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THE USE OF CONCRETE SLURRY WASTE TO IMPROVE THE PROPERTIES OF THE STABILISED SOIL

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Abstract. It is often necessary to use stabilising additives during construction to improve the resulting soil properties to ensure the good quality of civil engineering structures. These additives are often produced at high temperatures and with a high carbon footprint. This paper focuses on soil stabilization with waste concrete slurry, which is produced during the production of fresh concrete. The selected clay soil was stabilized with cement and CSW at 2, 4, and 6 % by weight of soil. Compressive strength, the resistance to freezing and thawing, Initial bearing index (IBI), and California bearing capacity (CBR) were monitored. The research did not confirm better performance of CSW binder even at higher dosage compared to cement, which was due to the high water content of the mixtures. Positive results were achieved especially in Freez-Thaw resistance.

Keywords: Concrete slurry waste, soil improvement, compressive strength.

1. Introduction

Concrete slurry waste (CSW) is produced as a waste material from the production of fresh concrete, which currently has only limited use. Here are some examples of the use of this waste material. Hardened CSW has been used as recycled aggregate or as a fine aggregate in concrete. The CSW has also been used as a lightweight aggregate or as a substitute for lime for liming acidity in agricultural soil, or as substitute for soil stabilisation [1]. To ensure quality construction, it is necessary to ensure good conditions in the building below. However, if there is no good quality soil on the site, additional investment and works are needed to improve the properties. Clayey soils often have low strength characteristics, and such soils cannot be used for the construction of civil engineering structures without modification of the properties. For this reason, the inadequate soils can be improved by using of stabilising materials [2]. As a chemical stabilising material, pozzolanic materials are most often used. Many researchers, for example Z. Wang et al. [3] used ordinary portland cement (OPC) to stabilize clay soil in China. They noted the degree of hardness decreases with the increase of the clay-water/cement ratio. A. Daraei et al. [4] used cement, quicklime, or gypsum to stabilize soil in Iraq. The adding quicklime to the soil reduced swelling and permeability. G. Barbhuiya et al. [5] used nano-silica to enhance various types of soil. However, these materials need to be manufactured, often at high temperatures and with a high carbon footprint, so it is necessary to look for available materials. Y. Cheng et al. [6] could use the natural resource of volcanic ash to improve soil properties in Kenya. However, such a source is not available everywhere.

In the Czech Republic, CSW is far more available, because it is produced at every concrete plant and, moreover, its use is very limited and largely ends up in landfill. By using this material, we reduce the landfilling of waste material, and improve the soils. According to P. Reiterman et al. [7] CSW contains calcium hydroxide (CH), C-S-H, aluminate hydrates, and non-hydrated particles of OPC. Thus, this material was supposed to combine the effect of the main practically used soil stabilizers – OPC and lime.

2. Experimental section

2.1. Materials

The main material used for this research was a clay soil with medium plasticity, tough consistency, and brown colour. This soil originates from the Czech Republic – the village of Rodov, can be classified as F6 according to ČSN 73 6133 [8] and also as CL according to USCS classification [9]. Figure 1, shows the grain size distribution of the used soil. A summary of the specific soil properties is shown in Table 1.

The ordinary Portland cement (OPC) CEM I 42.5 R, and concrete slurry waste (CSW) were also added to this soil to improve its properties. CSW is a material originating from concrete production. This material is obtained from the maintenance of the plant and from residual concrete that is returned from construction. The aggregate of the large fraction is first separated from this material, then it is stored in a sedimentation pond (Figure 2) where the sludge is settled. This sludge was further treated by filtering out excess water and dried at 105 °C. The resulting material was crushed in an OM20 laboratory mill from Brio Hranice. The material was sieved through a 0.5 mm size mesh sieve to achieve the desired properties.

