Deformability during short-term loading, shrinkage and creep of a cementitious soil composite on the basis of belozems of carbonate

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Abstract. The results of short-term (strength, tangent modulus and transversal deformation coefficient) and long-term (shrinkage and creepage deformations) experimental research of cylindrical test pieces manufactured from the cementitious soil of carbonate composition are considered. The obtained experimental data are compared with similar data defined for the light-weight concrete based on lithoid-pumice.

1. Introduction

Recently, there is a tendency of using cementitious soil in order to build separate critical parts of low-rise buildings and structures [1–5]. In particular, the experience of the implementation of the above-ground parts up to a mark of ±0.000, including foundations, cellar walls and socles of a building made of a monolithic, as well as a prefabricated cementitious soil, exists and finds wide expansion [5]. In the case of without basement low-rise buildings with a foundation laying depth of less than 1.3 m, it is recommended to use wall panels made of cementitious soil, and in case of presence of basements or deeper foundations it is advisable to use in the compound through the height cementitious soil panels with the bandaging of stitches.

The optimal designing of the above-mentioned cementitious soil parts of buildings and structures determines obtaining a clear submission of the mechanical behavior of the material close to operational.

It is known that the compressive strength of cementitious soil, suitable for the construction of foundations, should be at least 10 MPa. To obtain cementitious soil composite with such strength and cement consumption of not more than 12%, it becomes necessary to introduce surface active substances in the composition of the raw material mixture [6, 7, etc.].

According to the research [8], cementitious soil with the strength of 10 MPa and more can be obtained on the basis of belozem of carbonate composition without application of surface active substances.

In this work we present and discuss the data obtained as a result of short-term and long-term compression tests, as well as measurements of shrinkage deformations of cylindrical test pieces made of cementitious soil composite on the basis of belozem of carbonate composition.
Table 1. Characteristics of the components used for the manufacturing of cementitious soil, its composition and some parameters.

| Characteristics of infill material | Characteristics of the binder component |
|-----------------------------------|----------------------------------------|
| Name                              | Name                                   | Compressive strength, MPa |
| Belozem of carbonate composition  | Portland cement                        | 40.0                      |
| Maximum size, mm                  | Bulk density, t/m³                     |                           |
| 2.0                               | 1.1410                                 |                           |

| Cementitious soil composition     |                                        |                           |
|-----------------------------------|----------------------------------------|--------------------------|
| Material consumption on per 1 m³ | W/C                                    | Density at the most      |
| cementitious soil, kg             |                                        | compacted state, t/m³    |
| Cement                           | Belozem                                | Water                    |
| 141.0                            | 1269.0                                 | 252.0                    |
| 1.787                            | 1.946                                  | 10.5                     |

2. Research methodology

Cylindrical pieces, made of cementitious soil composite, served as an object of research:

(i) with a diameter of \((d)\) 5 cm and height of \((h)\) 5 cm — to determine the compressive strength of the material [5];

(ii) with \(d = 5\) cm and \(h = 20\) cm — for short-term and long-term tests.

To obtain cementitious soil composite were used

(i) the belozems taken from the areas adjacent to the territories of the Institute of Physics located in the residential district of Ajapnyak, Yerevan;

(ii) the portland cement of type 40, produced by the Ararat Cement Plant;

(iii) the ordinary pipe water.

According to the data of the analysis of chemical and mineralogical content of the belozem sieved through sieve No. 2, was determined that the belozem used in the cementitious soil composition was represented by dusty sandy loam.

The main characteristics of the components used for the making of cementitious soil and its composition are given in table 1.

Test pieces, made by direct pressing, after manufacturing were released from the molds after 14 days, and later, till the experimental researches at the age of 42 days, they were kept in wet sawdust.

Compression strength (using pieces with \(d = 5\) cm and \(h = 5\) cm) and fracture resistance (using pieces with \(d = 5\) cm and \(h = 20\) cm) of cementitious soil test pieces were realized at a loading speed of 3 mm/min.

Short-term testing of pieces was carried out according to the method presented in research [9].

The experimental data of short-term longitudinal \((\varepsilon_{\text{long}})\) and transverse \((\varepsilon_{\text{transv}})\) deformations were approximated by the following dependencies [9]:

\[
\varepsilon_{\text{long}} = \frac{a_1 \sigma / R}{1 - b_1 \sigma / R},
\]

\[
\varepsilon_{\text{transv}} = \frac{a_2 \sigma / R}{1 - b_2 \sigma / R}.
\]
The values of the deformation modulus concerning tangent $\tilde{E}$ at various stress levels of $\sigma$ were determined by the dependence \[14\]
$$\tilde{E} = E_0 \left(1 - \frac{b_1 \sigma}{R}\right)^2.$$

In dependencies (1)–(3) $R$ is the destruction resistance limit of the piece, $a_1$, $b_1$, $a_2$, and $b_2$ are approximation parameters, and $E_0 = R/a_1$ is the initial deformation modulus.

