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The Dependence of Durability and Deformation of Elements of Soil Cement Composite with Carbonate White Soil Mixture on Age

The results of an experimental study of changes in strength and deformability during the period of time subjected to short-term loading of elements made of a soil-cement composite based on white soil (belozems) of carbonate composition are discussed.

Research was carried out in accordance with current standards, as well as a well-known method that has been repeatedly tested earlier.

To assess the experimentally established data, the results of similar studies by other authors, carried out applying elements from soil-cement based on clay soils, as well as from lightweight concrete on lithoid pumice (volcanic rock), are also presented.

On the basis of the comparative analyzes of the experimentally established data, conclusions are formulated. The consideration of those may be useful both for the estimation of optimal schedules of the construction of buildings from a soil-cement composite, and for the assessment of their stress-strain state.

Keywords: *Soil cement, white soil (belozem), carbonate mixture, durability, deformation module of deformations, coefficient of transversal deformations, stress-strain state.*

Introduction

It is common knowledge that in many composite construction materials and soil cement is not exception. Cement is used as a connective component as a result, through merging and solidification composites are formed on its base.

There is scarce research (1,2) dedicated to the study of impact of time in regard to changes in the durability of soil cement. According to the abovementioned unique studies, right after its making during some time (time span lasts from 28 up to 60 days) the durability index constantly increases, leading to the compression of soil cement [1]. It should be noted that the speed of increase in the soil cement durability at the initial stages of observation (during the first 28 days after the production of the material) turns out to be quite essential, while later on it gradually fades[1].

The given research focuses on the results of studies, concerning the dynamics of changes that take place over time in the durability and resistance to deformation observed in the short-term loading of elements made of soil cement composite and white soil (belozem), carbonate mixture.

Materials and Methods

The objects of the research were test specimens - cylindrical elements made of soil cement composite with carbonate, white soil mixture:

- the diameter d = 5.0*cm*, height h = 5.0*cm* for the identification of durability limits of the material under compression,
- diameter d = 5.0*cm* and height h = 20*cm* for the identification of deformation characteristics of soil cement elements in short-term loads [2].

[1] GOST 18105-2018. Concretes. Rules for control and assessment of strength, Moscow, Standardinform, 2019.

For the production of soil cement composite the following components were used:

- white soil (structurally unstable soil on a territory. In areas where white soil extends it is not recommended to construct civil or industrial buildings) taken from the areas that are neighboring the Institute of Physics, situated in the residential district of Ajapnyak, Yerevan,
- portland cement of 40 *MPA* produced by Ararat cement factory (Armenia),
- tap water.

Based on the analysis of chemical and saline composition of white soil sifted through sieve N 2 it was ascertained that the white soil used in soil cement was presented through powder-like sandy loams [3].

The characteristics of the components used in the production of soil cement composite are highlighted in Table 1.

Table 1. The characteristics of the components used in the production of soil cement composite, its mixture and some data

Characteristics of filling aggregate				Characteristics of binding component	
Item		Admitted fineness, *mm*	Apparent density, t/m^3	Item	Compression strength, *MPa*
White soil of carbonate mixture		2.0	1.410	Portland cement	40.0
Composition soil cement					
Consumption of components for $1m^3$ soil cement, *kg*			W/C	Density at max. condensed condition, t/m^3	Strength at the age of 90 days, *MPA*
cement	white soil	water	1.787	1.921	11.2
141.0	1269.0	252.4			

It should be noted that the magnitude of maximum density in the soil cement skeleton - ρ_{dmax} defined by a standard method of compression, using the Proctor Compaction Test Equipment constitutes $1.61 gr/cm^3$. The value of solidity observed in the skeleton of freshly laid soil cement, ρ_d on average constitutes $1.58 gr/cm^3$ which is within the limit of admissible magnitude deviation in the given characteristics ($\rho_d = 0.983\ \rho_{dmax}$).

The production of various cylindrical specimens of soil cement composite was made via direct pressing under normal pressure of 4.8-5.3 *MPA*. This secures the production of an ultimately solid material [3].

