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НОВО ИЗСЛЕДВАНЕ НА ЯКОСТНИТЕ ХАРАКТЕРИСТИКИ НА ЦИМЕНТО-ПОЧВА ОТ ЛЬОСОВИДНА ГЛИНА ЗА ПРИЛАГАНЕ КАТО ОСНОВА НА ПЪТНИ И ЖП НАСИПИ

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A NEW STUDY ON THE STRENGTH CHARACTERISTICS OF LOESS CLAY SOIL-CEMENT FOR APPLICATION AS A BASE OF ROAD AND RAILWAY EMBANKMENTS

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Abstract:
Cement-soil strengths were investigated in the laboratory using a series of Proctor-compacted specimens after mixing loess clay and clay loam with different proportions of Portland cement and nano-cement additive.
The comparison is made based on the density and compressive strength of the test specimens. The experimental results are compared with the theoretical predictions for them. The optimization of the cement-soil mixture recipe has been achieved. Valuable guidance is provided for the practical application of the results.

Keywords:
Template, Formats, Instructions, Times New Roman, Left Justified

1. INTRODUCTION

The cement-soil technology is known in our country and around the world. It is applied to strengthen weak cohesive soils when they have to bear very heavy design loads. The research and application of this technology in Bulgaria has over 50 years of history and mainly concerns the strengthening of the loess in the Danube plain. The loess-cement cushion with a thickness of 4m under the foundation of the TV tower in the city of Ruse is considered the most significant achievement. There are prepared recommendations, instructions, recipes, but there are no valid standards or national norms for the design and implementation of cement-soil. This is primarily due to the wide variety of physical and mechanical properties of associated soils resulting from their mineral composition and geological history. This report presents a study on the strengthening with cement of just such a special variety of associated soils - loess clay.

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From world theory and practice, it is so far clear that the excessive content of Portland cement in the soil makes the mixture hard, but brittle and not resistant to dynamic impact. The behavior of such a mixture enriched with nano-additives has not yet been well studied under the conditions of dynamic impacts. So far, our theoretical and practical applications of loess-cement pillows have been based on the knowledge we have accumulated so far about typical loess. The application of the same knowledge, however, to loess clay and clayey loess, has not yet been supported by experimental evidence. With this research, we aim to achieve such an optimization between the parameters of the materials and the specific soil environment, so that the reinforced ground base for roads and railways can have the highest technical-economic effect.

I1. STATE OF THE ART

II.1. Short literature review

Our studies. show that in the last thirty years in Bulgaria there are almost no theoretical or research innovations on this topic, and on a global scale they are few and refer to regions in Southeast Asia and further afield.

In several publications, mainly in Bulgarian, the results of similar experiments are reflected and good practice is shared. The effect of reinforcing the failing loess base with portland cement was investigated and optimal values for the percentage content of primas were sought. There are no studies on the vibration-damping effect of loess-cement pillows. Eustatiev [1], [2] and [3], who led the initial large-scale research and implementation of loess-cement cushions for constructions in the Danube Plain, made the greatest contribution to the subject. Research developments are reported by Karastanev et al. [4] and [5]. There are three technical codes in Bulgaria that partially regulate the application of cement-soils {6], [7] and [8].

From the literature reviewed, some important established dependencies that apply to this project can be identified:

- Mixing the soil with cement gives a much higher strength of the soil, thanks to the Pozzolan reaction.
- Excessive cement content (over 7%) makes the product brittle and unsuitable for the foundation of road and railway embankments.
- There are very few experiments with soils that are derived from the pios - clayey loess and loess-like clay.
- There are no published results for measuring the California Bearing Capacity Ratio (CBR) for loess-cement pillows.

1I.2. Aims and objectives of the research

The main goal of the research is to look for the relationships between the content of the hydraulic binder (cement and nano-additives) and the improvement of the strength and deformation characteristics of the cement-soil: compressive strength, CBR, shear strength; modulus of deformation, modulus of elasticity, dynamic modulus of deformation.

The specific tasks are reduced to the preparation of combinations of soil, cement and nano-additives, for which to make three samples with different percentages of cement. Graphical and analytical relationships between the content of hydraulic binders and the strength and deformation characteristics of the product will be obtained from the analysis of the experimental results.

The results of the research can be widely applied in the construction of new highways, roads, railways, buildings, silos, etc. in the southern part of the Danube Plain, where these types of soils (clay loess and loess clay) are most widespread.