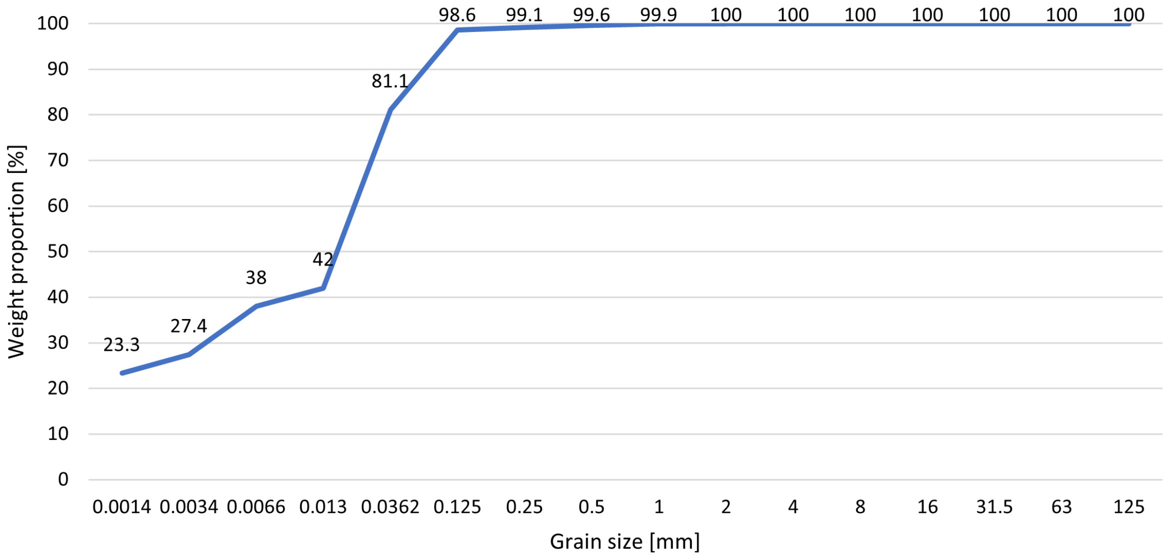

Figure 1. Grain size distribution – curve.

Organic content	0.2 %
Liquid limit	37.6 %
Plastic limit	19.8 %
Optimum moisture content (modified compaction according to ČSN EN 13286-2 [10]	13.0 %
Maximum dry density	1 930 kg m^{-3}

Table 1. specific soil properties.

Figure 2. CSW in sedimentation pond.

	R	C3	W2	W4	W6
Proportion of soil (F6 Cl)	100 %	100 %	100 %	100 %	100 %
Binder	0	3 %	2 %	4 %	6 %
Water	13 %	16 %	16 %	19 %	21 %

Note: C = cement, W = CSW

TABLE 2. Composition of the mixtures.

2.2. Composition of the mixtures

A reference mix composed of selected soils was first prepared for the purpose of this project. Then its properties were improved with use of cement in dose of 3 % by weight of the soil. The cement was further substituted with CSW at a dosage of 2 %, 4 %, and 6 % by weight of the soil. Water was added based on the results of the optimum moisture content determined by the Proctor modified test only for reference soil mixture. The moisture content was then increased by 1 % for every 1 % of added cement to soil, and 1.5 % for every 1 % of added CSW binder. Before testing began, it was assumed that the CSW binder would require a higher proportion of water to achieve the same consistency of the mixture, but this assumption was not confirmed and so the higher water content had a major effect on the final properties. The composition of all mixtures is shown in Table 2.

2.3. Methods

The following tests were performed to compare the effects of the CSW binder and OPC: Initial bearing index (IBI), and California bearing capacity (CBR), compressive strength, resistance to freezing and thawing (F-T). All samples were made according to ČSN EN 13286-2 [10] - modified proctor. With this method, the samples are compacted by a weight falling from a prescribed height and in a prescribed number. Then the samples were treated until the day of testing depending on the purpose.

The tests according to ČSN EN 13286-2 [10] were used for the determination of IBI and CBR (CBR was performed after 96 hours of curing in saturated state). These tests are based on the mandrel that is pushed into the test specimens at a certain speed, after the value of the force and the depth of penetration were measured. The IBI and CBR were determined from the measured values. Seven samples of each mixture were made for the determination of compressive strength. These samples were sealed in an impermeable bag and left in a humid environment for 7 days (2 samples), 14 days (2 samples), and 28 days (3 samples). The specimens were tested according to the ČSN EN 13286-41 [11] after the specified time. The resulting compressive strength is determined from the maximum load. A load is applied to the specimen until it breaks in this test.