Some of the produced cylindrical specimens made for the experiment were designed for defining the limits of durability of the soil cement composite as well as for singling out deformation characteristics of the material at different ages (time countdown after their production) were taken out of metallic mould 7 days after their making, later on they were preserved in humid sawdust for another 7 days. After that up until the beginning of experiments the specimens were left at the laboratory.

The measurement of durability limits observed in soil cement composite was made at the ages (τ) of 14 days, 28 days and 90 days, while the identification of deformation characteristics of the material was carried out at the ages of 28 days and 90 days.

Other cylindrical test specimens d = 5.0*cm* and h = 5.0*cm* were designated for studying the impact of air and humidity conditions on the growing durability of soil cement composite. Data on the methods used in these studies will be introduced below.

In the period of carrying out all the studies the average temperature at the laboratory was 23°C and average humidity - 57% (the conditions were close to those observed in natural environment characterized by levels of low humidity) [4].

The measurement of durability levels of pressure on the soil cement composite (using specimens d = 5.0*cm* and h = 5.0*cm*) was made at an average speed of the experimental equipment, displacing functional gears 3*mm* per minute.

The identification of deformation characteristics of soil cement (using the cylindrical specimens d = 5.0*cm* and h = 20.0*cm*) was made according to the method [5] which will be described below.

The loading of test specimens was fulfilled in a stepped way, each step corresponding to $0.1R$ (R is the resistance magnitude of specimen to destruction) of the durability of cylinders under each step was just sufficient to register the data from micron indicators, measuring the longitudinal and transversal deformations. At the level of pressing load corresponding to $0.8R$ the clock indicators measuring deformations were taken and the specimens were destroyed.

The empirical data on the longitudinal (ε) and transversal (ε) deformations of soil cement components were approximated by dependencies [5]:

$$\varepsilon_{\text{пр}} = \frac{a_1 \frac{\sigma}{R}}{1 - b_1 \frac{\sigma}{R}} \quad , \tag{1}$$

$$\varepsilon_{\text{поп}} = \frac{a_2 \frac{\sigma}{R}}{1 - b_2 \frac{\sigma}{R}} \quad . \tag{2}$$

The magnitude, concerning the module of deformation Ē and the coefficient of the transversal deformations $\bar{\upsilon}$ (an analogue of Poisson's coefficient of transverse strain in solid bodies) at different levels of pressure were defined according to the dependencies:

$$\overline{E} = \overline{E}_0 \left(1 - b_1 \frac{\sigma}{R}\right)^2, \tag{3}$$

$$\overline{\upsilon} = \frac{\varepsilon_{\text{поп}}}{\varepsilon_{\text{пр}}} = \frac{a_2 (R - b_1 \sigma)}{a_1 (R - b_2 \sigma)} \, . \tag{4}$$

In the formulas (1)-(4) a_1, b_1, a_2, b_2 are the parameters of approximation of the experimental data of deformations $\overline{E_0} = R/a$ illustrated in (3), the initial module of deformations of the material.

The number of test specimens designed for determining the level of durability of the soil cement at different ages was 4-6 while for identifying the deformation characteristics of the material 3-4 specimens were used. In the case of measuring the deformations of transversal specimens with d = 0.5*cm* and h = 2.0*cm* the maximum dispersion of the magnitude of the same measured characteristics in relation to their average arithmetic value was observed. The aforementioned specimens were tested at the age of 90 days since their making +7.1% and -6.2%.

Discussion of the obtained data

In Figures 1, 2 the data obtained through experiment are introduced (they are highlighted with markers) along with the curves approximating these data which describe the time changes observed in the absolute and relative values of durability and average density of soil cement composite with white soil carbonate mixture. In order to carry out a comparative analysis, the data, concerning the impact of age on the durability of soil cement based on clay soil were also included in work[2].

It is worth mentioning that the objects of the research[3] were cylindrical specimens with the diameter of 5.0*cm* and height of 12.5*cm*, having been made of clay soil (loamy soil – sandy loam) taken from the territory neighboring the city of Ekyabadan in the region of Iran[4]. The outlay of cement 40 *MPa* in dry mass of the soil cement made 7% while the composition of soil constituted 93%. The cylindrical specimens used for the experiment after being made were taken out of moulds and left in common laboratory conditions.