1II. USED MATERIALS

The soil for the mixture is taken from the project construction site for a new road embankment, and the hydraulic substances are supplied by the manufacturers and have technical certificates.

1II.1. Hydraulic binding agent

Portland cement CEM II/B-LL 32.5 R, according to BDS EN 197-1:2011, was used as a binder. The amount of cement to obtain these strengths is from 2% to 8%.

For one of the project combinations, the special hydraulic binder for cement soil stabilization Strentor of the manufacturer Holcim was used.

The connection water must comply with BDS 636-64.

1II.2. Cohesive soil

Suitable for this type of stabilization are plastic clay soils, as well as dusty soils. The loess clay used in this project has an average plasticity index Ip = 21.88% < 35%; The pH of the soil is above 7, i.e. the environment is not acidic, and the amount of water-soluble salts is below 4%; sulfate content is less than 0.25%; nitrates are less than 0.1%. Content of soil particles passing through a sieve with an opening of 0.063 mm is greater than 25 %. The soil is characterized as loamy clay with type I slump - slump from its own weight up to 5 cm.

The other characteristics of the loess clay with which this experiment was carried out are as follows:

- relative subsidence (δ) of loess: δ = 0.7% to 1.3% or average: 1.00%. These values are low for typical loess, but for loess-clays and clayey loess are possible;
- pore coefficient = 0.65 to 0.70 or average: 0.675;
- volume density of the skeleton ρd = 1.50 to 1.61 t/m^3 or average: 1.555 t/m^3;
- water content wn = 18% to 20.07% or average: 19.03%;
- degree of water saturation Sr = 0.71 to 0.86 or average: 0.785.
- The oedometric modules $E_{oed.}$ of the loess clay here has characteristically very low values, which vary from 5.4 MPa to 6.9 MPa. The general deformation moduli have the same values. Penetrometer-determined moduli of total deformation E_0, which are generally considered authoritative, range from 5.87 MPa to 11.38 MPa, or an average of 8.625 MPa.
- Moduli of elasticity Ee are low, between 15 MPa and 30 MPa.
- Initial crash load rinit. of the loess clay at these low strain moduli was assumed to average 177 kPa.
- CBR=7.6% to 8.62% (average 8.15%) – weak ground base.

1V. EXPERIMENT DESCRIPTION

1V.1. Experiment preparation

The so-called "stiff mix" is used to build a loess-cement cushion. The stiff mix is prepared with a cutter and compacted at the optimum water content (wopt) until the maximum bulk density of the framework (rd,max) is reached.

When making the stiff loess-cement mixtures, wopt is determined according to BDS 3214-72 (Proctor's test).

The soil is crushed with a wooden hammer. It is then sieved through a sieve with a diameter of 10 mm, as shown in Fig. 1a.

For each individual experiment, 5 kg of loess clay is used, to which the appropriate amounts of water, cement, nano-cement or hardening additive are added, as seen in Table. 1. Stir the mixture well and let it stand for about 1 hour, then stir again. Next, prepare the test cubes with dimensions of 15/15/15 cm, as shown in Fig.1b. The filled soil is standardly compacted in five layers with 50 blows using the Proctor device (Fig. 1c). After aging (Fig. 2a, b) of the cubes, they are tested for axial pressure with an ADR 2000 press (Fig. 3a, b). The loading speed is 6.8 kN/s.

Table 1. Quantities of added materials to 5 kg of soil.

№ test	Name	Cement		Nano-cement	Stentor	Water
		g/1kg	*g/5kg*	*g/5kg*	*g/5kg*	*g/5 kg*
I	Ordinary portland cement 2%	16.8	84			740
II	Ordinary portland cement 2%+нано-цимент (3% resp. the cement)	16.8	84	2,52		740
III	Strentor2%	16.8	0	0	84	740
IV	Ordinary portland cement 6%	50.5	252.5			875
V	Ordinary portland cement 6%+nano-cement (3% resp.the gement)	50.5	252.5	7.58		975
VI	Strentor 6%				252.5	975

An optimum water content of 18.85% was achieved. Another 65g of water was added to bind the cement, bringing the total water content to 20.65%. A little more water is added for the next cubes, and thus 25.35% is reached.

