Freeze-thaw testing of stabilized soil samples used for riverbank consolidation

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Abstract. Riverbank erosion is a common problem of the Romanian freshwater system. Classic riverbank stabilization methods consisted of using different type of concrete, however concrete manufacture consumes large amount of non-renewable raw materials and energy, and it is a carbon-intensive process. Many efforts are, therefore, being undertaken towards the developing “greener” solutions. There are different type of retaining walls resulted from the need to avoid reinforced concrete wall solutions, such as gabion walls, solid masonry walls, rocky embankment prisms, and wooden pile retaining systems. But all of these solutions converge on gathering raw material from an external source, and transporting it on location. In Romania acquiring crushed stone tends to become problematic, especially, in the areas outside the Carpathian mountain range. Therefore a solution of using local soil as a base for a stabilized soil layer is very practical and economical from a technologic point of view. Being a hydrotechnical application, the freeze-thaw resistance of the stabilized layer is crucial for the lifetime of structures. The objective of our study was to determine this parameter, in accordance with the Romanian norms and regulations.

1. Introduction

1.1. Objective of the study
An experimental project was carried out on “Căpuș” river from Cluj county, by building a slope protection system on both sides of the riverbank. The initial state revealed severe erosion problems, that were only aggravated by the seasonal floods, as seen in figure 1.

Riverbank stabilization was made from stabilized soils, using hydraulic binders from our partners the Lafarge Holcim Group Romania, and were selected according to their expertise, and results of the laboratory analysis. On the left bank a small dam was built, stabilizing the local soil with Doroport TB25© [1]. The right side of the river was considerably steeper, so designing a slope protection was more convenient. This system was built using soil-Dorosol C30© [2] admixture. Being in constant contact with water through all seasons raises the question of durability, and stability of formula under various temperature and moisture conditions. Therefore, one of the most important parameters for the present project was to determine the weight loss through freeze thaw testing.
1.2. State of the art
There are several studies concerning freeze-thaw testing of stabilized materials. Su et al. [3] evaluated the effect of freeze-thaw cycling on the mechanical properties of cementitiously stabilized materials (CSM). Ultrasonic testing was applied to monitor the P-wave velocity (constrained modulus) change during the freeze-thaw cycling. Unconfined compression strength (UCS) test was performed at the end of freeze-thaw cycling. It was found that freeze-thaw cycling could be detrimental to CSM as the constrained modulus decreased to 7% to 96% depending on the CSMs. The residual UCS was 35% to 84% of the initial UCS at the end of the test. The results showed that freeze-thaw cycling is an aggressive test, which result in degradation in the constrained modulus (D) and UCS for cementitiously stabilized materials (CSMs). Binder content has been proven to influence freeze-thaw durability significantly. Resistance against freeze-thaw cycling increases with increasing UCS.

Yin et al. [4] studied frost resistance durability of strain-hardening cement-based composites (SHCC) under combined flexural loading at different levels and under chloride attack. The loss of weight, dynamic elastic modulus, and microstructure characteristics of SHCC specimens were determined, and the influence of loading level on frost resistance was analyzed. In addition, the effect of freeze–thaw action on the flexural performance and diffusion properties of chloride in SHCC under the combined loads were investigated. The results show that the process of degradation was accelerated due to the simultaneous action of flexural loading and freeze–thaw cycles in the chloride environment, and SHCC suffered more serious damage at a higher loading level. However, flexural strength decreased by only 13.87% after 300 freeze–thaw cycles at load level $S = 0.36$. The diffusion properties of chloride in SHCC under constant flexural loading were affected by the freezing and thawing cycle.

Another study conducted by Jang [5] provided experimental results to investigate the mechanical properties of sustainable strain-hardening cement composite (2SHCC) for infrastructures after freeze-thaw actions. To improve the sustainability of SHCC materials in their study, high energy-consumptive components—silica sand, cement, and polyvinyl alcohol (PVA) fibers—in the conventional SHCC materials were partially replaced with recycled materials such as recycled sand, fly ash, and polyethylene terephthalate (PET) fibers, respectively. To investigate the mechanical properties of green SHCC that contains recycled materials, the cement, PVA fiber and silica sand were replaced with 10% fly ash, 25% PET fiber, and 10% recycled aggregate based on preliminary experimental results for the development of 2SHCC material, respectively. The dynamic modulus of elasticity and weight for 2SHCC material were measured at every 30 cycles of freeze-thaw. The effects of freeze-thaw cycles on the mechanical properties of sustainable SHCC were evaluated by conducting compressive tests, four-point flexural tests, direct tensile tests and prism splitting tests after 90, 180, and 300 cycles of rapid freeze-thaw. Freeze-thaw testing was conducted according to ASTM C 666 Procedure A. Test results show that after 300 cycles of freezing and thawing actions, the dynamic modulus of elasticity and weight loss of damaged 2SHCC were similar to those of virgin
2SHCC, while the freeze-thaw cycles influence mechanical properties of the 2SHCC material except for compressive behavior. Freeze-thaw exposure has little effect on the tensile performance of conventional SHCC materials. However, tensile performance of the sustainable SHCC replaced partially with recycled components is slightly different from that of conventional SHCC tensile specimen after repeated freeze-thaw cycles.

2. Materials and methods

Two different soil types were encountered on the sides of the riverbank. Granulation analysis shown in figures 2 and 3 reveal that the left embankment is composed of a slightly clayey sand, while the right embankment is formed from a clayey soil.

Figure 2. Granulation analysis on left embankment.

Figure 3. Granulation analysis on right embankment.