Experimental researches of the creep of test pieces under compression were realized on spring power installations. Three twin pieces were tested and shrinkage deformations were measured on the same number of corresponding twin pieces. The magnitude of the compressive stress for loaded pieces was $0.4R$. Pieces were loaded for 158 days. The temperature of the laboratory room during the research was $22 \pm 5^\circ\text{C}$.

3. Resistance of cementitious soil to deformation under short-term loading

Before proceeding to the discussion of the issue discussed here, we find it advisable to pay attention to some data of the water-physical parameters of belozem and cementitious soil (table 2), determined in laboratory conditions.

According to these data, the maximum density of the cementitious soil skeleton $\rho_{d_{\text{max}}}$, determined by the standard compaction method on a Proctor device, is $1.61 \text{ g/cm}^3$. The density of the skeleton of a freshly laid cement-soil $\rho_d$ is $1.58 \text{ g/cm}^3$, which is within the permissible variation of the deviation of this characteristic ($\rho_d = 0.983 \rho_{d_{\text{max}}}$).

Figures 1 and 2 show the experimental data (they are indicated by marks) of the dependencies of the longitudinal ($\varepsilon_{\text{long}}$), transverse ($\varepsilon_{\text{transv}}$) deformations and the coefficient of transverse deformations $\tilde{\nu}$, an analog of the Poisson’s coefficient of linear resilient bodies) on the compressive stress $\sigma$ of cementitious soil test pieces in comparison with the curves constructed according to the corresponding formulas. Formulas $\varepsilon_{\text{long}} = f(\sigma)$ and $\varepsilon_{\text{transv}} = \varphi(\sigma)$ are given above, and the dependence of the coefficient of transverse deformations $\tilde{\nu}$ from $\sigma$ has this form:

$$\tilde{\nu} = \frac{\varepsilon_{\text{transv}}}{\varepsilon_{\text{long}}} = \frac{a_2(R - b_1 \sigma)}{a_1(R - b_2 \sigma)}.$$

The following values were taken for the approximation parameters of the experimental data:

$$a_1 = 203.2, \quad b_1 = 0.43 \quad \text{and} \quad a_2 = 29.0, \quad b_2 = 0.694.$$

As we note from the data in figures 1 and 2, the empirical description by the dependencies (1), (2), and (4) experimental data obtained during a short-term test of cementitious soil pieces can be considered acceptable.

According to the data given in table 3, it is possible to get an idea of the change calculated according to the value of the tangential modulus of deformation of cementitious soil test pieces depending on the level of relative compressive stress $\sigma/R$.

### Table 2. Water-physical parameters of belozem and cementitious soil.

| Cement content, % | Plasticity limit | Optimal moisture content $W_{opt}$ | Max. density of the skeleton, g/cm$^3$ |
|-------------------|------------------|------------------------------------|----------------------------------------|
|                   | Upper limit $W_L$ | Lower limit $W_p$ | plasticity index $I_p$ |                            |                                      |
| 0                 | 0.245            | 0.190                        | 0.055                                  | 0.212                       | 1.58                                 |
| 10.0              | 0.230            | 0.188                        | 0.042                                  | 0.209                       | 1.61                                 |
4. Resistance of cementitious soil to shrinkage and creep

We consider it necessary to note the following before moving on to discussing the tasks posed here.

It is known that the phenomena of shrinkage and creep are characteristic properties of composite materials based on cement binder — specifically concrete.

Assuming that in cementitious soil compositions, in which cement is usually used as a binder component, and as a result of its setting and hardening are formed composite materials on its basis, it can be considered acceptable to comment on the results of the research of cementitious soils shrinkage and creep phenomena, taking as a warp the generally accepted hypotheses and ideas that justify the mechanisms of manifestation of the same properties of concrete.

It should be noted that few studies have been devoted to the research of shrinkage and creep of deformations of cementitious soils. From the literature search, we managed to find only a
work, which presents the results of a study of creep deformations of cementitious soils obtained on the basis of clay soils (loams) taken from the sites near the territory of Arak city, located in Eiqabad region of the Islamic Republic of Iran [10].