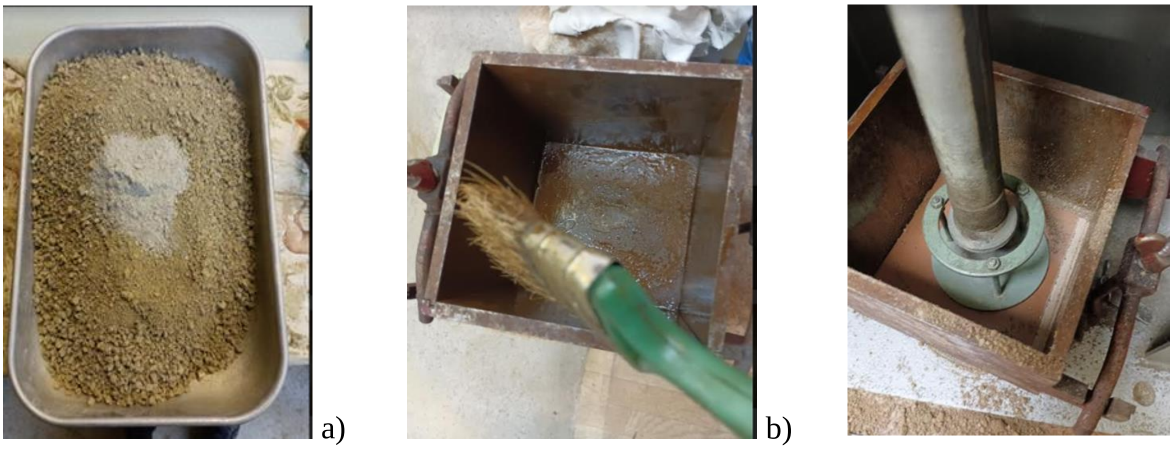

Figure 1. The sieved soil (a); sample form (b); compaction (c). (photo by S. Kostova)

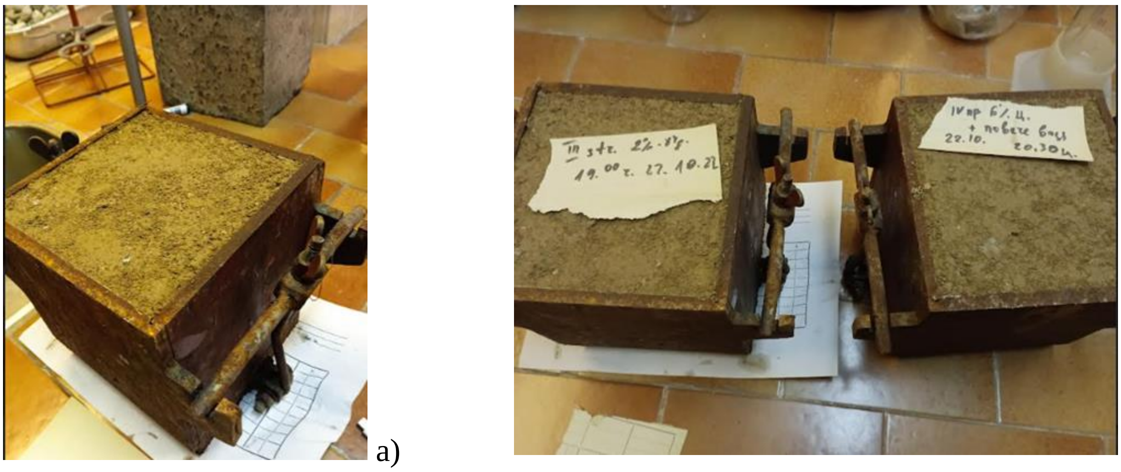

Figure 2. Compacted samples (a); sample aging (b). (photo by S. Kostova)

1V.2. Carrying out the experiment

The destruction begins with the formation of vertical cracks on the cubes, and upon complete destruction, a collapse occurs from the base towards the center and two opposite truncated pyramids are formed - upper and lower, whose small bases touch in the center of the cube. The cubes break down like concrete bodies (Fig. 3c, d). The destruction of the consolidated soil bodies is fragile and its shape is as expected.