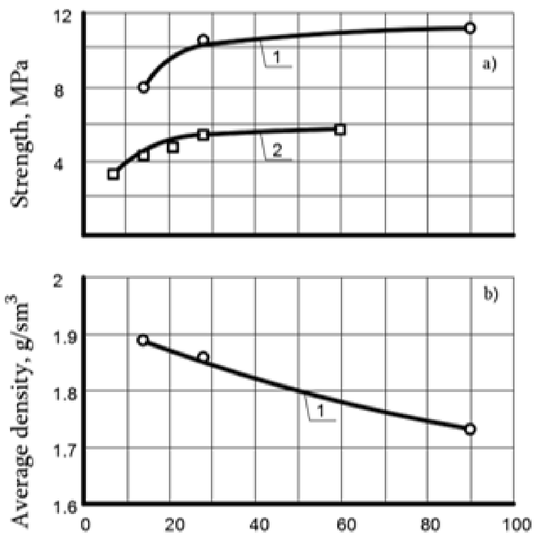
After their production, the specimens underwent a short-term testing for the sake of identifying the durability of the soil cement under pressing in 7 days, 14 days, 21 days, 28 days and 60 days.

As a result of short-term test, we managed to confirm that with the increase of the age τ from 14 days to 90 days soil cement with the base of white soil and carbonate mixture initially underwent a monotonous growth at a high speed which later gradually decreased (Fig. 1a, curve 1). According to the data introduced in Fig. 2

[2] GOST 18105-2018. Concretes. Rules for control and assessment of strength, Moscow, Standardinform, 2019.
[3] Ibid.
[4] Ibid.

(curve 1) the magnitude of the durability growth indicated above at the age of 28 days and 90 days makes correspondingly, more than 31% and about 40% compared with the initial value of the given characteristics defined at the age of 14 days.

After the experiment specimens were left in the lab, the observed loss of humidity during the time mentioned above (28 days and 90 days) compared with its initial value made 1.6% and 8.4% (Fig. 1b, curve 1).

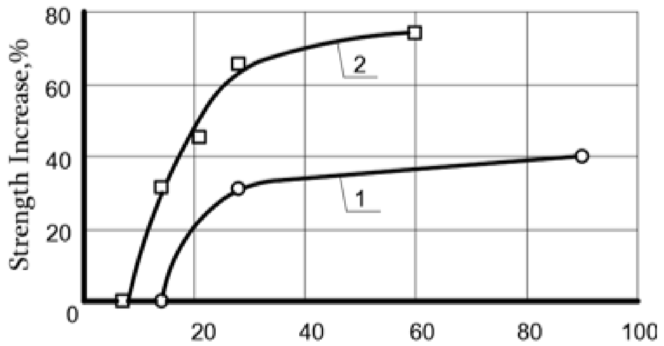


Age, days

Fig. 1. *Curves of the dependence of the strength value (a, curve 1), the average density (b, curve 1) of the soil cement based on white soils of carbonate composition and the strength (a, curve 2) of the soil cement based on clay soils on the age of the material*

Practically, a similar picture is observed in the research, concerning the impact of time on the levels of durability of soil cement based on the clay soil (Fig. 1a, curve 2). In this case the durability growth of the material at the age of 14 days, 21 days, 28 days and 60 days compared with the initial magnitude of the given characteristics (confirmed at the age of 7 days) approximately makes 31.3%, 45.4%, 65.6%, 74.2% respectively (Fig. 2, curve 2).

It has been mentioned above that the magnitude of the durability growth of soil cement based on the white soil carbonate mixture at the age of 90 days compared with its value of durability at the age of 14 days approximately makes 40%. While according to the data introduced in research[5], the difference between durability value of soil cement based on clay soil identified at the age of 60 days and 14 days approximately constitutes 42.9% (Fig. 2) which, as it can be noticed, slightly increases the value of analogous characteristics identified in soil cement based on white soil and carbonate mixture.



