The renewal of the bearing capacity of rubble masonry by the composite solution

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Abstract. The possibility of the involving nanotubes as modifiers of the structure of the composite solutions to ensure the safety and durability of the rubble foundation is considered. The greater efficiency of injection can be achieved by integration the composite solutions into the foundation body. The various compounds are integrated into the composite’s composition, in particular nano-additives in order to modify the structure of the cement stone, increase the strength properties, increase its crack resistance, change the dynamic viscosity. The strength indicators of the produced composition with the involved boehmite were measured according to GOST methods, and ultrasound analysis was performed. The bentonite clay in a composite solution increases its plasticity and viscosity, maintains resistance to the delamination. The oxides in clay are the basis for hydraulic binders and have a chemical affinity with cement. It was found that most of the particles in P2T2A bentonite don’t exceed 10 microns. The addition of the boehmite to the composite system can lead to more dense packing of a cement stone. It’s achieved by filling the voids formed during the formation of a cement stone. The composite solution modified by the boehmite has increased the strength and continuity of the structure.

1. Introduction

The development of a fracturing, the loss of the strength or the complete exhaustion of the load-bearing capacity of the building’s foundations occurs due to the destructive processes, an unequal foundation’s sinking, the impact of the precipitation, temperature changes, as well as non-compliance with the regulatory documents. Therefore, ensuring the safety and durability of the foundation has always been relevant.

Large part of the foundations can be subjected to significant damage such as the formation of cracks, leaching of a weak limestone and clay solutions and other deformations that affect the normal operation of the foundation. It’s occurs as a result of the adverse hydrogeological conditions, underground works, pipelines and tunnels, changes a space-planning decisions, infiltration of a rain and melt water etc.

The foundations of a buildings and structures located in the immediate vicinity of the new construction are particularly affected. The integrity of the foundations is violated when the engineering communications are laid in the area of the existing foundations. [1-3]
The method of reconstruction of the foundations is chosen depending on the nature of the deformation. Of particular interest are foundations made of masonry, in particular made of rubble stone. There are the following activities for the construction of foundations of this type: a holders installation, cementation of a masonry and (or) partially the foundation soil.

The cementation of masonry carries out by injecting the cement or other solutions in the emptiness of a foundation body. The popularity of this method is due to its efficiency in the reconstruction of the objects whose foundations have partially or completely lost their bearing capacity (Fig. 1).

![Figure 1](image1)

**Figure 1.** The cementation of a masonry by injection: 1 – reinforced foundation; 2 – a wall; 3 – injector.

The node of the pipeline input through the load-bearing enclosing structure is shown in Figure 2.

![Figure 2](image2)

**Figure 2.** The node of the pipeline input through the load-bearing enclosing structure: 1 – pipeline; 2 – a wall; 3 – injector.

The greater efficiency of injection can be achieved by integration the composite solutions into the foundation body. The various compounds are integrated into the composite’s composition, in
particular nano-additives in order to modify the structure of the cement stone, increase the strength properties, increase its crack resistance, change the dynamic viscosity.

Over the past decade, the number of works reflecting the applied nature of nanomaterials in the production of various building materials has increased significantly. [4-7]

In work [8] the masonry solution containing cement, filler, nanocatalyst (fullerenes) and water is described. The claimed technical result is an increase in strength and frost resistance, however, there is no information about the hardening mechanism.

The nano-additives and nanomodifiers consisting of nanoparticles of natural and technogenic origin can be used for the manufacture of the cement-containing solutions and concretes. The maximum efficiency of a nanoscale and nanocrystalline additives is achieved by regulating their quantity. The application nanotechnology components may help to reduce the cost of the used solution by reducing the consumption of the mineral binders. The introduction of nanomodifiers changes the rate of hydration and morphology of mineral particles. Some types of the nano-additives, under certain conditions, can be attributed to nanotechnologia raw materials. As part of the strategy for the development of the building materials industry, the cement-bentonite solution based on the waste of technogenic origin – boehmite (nanocrystalline powder of aluminum oxides and hydroxides, which is the product of the reaction of hydrogen production from aluminum) was synthesized. The boehmite as nanosurface doesn’t have a wide distribution in the market of production of building materials. [9-14]

The aim of the work was to confirm the possibility of using the produced composition as an injection solution to restore the bearing capacity of rubble masonry.

2. Methods
The main component of the injection solution is cement. The particle size of the samples was determined by laser diffraction according to ISO 13320-1: 2009 «Particle size analysis. Methods of the laser diffraction». Particle sizes range from 1 to 90 microns. In addition to cement, the composition of the composite solution contains bentonite. Bentonite clay in a composite solution increases its plasticity and viscosity, maintains resistance to delamination. The oxides in clay are the basis for hydraulic binders and have a chemical affinity with cement.