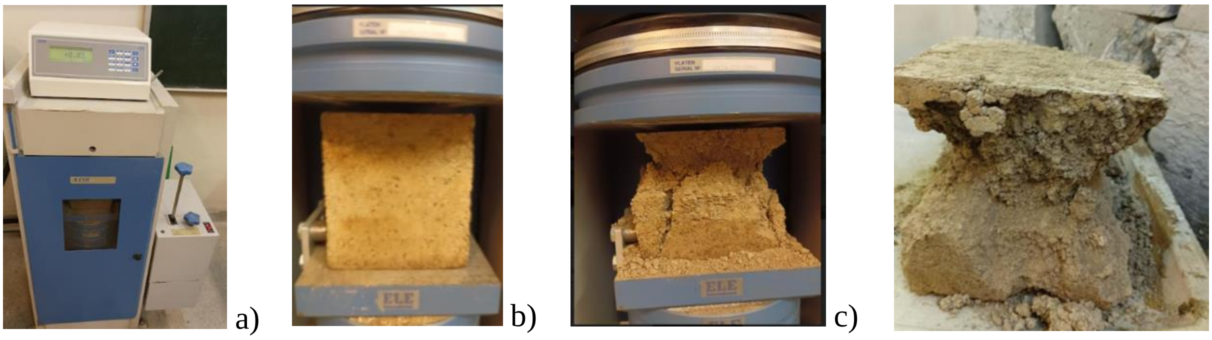

Figure 3. The press (a); start of trial (b); fractured sample (c), fracture pattern (d).
(photo by S. Kostova)

V. EXPERIMENTAL RESULTS, ANALYSIS AND CONCLUSIONS

The axial pressure test results are shown in Table 2.

Table 2: Cement content in percentage and achieved axial compressive strength

№ test	Name	R, кPa	Comparisons of the results
I	With ordinary portland cement 2%	23.04	Baseline value
II	With ordinary portland cement 2%+nano-cement (3% of cement)	26.22	113.87% over Test I
III	With Strentor2%	21.78	94.53% of Test I
IV	With ordinary portland cement 6%	51.56	223.78% over Test I
V	With ordinary portland cement 6%+nano-cement (3% of cement)	58.67	113.79% over Test II
VI	Със Strentor 6%	48.44	93.95% of Test IV

- The Portland cement content of 2% in the mixture is insufficient to achieve a sufficiently high strength of the loess-cement cushion;
- The used portland cement CEM II/B-LL 32.5 R (according to BDS EN 197-1:2011) is weaker than the design CEM I 42.5 N SR5 and this significantly reduces the value of the compressive strength of the mixture;
- The Strentor hydraulic binder gives a compressive strength that is only 6% lower than that obtained with the same amount of Portland cement. This is evident from the comparison of the values from experiment I with experiment III and from experiment IV with those from experiment VI;
- The nano-cement addition of 3% relative to the mass of Portland cement increases the strength of the sample by 13.8%;
- The increase in cement content from 2% to 6% (by 300%) leads to an increase in the compressive strength of the mixture by about 223%. This means that it is effective to use a higher grade of cement to have optimal values for the compressive strength of the mixture at a cement content of about 6% to 7%;

- The high hygroscopicity of cement requires an additional amount of water (about 9% increase in water content) above the optimum for the soil;
- The too low percentage of the sand fraction in the tested loess clay does not create prerequisites for a violent Pozzolanic reaction when mixing with cement, nano-cement and various hydraulic binders. This does not allow achieving very high values for the compressive strength of the mixtures, as would be the case with loess with more sand.
- In the practical application of cement-soil cushions in such loess-like clay, it is necessary to use high-grade cement and thicker layers of mixtures, sufficiently well compacted.

The experiments showed a linear relationship between the increase in compressive strength and the content of hydraulic binders:

- For Portland cement, the slope has the form: $y=7.13x+8.78$ (1)

or approximately: $y=7x+9$ (2)

- For portland cement with 3% nano-cement: $y=8.1125x+9.95$ (3)

or approximately: $y=8x+10$ (4)

- For Strentor the dependence has the form: $y=6,665x+8.45$ (5)

or approximately: $y=6,5x+8,5$ (6)

From the analytical linear relationships obtained, it is evident that the strength increases most rapidly with additions of nano-cement, and the addition of Strentor is only slightly less effective than Portland cement. On the other hand, the addition of Strentor as well as the nano-cement is expected to make the cement-soil more resistant to dynamic impacts.

These studies need to be continued in order to examine a larger number of uniform samples and combinations from which to confirm reliable endpoints.

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