Age, days

[5] GOST 18105-2018. Concretes. Rules for control and assessment of strength, Moscow, Standardinform, 2019.

Fig. 2. *Curves of the dependence of the strength increase in comparison with its initial value of soil cement based on white soils of carbonate composition (curve 1) and clay soils (curve 2) on the age of the material*

It has already been stated that before doing short-term tests the experiment specimens at different ages in the abovementioned second test right after their making were preserved in the laboratory, whereas in the first test the specimens were taken out of metallic moulds in 7 days and placed in humid sawdust being kept for 7 days thence, the latter were left in the laboratory. This testifies to the fact that there is a great probability that the degree of humidity for 14-day-old experiment specimens of soil cement based on white soil carbonate mixture is relatively greater than the humidity extent observed in specimens of soil cement based on clay soil (we weren't able to find corresponding data, concerning the test on the second type of soil cement mentioned above)[6].

It should be stated that the value of average density of soil cement based on white soil carbonate mixture constitutes 1.57-159*gr/cm*^{3} (see above) while the value of the soil cement based on clay soil approximately makes 1.61*gr/cm*^{3} [7]. It should also be noted that for the production of the abovementioned two types of soil cement the Portland cement has been used as a connecting component, having equal durability under pressure - 40 *MPa*. Consequently, it is permissible to make a comparison between the indices of the same physic-mechanical characteristics common to those types of soil cement.

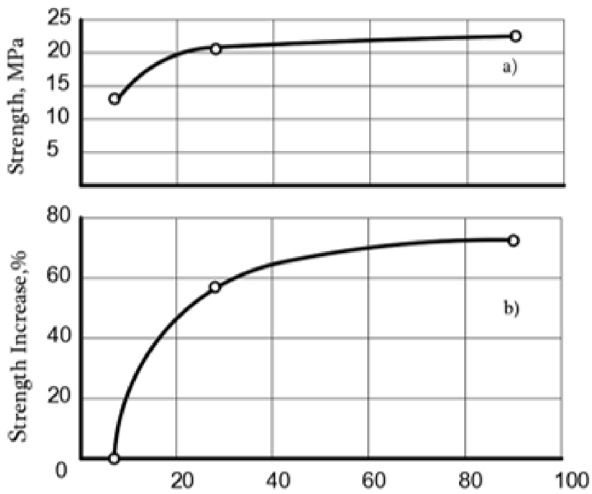
In the work [6] it was stated that for the evaluation of defined mechanical characteristics of soil cement composite it is appropriate to use the corresponding data on other construction materials where the connective component of soil cement is taken into account e.g. for light cement concrete.

According to the abovementioned, in order to make corresponding comparisons we are going to use the data obtained in the research[8], concerning the durability dependence of lightweight lithoid pumice concrete (volcanic mountain type) on the age.

In these studies the cubical specimens being of 15.0*cm*, the body mass 1:1, 54:2, 4, w/c ratio = 0.95 made of lithoid pumice concrete composite were the object for examination. Portland cement of 40*MPa* produced by Ararat cement factory (Armenia) was used.

The cubical specimens made of lithoid pumice concrete right after being taken out of moulds were left in the laboratory where the average temperature was 22°C and the relative humidity - 65%.

The work[9] introduced data that was obtained via experiments, concerning the absolute durability value of lithoid pumice concrete. Based on the durability value of lithoid pumice concrete the growth of the given characteristics acquired throughout time was measured as compared with the durability of the material established at the age of 7 days. We consider it to be appropriate to highlight the latter with curves in Fig. 3.



[6] GOST 18105-2018. Concretes. Rules for control and assessment of strength, Moscow, Standardinform, 2019.
[7] Ibid.
[8] SNiP 2.03.01-84*. Betonnye i zhelezobetonnye konstrukcii, Moscow, 1989, p.77.
[9] Ibid.

