	8.00 81.60	10.00 102.00
Axial compression (prism strength), $f_{cd,r}$	1.45 14.70	2.10 21.00	3.10 31.00	3.80 38.80	6.10 62.00	7.60 77.60
Axial tension, $f_{ctd,r}$	0.14 1.45	0.20 2.10	0.30 3.10	0.35 3.55	0.55 5.65	0.65 6.65

Notes:

1. Values above lines are in MPa, values below lines are in kg/cm².
2. To calculate the required resistances for soil-concrete, design resistances shall be multiplied by the safety factor for concrete in terms of compression and tension, $\gamma f = 1.5$.
3. For soil-concrete made of non-optimal soil mixtures, the values listed in the table shall be multiplied by the factor $f_{b1} = 0.8$ or, in case of operation in water, $f_{b2} = 0.9$.
4. For soil-concrete made of natural soils in Belarus, the reference modulus of elasticity is 1x103 – 20x103 MPa.

For all types of soil-concrete made of optimal mixtures, the initial soil-concrete lateral deformation factor (the Poisson number) may be assumed to be 0.1-0.2.

CONCLUSION

On the basis of the research carried out under laboratory and field conditions with regard to the soil-concrete for in situ compaction piles and the research result tests carried out in industrial environment in the Republic of Belarus, it can be asserted that the soil-concrete, with sands and clay soils (sandy soil, sandy clay) from the Belarusian region used to prepare it, is a reliable and durable material for pile foundations of low- and moderately-loaded buildings and structures as well as geomassives, and it provides reduction of their production costs at least up to 50% as compared with piles made of commonly used materials (concrete, mortar) due to application of locally available soil that is nearly free.

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