Three samples were prepared from each mixture for the F-T resistance. These samples were placed in an impermeable bag and left in a humid environment for 28 days. After this time, the samples were subjected to 13 cycles of freezing and thawing at the temperature of -15 °C. The result is the number of cycles that the test specimens have resisted without signs of destruction.

3. Results and discussions

The achieved IBI and CBR are shown in Table 3 and Figure 3. The IBI results of the studied mixtures correspond to the amount of water in the mixtures. Mixture R with the lowest water content of 13 % achieved the highest IBI. Similarly, mixture W6 with 21 % water achieved the lowest IBI.

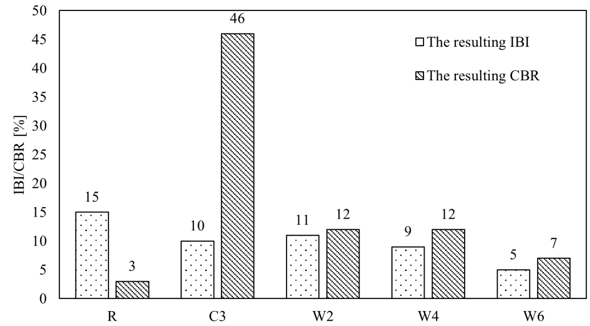

FIGURE 3. The resulting IBI and CBR.

	R	C3	W2	W4	W6
IBI (2.5 mm)	12.7	9.5	10.5	8.9	4.4
IBI (5.0 mm)	14.8	10.3	11.3	9.1	4.9
The resulting IBI	**15.0**	**10.0**	**11.0**	**9.0**	**5.0**
IBI (2.5 mm)	2.3	29.1	9.4	9.6	6.1
IBI (5.0 mm)	2.6	45.8	12.2	12.2	7.0
The resulting IBI	**3.0**	**46.0**	**12.0**	**12.0**	**7.0**

TABLE 3. The resulting IBI and CBR [%].

On the other hand, treatment time had a positive effect on the CBR result. The most significant result was observed on C3 mixture with cement as the binder was activated and CBR reached 46 %. The mixtures with CSW achieved a higher CBR than the reference soil, but the resulting value was round 10 %. These results correspond with the strength results. Again, a longer curing time was needed for better binder activation, and in the short term, the higher dose of CSW together with the higher dose of water did not show better properties than the lower dose of CSW.