Age, days

Fig. 3. *Curves of the dependence of strength and its increase in time in comparison with the initial value of lithold pumice concrete on age*

We can see from the data illustrated in Fig. 3.a, that over time the durability value of lithoid pumice concrete, being under pressure at first increases at a high speed (up to the age of 28 days) and later fades gradually.

The comparison of the data introduced in Fig. 3.b shows that the magnitude of durability growth of lithoid pumice concrete observed at the age of 90 days compared with the magnitude of the given characteristics defined at the age 14 days (in the research this age will be further referred to as initial) constitutes about 42% which slightly exceeds the magnitude of the analogous index established for the soil cement based on the white soil carbonate mixture about 40% (Fig. 2, curve 1). It should be noted that in the dry mass of these two construction materials Portland cement 40 MPa produced by Ararat cement factory (Armenia) has been used as a connective component.

It has been mentioned above that such studies were carried out for investigating the impact of air and humidity on the growing durability of soil cement composite based on white soil carbonate mixture. These studies were carried out with the implementation of method described below.

Some of the cylindrical specimens of the experiment with d = 5.0*cm* and h = 5.0*cm* being taken out of metallic forms after 7 days since their making were immediately put into a package filled with wet sawdust. Further maturing of the experiment specimens took place in the following conditions:

1. Some of the specimens of the experiment after having remained in wet sawdust for 28 days were taken out of the aforementioned package and kept in the laboratory up until the experiment was made.
2. The rest of the specimens were kept in the wet sawdust up until the experiment was made.

The tests of all the aforementioned specimens were done in 180 days after their production. The magnitude of average density and maximum density common to the soil cement skeleton were defined.

The results of the measures are introduced in Table 2.

Table 2

Conditions of ageing of soil cement	Indices of physic-mechanical characteristics of soil cement		
	Density of skeleton, gr/cm^3	Average density, gr/cm^3	Durability under pressure, *MPa*
I	1.59	1.675	11.8
II		1.927	13.9

According to the data in Table 2, the maturing in the highly humid environment (in this case in wet sawdust) turns out to have a favorable impact on the growing durability of the soil cement in the course of time.

It should be mentioned that a phenomenon similar to the one illustrated above has been observed earlier in another construction material based on the Portland cement i.e. cement lithoid pumice concrete [7].

Cubes of side sizes 10.0*cm* served as experiment specimens for the studies. The cubes were made of cement lithoid pumice concrete based on the mass 1:1, 513:2, 368, w/c ratio = 0.88. The Portland cement with durability under pressure makes 38 *MPa* produced by Ararat cement factory.

According to the data introduced in the work [7] the durability magnitude of cubic specimens made of cement lithoid pumice concrete made 20.6 *MPa* at the age of 14 days, while after their making for 63 months the latter were kept in favorable conditions (they were preserved in hydro-isolated state), having a positive impact on growing durability. In these conditions their durability constituted 42.2 *MPa*.

Let us discuss the results of the studies on the deformation characteristics of the short-term load of soil cement based on the mixture of white soil carbonate where cylindrical specimens of d = 5.0*cm* and h = 20.0*cm* were used. It should be stated that the resistance magnitude of these specimens under pressure during their destruction in case of τ = 28 days made R = 7.4 *MPa* and in case τ = 90 days the resistance constituted 8.0 *MPa*.

In Fig. 4 the empirical data on ε for longitudinal and ε for transversal deformation specimens are shown with markers along with the curves approximating these data constructed according to the dependencies (1) and (2) respectively. For the approximation of the coefficients the following were taken into account:

in case of τ = 28 days - a_1 = 180.0, b_1 = 0.28, a_2 = 24.0, b_2 = 0.60,
in case of τ = 90 days - a_1 = 138.0, b_1 = 0.53, a_2 = 30.0, b_2 = 0.60.