Cementitious soil shrinkage
The data obtained as a result of observations of the development of in time shrinkage (swelling) strain of cementitious soil cylindrical pieces in the longitudinal and transverse (diametrical) directions and the laboratory room humidity change $W$ during the observation period are shown in figure 3.

Comparison of figure 3a with the corresponding work data [11] shows that under conditions of free moisture exchange in the laboratory room, behavior of deformation of cementitious soil cylindrical pieces in time in the longitudinal direction has qualitatively the same character that is observed for prismatic pieces ($15 \times 15 \times 60$ cm) made of lightweight concrete based on tuff aggregate (volcanic rock), in the same direction.

According to the data of shrinkage of tuff concrete elements in the longitudinal direction, the author [11] notes three periods of development of this process in time: expansion (swelling) of the element, shrinkage with a gradually damping speed, and an established state with an almost constant shrinkage value.

Following the author [11], we also consider it advisable conditionally to note three stages of the development of shrinkage deformations in time, and especially:

- stage I — development with a significantly developing and sharply feeding rate of shrinkage deformations (from 3 to 66 days);
- stage II — steady state with practically constant value of shrinkage (from 9 to 66 days);

As in the previous case, in this case too, we also consider it expedient to note three main stages of the development of shrinkage deformations in time, and especially:

- stage I — development with a significantly developing and sharply feeding rate of shrinkage deformations (during the first 9 days);

Figure 3. Curves of deformation of shrinkage (swelling) of cementitious soil experimental pieces in the longitudinal (curve 1) and in the transverse (curve 2) directions (a) and changes in time the humidity $W$ of the laboratory room (b)
stage III — the variability of shrinkage deformations, caused mainly by the violation of the established moisture equilibrium between the objects of research and the environment due to a sharp change in the humidity of the same environment (from 66 days to the end of the experiments, see Figures 3a and 3b).

It should be noted that the relation of the values of shrinkage deformations of cementitious soil cylindrical pieces in the transverse and longitudinal directions at the stage of the above mentioned steady state is about 1, 2, and at the end of the study — about 1.38.

Cementitious soil creep
It is known that creep of a material is its property to endure non-elastic deformations in time in the direction of action (along) the load applied to it.

It is also known that for the constantly loaded elements, creep deformations that develop over time in the direction of this load, are usually accompanied by deformations, which are in the transverse direction to the load line and this deformations are called transverse creep deformations. Moreover, the linear dimensions of the transverse section of the element under the influence of the compressive load, over time, increase.

Figure 4 shows the experimental creep data obtained by us (they are shown by labels) and the curves approximating these data.

Presented on figure 4 curves describing the development process of creep deformation over time both in the longitudinal and in the transverse directions should be conditionally divided into stages, as it was done when considering shrinkage deformations in the mentioned directions of cementitious soil test pieces, which are twin creep-tested pieces.

In the case of creep deformation data in the longitudinal direction of the test pieces, three stages of its development in time can be noted (see figure 4):

- stage I — development with an initial high and gradually feeding rate of creep deformation (within approximately 66 days after loading of the pieces);
- stage II — development of creep deformation with a variable speed (from 66 to 115 days);
- stage III — practically established state with some oscillations in the value of creep deformation (from 115 days to the end of the observation).

Comparison of data figure 4 shows that at the first stage of the development of creep deformation, cementitious soil pieces gain a significant part (about 80%) of the magnitude of creep deformations acquired by them after 158 days after being under constant load, i.e. till the end of the experiment.
Table 4.

| Composite material type | Density, t/m³ | Compression strength, MPa | Resistance to fracture of experimental cylindrical pieces, MPa | Initial modulus of resilience, MPa × 10⁻² | Poisson’s coeff. | Long deform. × 10⁻⁵ | Shrinkage | Creep measure* |
|-------------------------|---------------|---------------------------|---------------------------------------------------------------|------------------------------------------|-----------------|-----------------------|------------|---------------|
| Cementitious soil       | 1.610         | 10.5                      | 8.5                                                           | 42.0                                     | 0.15–0.16       | 170–176               | 190–195    |               |
| Lithoid pumice concrete | 1.715         | 25.9                      | 16.1                                                          | 146.0                                    | 0.11–0.12       | 75.0                  | 18–19      |               |

* — creep deformation value of the unit voltage.

It should be noted the high values of the creep deformation of cementitious soil cylindrical pieces in the longitudinal direction $\varepsilon_{\text{long}} = (650 - 660) \times 10^{-5}$.