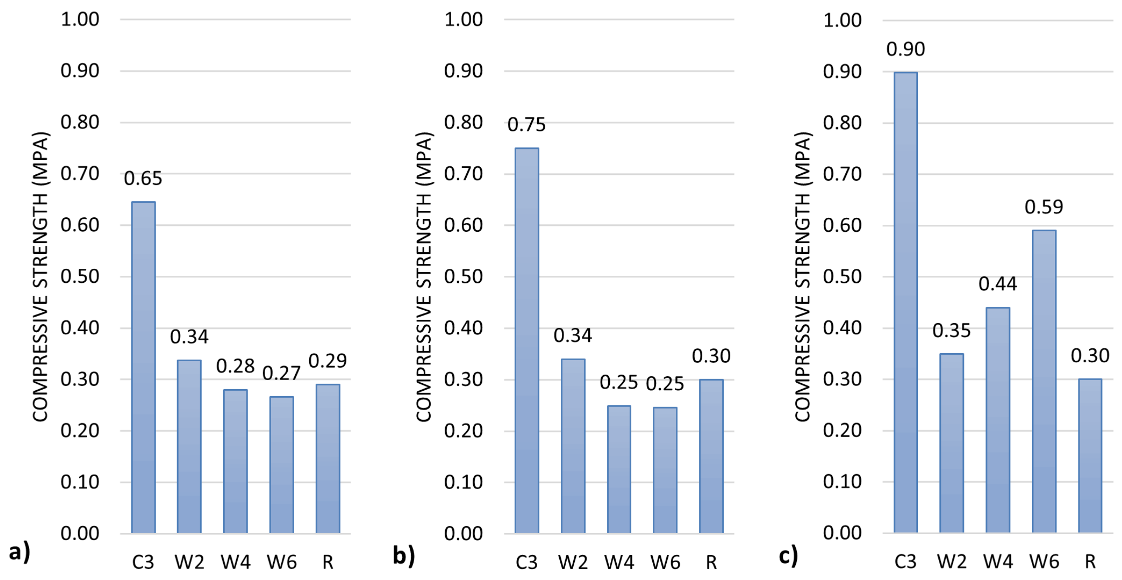

Figure 4. Evolution of compressive strengths; a) 7 days, b) 14 days and c) 28 days.

An overview of the compressive strength results in MPa is summarized in Table 4, and Figure 4. The reference mixture without the use of stabilising components did not show an increase in strength over time. This result was expected as the soil did not naturally contain any hydraulic components. Stabilization with cement was the most effective as it achieved the highest compressive strength. This result is consistent with the research of S. I. Haralambos [12], who investigated the effect of cement dosage on different types of soils. He noted that the addition of cement to all soil types increased the compressive strength and stiffness of the soil-cement mixture.

Curing time	R	C3	W2	W4	W6
7 days	0.29	0.65	0.34	0.28	0.27
14 days	0.30	0.75	0.34	0.25	0.25
28 days	0.30	0.90	0.35	0.44	0.59

Table 4. Compressive strengths of the mixtures (MPa).

Mixtures W2, W4, and W6 initially achieved low strengths due to the higher dose of water. The increase in strength became apparent after a longer curing time (after 14–28 days). After this time, the increase in strength was most significant for the mixture with the highest CSW content.

The results show that the low dose of CSW improved the strength properties insignificantly. Higher dose of CSW with higher water content was more effective, longer treatment time was required for the soil strength to show.

The F-T resistance is shown in Figure 5. The reference soil did not resist even 1 of the 13 freezing cycles, therefore it can be considered as non-frostproof. Samples with cement and the lowest CSW binder dose (and the same water content) resisted the most freezing cycles. Mixtures with 4 % and 6 % CSW binder resisted only 4 freezing cycles.

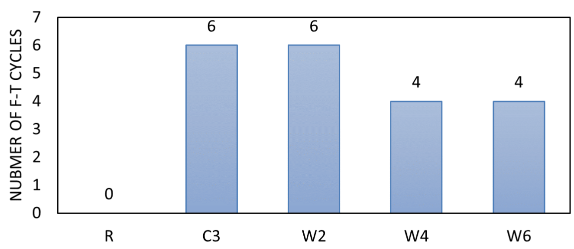

Figure 5. The resistance to freezing and thawing.

The addition of cement as a stabilizing additive improved the F-T resistance, which corresponds with the Y. Lu et al. [13] research. They noted that effective content of cement stabilizer was 5 % in their study.

The addition of a stabilizing CSW improved the resulting frost resistance too, but samples with higher water content in the mixture (W4, W6) resisted a lower number of cycles. Overall, it can be noted that the addition of CSW improves the resulting F-T resistance, but the water content of the mixture must also be taken into account.

4. Conslusion

The purpose of this research was to compare the properties of clay soil stabilized with ordinary cement and waste material from fresh concrete production (CSW). The research showed that CSW improves the compressive strength of the soil, but only after a longer treatment. However, stabilization with cement was more effective. Mixtures with cement and low CSW content showed comparable F-T resistance, mixtures with higher CSW content and higher water dosage showed lower F-T resistance, still better that the reference soil without treatment. Increasing water dosage in mixtures with cement and CSW binder negatively affected IBI, on the other hand, CSW binder positively affected CRB and the mixture with cement achieved very good values.

Overall, even the higher dose of CSW binder did not achieve comparable results to cement. This was mainly due to the different dosage of water in the mixture and therefore the comparability of the results is limited. The positive effect of the CSW binder was generally more obvious after a longer treatment time than for the samples with cement, which is an important finding for practical use. Further research will focus on comparing the properties of soils with the same water content at different percentages of CSW binder.

Acknowledgements

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