To achieve this aim, strength indicators were measured according to GOST 17624-2012 methods [15], ultrasonic analysis based on the results of the study on the ultrasonic concrete strength meter «PULSAR 1.1» was performed. This device was used to measure the velocity of ultrasonic waves passing through the composite composition. The speed of ultrasound was determined by the time of its passage through the composition. Measurements were carried out in 12 series of 3 samples with different concentrations of the boehmite.

Boehmite particle size was determined by x-ray phase analysis using an x-ray powder diffractometer of the DRON-3 type [16]. The method is based on the phenomenon of diffraction broadening of the lines of the diffraction pattern.

The preparation of the samples was carried out as follows: grinding of samples was carried out, then the samples were placed in a standard cuvette with a top load.

3. Results
The main component of the composite solution is cement. The particle sizes range from 1 to 90 microns. In addition to cement, the composition of the composite solution includes the bentonite. The bentonite clay in a composite solution increases its plasticity and viscosity, maintains resistance to the delamination. The oxides in clay are the basis for hydraulic binders and have a chemical affinity with cement. It was found that most of the particles in P2T2A bentonite don’t exceed 10 microns.

The composition of bentonite, established by the method of semi-quantitative x-ray phase analysis, includes the montmorillonite (75-80% by weight), quartz (15-17%), kaolinite (1-2%) and the muscovite-type hydrosludes (1-2%). The sorption capacity of the bentonite is 113.3 mg*EQ/100 g.

The boehmite is an orthorhombic crystal structure with elementary cells: a=2,87, b=12,23, c=3,7 Å (Fig.3).
In the boehmite, aluminum ions are surrounded by oxygen ions, which are inside octahedrons and form zigzag chains due to hydrogen bonds. [14,17]

The size of the crystals (determined by x-ray method) is fluctuated within 30-60 nm. Therefore, it can be concluded that these particles are nanoscale.

Based on the morphostructural features of the structure of nanoscale particles, it follows that the addition of the boehmite to the composite system can lead to more dense packing of a cement stone. It’s achieved by filling the voids formed during the formation of a cement stone. According to the x-ray phase analysis of the boehmite, as well as the form of crystallites, it was assumed that this modifier has a developed phase interface and its introduction into the binder will have a significant impact on hydration. The liquid glass is used to increase the rheological parameters of the composite solutions. In the manufacture of the solution, the liquid glass with a density of 1.46 g/cm³ and a silicate modulus of 2.7-3.4% was used.

It was previously determined that with the addition of 0.208% boehmite, the strength of the composite solution was increased by about 20% after 28 days of storage. Thus, the introduction of the boehmite additives – high-aluminum waste hydrogen production from aluminum – in the optimal amount allowed to obtain a composite solution characterized by increased strength in comparison with solution without nano-additives [14].

The ultrasonic analysis is used to determine the processes of formation of the structure of the composite solution. The results of the ultrasonic analysis confirm the formation of a denser matrix in the presence of 3D-NKM boehmite.

It is established that the maximum increase in the ultrasound velocity is achieved by the adding 0.208% boehmite to the cement mass (Fig. 4). The obtained results are consistent with the data on the change in the strength of the composite solution with the addition of the boehmite. Therefore, the structure of the composite solution with the increased continuity is formed [17].
Figure 4. The dissemination speed of the sound oscillation (1) and the strength (2) to the concentration of the boehmite to the mass of the cement, %.

The change in the structure formation of the composite solution modified by the boehmite can be explained by the appearance of new formations in the structure of the cement stone and the affinity of the mineral composition of the boehmite with the bentonite and cement. It is known from the literature that the addition of the small amounts of nanotubes has a direct effect on the change in the crystallization rate and morphology of formations in the space of a cement stone [18]. Therefore, it can be assumed that the boehmite particles are able to distribute in its hydrated environment, completely filling the voids formed, and achieve to the formation of a dense and more finely crystalline structure compared to the control sample.

4. Discussion
In order to fully confirm the possibility of using the composition, researches of the joint operation of the solution with the masonry material are necessary. Currently, the processing of the results of determining the deformation characteristics, the study of frost resistance and the equivalent economic assessment are carried out. The results will be presented to the public at subsequent research conferences.

5. Conclusions
The suggested composite injection solution modified by the addition of the boehmite has increased the strength and continuity of the structure. The research of rheological properties will provide a clearer idea of the influence of the boehmite on the composite system.

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