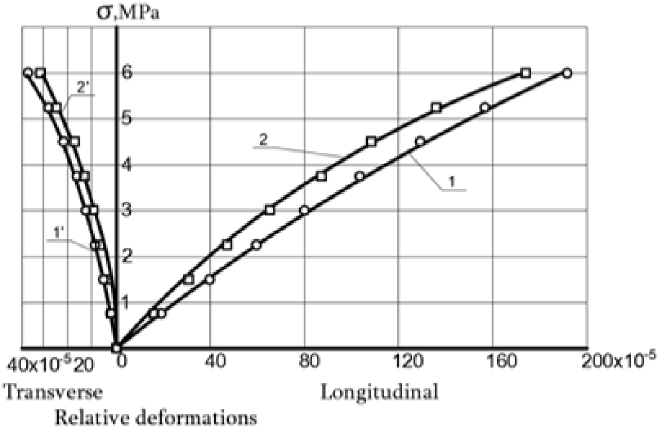


Fig. 4. *Deformation curves of soil cement samples based on white soils of carbonate composition (τ = 28 days - curves 1 and 1', τ = 90 days - curves 2 and 2')*

According to the data in Fig. 4 it can be stated that it is acceptable to use dependencies 1 and 2 for making the approximation of empirical data of the deformations. From the data in the same Figure it can also be noticed that the specimens of τ = 90 days being tested show greater resistance to deformation both in longitudinal and transversal directions compared to their counterparts of τ = 28 days.

From the data illustrated in Fig. 5 it can be concluded that a similar tendency mentioned above is observed in the coefficients of transversal deformations υ of soil cement specimens. From the data of the same Figure highlighted with markers it follows that the results obtained via experiments are satisfactorily described through approximating curves based on the dependencies (4).

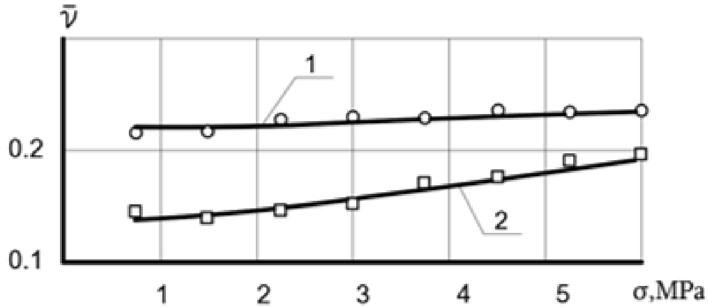


Fig. 5. *Curves of the dependence of the coefficient of transverse deformations of soil cement samples on strength (τ = 28 days - curve 1, τ = 90 days - curves 2)*

The value (calculated on the basis of dependency) of the tangent module of deformation $\bar{E}$ at different levels of pressing stress σ is brought in Table 3.

Table 3

The age of soil cement, τ	The module of deformation according to tangent x 10^{-2} in *MPa* under stress σ (*MPa*)			
	0	1.5	3	4.5
28 days	41.1	36.6	32.3	28.3
90 days	58.0	47.0	37.2	28.6

The comparison of the data introduced in Table 3 indicates that the observable great difference in $\bar{E}$ values of soil cement made at the age of τ = 90 days, τ = 28 days under σ = 0 (more than 41%) with the increase of level observed in the compression stress σ gradually decreases while in the case of σ = 4.5 *MPa* the given difference practically disappears.

Conclusion

1. The relative difference of humidity between the test specimens of soil cement based on the mixture of white soil, carbonate and specimens of clay soil (for the production of which the cement of the same quality, exhibiting the same activity was used) has little impact on the growing durability of these specimens, the maturity process of which took place in the environment with low humidity (W≤75% [4]). This testifies to the fact that while making the mixtures of these types of soil cement much more water is used compared to the amount of water necessary for prompting chemical reactions in the production of cement stone. A similar practice is common for making mixture of cement concrete in order to provide concrete workability while moulding products in it.
2. The similar intensity of growing durability over time (starting from the aforementioned initial age τ) observed in the soil cement on the basis of white soil and carbonate mixture, in soil cement based on clay soil along with cement concrete where the same type of cement was used enables us to conclude that the given process (the process of gaining durability) mainly depends on the characteristics of the connective component in the cement used in the mixtures of these construction materials.
3. The process of ageing in the environment with high levels of humidity (in wet sawdust) has a favourable impact on the growing durability of the soil cement based on the mixture of white soil carbonate gain over time

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