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Dome houses made of soil-concrete based on local raw materials

Купольные дома из грунтобетона на основе местного сырья

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Key words: soil-concrete; magnesia binder; dome houses; strengthening of soil foundation; water resistance

Ключевые слова: грунтобетон; магнезиальное вяжущее; купольные дома; укрепление основания; водостойкость

Abstract. The work presents the results of research on the strengthening of soil basement in the center of the urban nucleus of Vladimir, which are loam, sandy loam in soft-plastic state, and also sandy loam with silt. The technology of applying the strengthening composition in the soil has been developed. The results of the investigation of physical and mechanical properties of soils and their water resistance have been presented. The microstructure of the concrete has been studied and compositions of masonry material suitable for the construction of residential premises have been developed. The advantages and prospects of development of domed buildings have been studied. The expediency of using domed buildings in terms of energy efficiency has been substantiated. The possibility of using the developed building materials for the construction of domed buildings has been considered.

Аннотация. В работе представлены результаты исследований по укреплению грунтового основания в центре городского ядра Владимира, который представляет собой суглинки, супеси в мягкопластическом состоянии, а также супесь с илом. Разработана технология применения упрочняющей композиции в почве. Приведены результаты исследования физико-механических свойств полученного материала и его водостойкости. Изучена микроструктура грунтобетона и разработаны материалы кладки, подходящие для строительства жилых зданий. Изучены достоинства купольных зданий, перспективы развития. Обоснована целесообразность применения куполообразных зданий с точки зрения энергоэффективности. Рассмотрена возможность применения разработанных строительных материалов при строительстве купольных зданий.

Introduction

The paper presents research data on strengthening of soil foundation (such as loam, sandy loam in soft-plastic state, and also sandy loam with silt) in the center of the urban nucleus of Vladimir city. This research includes manufacturing technology development of applying the strengthening composition in the soil and compositions for masonry materials suitable for the construction of residential premises. The scientific work shows research data of physical and mechanical properties of soils as well as their water resistance. Additionally, there has been studied concrete microstructure and justified the perspective of domed buildings from the standpoint of energy efficiency.

There are a lot of examples of housing made of soil in almost all countries of the world, including Russia (Priory Palace in Gatchina, built in 1798). The application of such material is governed by its strength, environmental friendliness and cost effectiveness [1].

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Nowadays, when it seems that there is nothing left to invent in the construction field, the global issue to improve the energy performance of buildings and structures remains open. From the energy point of view, the determining factor is the shape of the building. As it is known, dome is one of the most stable shapes in nature. To increase the adhesion of the dome to the base surface, the spoiler effect is used. The dome (bubble) house, erected from compact-grained soil-concrete is a stable structure [2].

Energy performance of the domed house lies in the shape of the spherical structure. There is an inverse dependence between the area of the external face of the structure and energy consumption for room heating. The less the area of walls and roof is, the higher the performance coefficient is. The heat loss through the building footing depends on the ratio of the perimeter of the floor to its area. In this case, the dome, having a smaller perimeter-to-area ratio, in comparison with a conventional house, gains the upper hand [3–5].

One of the advantages of domed buildings is that wall structures and roofing are made of the same materials. It gives the possibility to put them up in a single cycle. This fact in combination with full mechanization and automation makes it possible to reduce the construction period and the cost of the erected building. As a result, one of the promising areas of domed construction is the erection of above-ground structures by means of 3D printing. In the course of this study, there was considered a possibility of a single cycle construction with the use of a 3D printer. While the roofing is being assembled, the mortar layers will be compressed and will not allow the entire roof to collapse even in the process of construction without auxiliary devices such as formwork and other supporting tools. However, in sloping roof structures the mortar has to have an extremely high setting speed to prevent local dropout of the material. In addition, a precise adjustment of the printer speed is required [6–8].

There have been created a number of models, which confirmed the possibility of building construction by means of a 3D printer in a single cycle.

Figure 1 shows a dome house model printed on a 3D printer.

Figure 1. Dome house model printed on a 3D printer

One of the main factors affecting durability and reliability of buildings is the stability of the footing on which the building is erected. The reason for footing instability is the state of the soil, depending on its origin [9, 10].