Let’s consider the behavior over time of creep deformations in the transverse direction of cementitious soil cylindrical pieces (figure 4). In this case, the process of development of the creep deformation over time, conditionally, can be divided into 2 stages, namely:
stage I — development with an initial high and sharply feeding rate of creep deformation (during the first 10 days);
stage II — steady state with sensitive fluctuations in the magnitude of creep strain (from 10 days to the end of the experiments).

It should be noted that at the first stage of the deformation process, cementitious soil pieces gain almost the entire value of the creep strain recorded at the end of the experiments.

We can also note the high value of the ratio of creep deformations in the longitudinal and transverse directions of cementitious soil cylindrical pieces $\varepsilon_{\text{long}}/\varepsilon_{\text{transv}} = 9.4 - 10.8$.

According to the measurements, the amount of moisture loss by the pieces during the lengthy tests is 16–18% and practically does not depend on the fact that they were under load or were left in an unloaded state (shrink pieces).

5. Comparison results

In order to evaluate the physicomechanical properties of cementitious soil that we determined, table 4 shows the parameters of some characteristics of this material and concrete on lithoid pumice (volcanic rock) [12, 13].

Note that cubes with an edge of 10 cm were used to establish the strengths of lithoid pumice concrete, and cylindrical specimens with a diameter of 5.5 cm and a height of 22 cm were used for deformation characteristics [12]. In creep experiments, the relative compressive stress $\sigma/R$ was 0.311 [13]. All measurements were performed after 28 days after the manufacture of lithoid pumice concrete pieces. A lithoid pumice concrete with a mass of 1 : 1.432 : 2.50, $W/C = 0.86$ was used.

Comparison of the data of table 4 shows that cementitious soil has a significantly lower strength and, especially, resistance to deformation in comparison with the similar characteristics defined for concrete on lithoid pumice.

References
[1] Ferreira A J M, Camanho P P, Marques A T, and Fernandes A A 2001 Modelling of concrete beams reinforces with FRP re-bars Compos. Struct. 53 (1) 107–16
[2] Promis G, Ferrier E, and Hamelin P 2009 Effect of external FRP retrofitting on reinforced concrete columns for seismic strengthening Comp. Struct. 88 (3) 367–79
[3] Chudinov S A 2010 Research of influence of technology factors on soil cement durability Vestnik Povolzhsk. Gos. Tekhn. Univ. Ser. Les. Ekol. Prirodopoloz No. 1 46–52
[4] Ivanov V V and Eremin V Ya 2014 Up-to-date technologies and materials for construction, repairs, and reconstruction of buildings’ foundations Gradostroit. 29 (1) 78-81
[5] Ramzanov A A, Badaeva A D, Lanin E B, and Alnashash T A 2015 Soil-concrete in a foundation construction Stroit. Unik. Zdanii Soorozh. No. 3(30) 111–28
[6] Khristoforov A I, Khristoforova I A, and Eropov O L 2012 Improvement of properties of cement-sand concrete by introduction of peahens and organic substances in concrete mix Vestn. Tambov. Univ. Ser. Estest. Tekh. Nauki 17 (2) pp 714-717
[7] Brandt J R T 2002 Behavior of Soil-Concrete Interfaces pp 20-25
[8] Karapetyan K A, Hayroyan S G, and Manukyan E S 2018 About the possibility of obtaining cementitious soil composites of high strength on the basis of belozems of carbonate composition J. Phys. Conf. Ser. 991 012032
[9] Karapetyan K S 1964 Influence of anisotropy on the creep of concrete during the compression and stretching depending on the scale factor Izv. AN ArmSSR. Ser. Fiz.-Mat. Nauki 17 (4) 71–90
[10] Hayroyan S and Attarpury A 2012 Creep of cementosols during compression Topical Problems of Continuum Mechanics: Proc. of Int. Conf. Dedicated to the 100th Anniversary of Academician N.Kh. Artyunyan. 08–12 October 2012, Tsakhkadzor, Armenia. Vol. 2 (Yerevan: EGUAS) pp 260–4
[11] Karapetyan K S 1950 Experimental study of shrinkage of tuff concrete Izv. AN ArmSSR. Ser. Fiz.-Mat. Estest. Tekh. Nauki 3 (7) 619–25
[12] Karapetyan K A 1999 The heterogeneity of the strength and deformation properties of lightweight concrete based on age Information Technology and Management. 4. Materials of the Int. Conf.: Applied and Mathematical Aspects of Natural Science (Yerevan: Noyan tapan) pp 35–8
[13] Karapetyan K S and Karapetyan K A 1982 Heterogeneity creep of concrete element Proc. AN ArmSSR 75 (2) 65–70