Nowadays, cities are developing at a quick rate, and the most favorable areas have already been "covered" (built up) with industrial and civil buildings. However, having examined a city map in details, almost everywhere one can see "white spots" i.e. city areas that do not have any buildings. The reason is the occurrence in these territories of soft soils such as clay, loam, sandy loam, and peat. These types of soils are subject to mandatory strengthening before building any structures on it. In Vladimir city there are a number of undeveloped sites that are vivid examples of such "white spots" [11–13].

Methods

In this paper there was set a task of integrated use of soil and a magnesia binder derived from dolomite raw materials to construct spherical buildings. There was made an attempt to strengthen foundation soil as well as to create a structural material for the erection of the aboveground part of the dome building.

Man-made soil formed on the territory of the former brick factory in the central part of Vladimir (in the vicinity of the urban nucleus) was selected as weak soil for strengthening. Due to the low bearing capacity of the foundation, it is impossible to build by traditional methods on this territory. Therefore, there was made an attempt to use the best properties of the magnesia binder and clay soil [14–16].

Table 1 shows characteristics of the investigated foundation at one of the construction sites.

Table 1. Characteristics of the investigated foundation at one of the construction sites

Number of engineering-geological element	Classification of soils according to National State Standard 25100-2011	Normative values										
		Moisture, u.s.			Plastic index, Ip, u.s.	Soil density, ρ, G / cm^3	Porosity fractions, e	Saturation degree, Sr, u.s.	Soil permeability, M/day	Shearing strength		Stiffness modulus
		Natural, W	At the yield point, WL	At the rolling edge, Wp						Angle of internal friction	Specific cohesion	
1	Made-up soil	No limitation										
2	Fine sand, quartz, loose	0.186	Wet			1.79	0.76	0.65	1.0-4.7	27	-	17
		0.257	Water-saturated			1.90		0.90				
3	Stiff loam	0.219	0.314	0.163	0.151	1.89	0.654	0.86	<0.1	14	0.0210	11
3a	Very soft loam	0.286	0.302	0.157	0.145	1.97	0.648	1.0	<0.1	19	0.0119	8

Dolomite is a mineral from the carbonate class with the following chemical composition CaCO3 • MgCO3. The authors obtained a magnesia binder by the semi-sintering of dolomite powder (which is a mining waste) from the Melekhovsky deposit. The obtained binder contains 28 % of MgO [17, 18].

The introduction of semi-sintered dolomite waste into the clay soil makes it possible to change the colloidal and chemical properties of the foundation for strengthening due to pore saturation with magnesium cations. The hydration process of the mixture proceeds under the most favorable conditions for hardening. The use of semi-sintered dolomite waste can improve the strength of the foundation. [19, 20]

In the course of the work there were investigated compositions of soils strengthened by the magnesia binder (semi-sintered dolomite). To obtain an optimal clay-magnesia ratio there was developed an array of compositions which were tested for strength, water and frost resistance.

Results and Discussion

Table 2 presents the compositions of the synthesized samples.

Table 2. The compositions of the synthesized samples

Soil-concrete composition	**Clay soil, g**	**Semi-sintered dolomite, g**	**Bishofite, ml**	**Water, ml**	**KH2PO4, g**	**Water resistance**
SC-50	500	500	100	145	55	0.78
SC-40	600	400	75	170	60	0.81
SC-30	700	300	60	205	65	0.84
SC-20	800	200	40	205	70	0.93

Bar chart 1 illustrates the strength test data for the investigated compositions on the 28th day of their hardening, depending on clay-magnesia binder ratio.

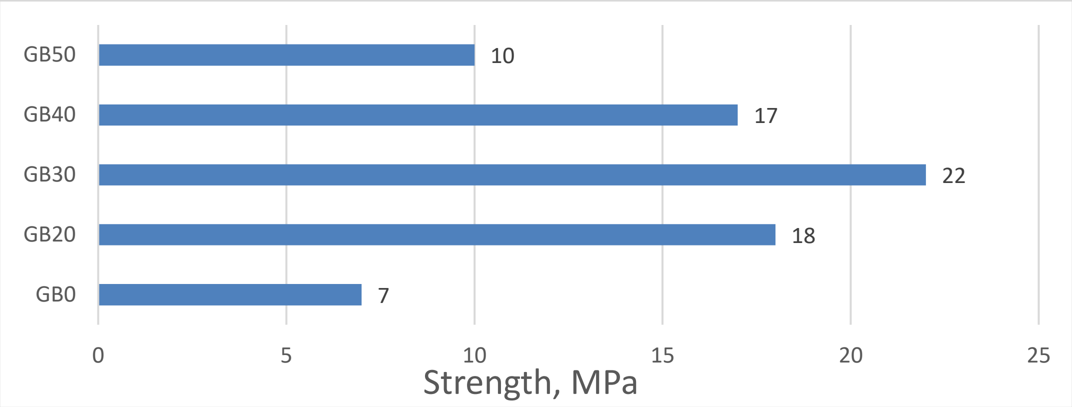

Figure 2. Bar chart 1. The strength test data for the investigated compositions on the 28th day of their hardening, depending on clay-magnesia binder ratio

As we can see from Table 2 and bar chart 1, the most optimal composition is SC-30 containing 700 g of clay soil, 300 g of semi-sintered dolomite, 60ml of bischofite, 205 ml of water, 65 g of potassium dihydrogen phosphate.

The strengthened foundation is a soil conglomerate containing hydro silicates and hydro alliumates. Potassium hydrogenphosphate binding of water, which is found in the soil leads to an increase in water resistance of the soil and, as a result, increases its strength.

In the course of the work there was set a task to obtain a structural material from the soil to construct spherical buildings. For this purpose, the authors carried out studies on the creation of wall materials both for concrete blocks and mortars for building technology using a 3D printer. The composition GB-30 is the most suitable for 3D printer technologies. With the aim to obtain soil-blocks as a masonry material there were developed compositions listed in Table 3.

Table 3. Composition of soil blocks

Soil-concrete composition	Clay, g	Semi-sintered dolomite, g	Bischofite with the addition of asbestos, ml	Wood aggregate, g	KH2PO4, g.
SC-25	700	250	200	50	60
SC-20	700	200	200	100	65
SC-15	700	150	200	150	70
SC-0	700	0	0	300	0

The composition of masonry soil-concrete except for clay soil includes:

Magnesia binder, containing 28 % of MgO.

Bishofite with the density of 1.2 g/cm^3, which is $MgSO_4$ as a grouting fluid

Bun or sawdust as a filler

Single-substituted potassium dihydrogen phosphate used as an additive that increases water resistance.

The main criteria to evaluate the synthesized compounds are mechanical strength (Rc) and water resistance. Bar chart 2 presents the investigated properties. The obtained samples, with the exception of SC-0, show water resistance higher than 0.8.

The results of strengthening man-made soils completely consistent with the concept of authors [13, 17–19] and served as the basis for the creation construction material which was not used in 3D technology before. With the aim of creating environmentally friendly building materials on the basis of the developed compositions with the introduction of an organic lightweight aggregate, in 2017-18 the expansion of the study is planned.

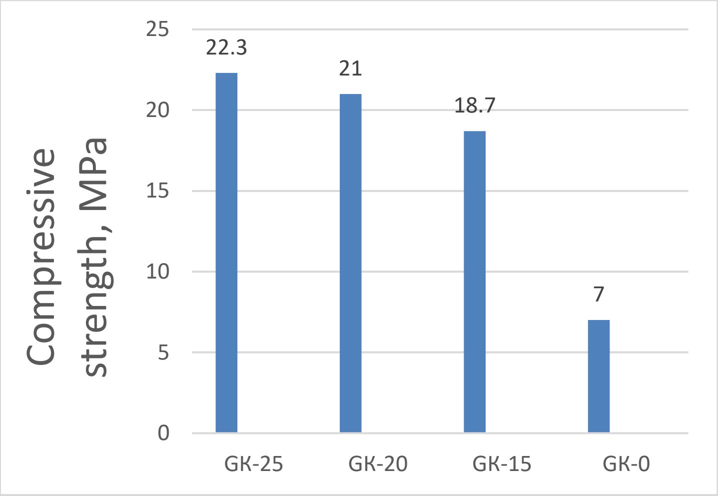

Figure 3. Bar chart 2. The investigated properties

Conclusions

This paper investigates the possibility to use soft man-made clay soils as a natural foundation, strengthened by semi-sintered dolomite waste; there have been selected components for composite mixing and improvement of its water resistance. There have been created samples of constructional materials as well as provided examples of complex approach to use domestically-produced raw materials to create non-waste technologies for the construction of energy-efficient housing using the technology of erecting buildings on a 3D printer. There have been considered the possibility of erecting buildings on a 3D printer in a single cycle. This research makes it possible to predict the availability to expand the resource base in the construction industry and to use previously unsuitable sites for construction purposes.

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