This fact led to using two different hydraulic binders, after performing a series of geotechnical analysis. Stabilization effects on shear strength parameters (cohesion, internal friction angle), and oedometric modulus were described in a separate article [6]. Doroport TB25 was used on the left side, and Dorosol C30 was mixed with the soil from the right side. From an economic point of view 3% and 5% hydraulic binder content was considered.

2.1. Romanian regulation

Freeze-thaw testing methodology for Romania is described in STAS 10473-2-86 [7]. It sets a curing time of 13 days for stabilized samples, which then should be subjected to 14 freeze-thaw cycles, each of them consisting in 16 hours of exposure to a temperature of -5°C (±1 °C), followed by 8 hours of immersion in water (the water temperature should be 25 ± 2 °C). Prior to freeze-thaw cycles, samples are to be submerged in water for a day, and weighed before starting the test. The stabilized soil samples should be visually inspected after each cycle and one should note the number of cycles at which cracks and other degradation are observed. After completing the test, samples should be wiped with a wet rag, and brushed to remove all the parts affected by freeze-thaw cycles. Then another set of weighing will determine the weight lost during the test.

The weight loss parameter ($P_{id}$) is determined from the following formula:

$$P_{id} = \frac{m_{13+1lm} - m_{14 cicl}}{m_{13+1lm}} \times 100$$

where $m_{13+1lm}$ is the weight of the samples at 13 days of age, plus 1 day immersed in water; $m_{14 cicl}$ is the weight of the samples weighed after 14 freeze-thaw cycles.

2.2. Sample preparation and testing

A number of 12 samples were prepared using combinations of local soils with 3 % and 5 % of Doroport TB25, and Dorosol C30. Extracting unaltered samples from the location of the project with a double core boring device would have been problematic and costly, due to the steepness of the embankments. There would have been a high chance to extract already cracked samples, which would be irrelevant for the present stage of the study, and this determination in particular. Proctor test were carried out on both soil types in laboratory conditions, before building the slope protection system, in
order to determine optimal compaction moisture content for all combinations with 3 % and 5 % hydraulic binder [6]. Optimal water content for the left riverbank was around 11%, while on the right side it was near to 13 %. The recipe for stabilization included 5 % of hydraulic binder on both sides of the embankment. On site compaction was made considering these values, and closely monitored by our team and our partners from Lafarge Holcim Group Romania. Therefore, the samples for the present study were prepared and extracted from the Proctor device, according to previously set values, in the Lafarge Holcim factory’s laboratory from Turda, as shown in figures 4 and 5.

After a 13 day curing time the samples were submerged and weighed, the recorded values are presented in table 1.

| Table 1. Weight of the samples at 13 days of age, plus 1 day immersed in water (m_{13+1im}) in grams (g). |
|---------------------------------------------------------------|
| Dorosol C30 3% - right embankment | Dorosol C30 5% - right embankment | Doroport TB25 3% - left embankment | Doroport TB25 5% - left embankment |
| P1 | 1992 | 2142 | 1985 | 2080 |
| P2 | 1971 | 2150 | 1970 | 2101 |
| P3 | 2001 | 2155 | 1965 | 2092 |

Samples before testing are presented in figure 6.

![Figure 4. Sample compaction inside the Proctor device vessel.](image)

![Figure 5. Extracted sample](image)

![Figure 6. Stabilized soil samples, before freeze-thaw testing (from left to right Dorosol 3%, Dorosol 5%, Doroport 3%, Doroport 5%).](image)
After 14 days of testing in the laboratory of the Technical University of Cluj-Napoca, constant visual inspection concluded that the clayey soils treated with Dorosol C30© presented several cracks, while the sandy soils from the left embankment treated with Doroport TB25 showed no or minor alterations. At the end of the cycles samples were wiped and brushed. Another weighing was conducted, values are presented in table 2.

**Table 2.** Weight of the samples after 14 freeze thaw cycles ($m_{14cic}$) in grams (g).

|                | Dorosol C30 3% - right embankment | Dorosol C30 5% - right embankment | Doroport TB25 3% - left embankment | Doroport TB25 5% - left embankment |
|----------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| P1             | 1987                              | 2137                              | 1975                              | 2071                              |
| P2             | 1887                              | 2144                              | 1960                              | 2072                              |
| P3             | 1952                              | 2149                              | 1958                              | 2086                              |

Samples after testing are presented in figure 7.

**Figure 7.** Stabilized soil samples, after freeze-thaw testing (from left to right Dorosol 3%, Dorosol 5%, Doroport 3%, Doroport 5%) Significant cracks appear on the samples treated with Dorosol, as seen on the right picture.

3. Results and discussion

Applying the formula from STAS 10473-2-86 gives the weight loss parameter ($P_{id}$), presented individually for every sample, and as an average value for the groups of three, in table 3.

**Table 3.** Weight loss parameter ($P_{id}$) in percentage (%).

|                | Dorosol C30 3% - right embankment | Dorosol C30 5% - right embankment | Doroport TB25 3% - left embankment | Doroport TB25 5% - left embankment |
|----------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| P1             | 0.25                              | 0.23                              | 0.50                              | 0.43                              |
| P2             | 4.26                              | 0.28                              | 0.51                              | 1.38                              |
| P3             | 2.45                              | 0.28                              | 0.36                              | 0.29                              |
| Average        | 2.32                              | 0.26                              | 0.46                              | 0.70                              |

A significant improvement is noted on the average resulted from the samples mixed with Dorosol C30©. The samples with 3% hydraulic binder were the first to present cracking marks after cycles 3 and 4, and by the end of the test, the successive immersion, wiping and brushing left visible marks on the sides. Given the differences between obtained values more tests should be carried out on this type of admixture to draw viable conclusions. The results from the set with 5% Dorosol are remarkably similar, so this can be considered a reference value. The same thing can be said about the samples stabilized with 3% Doroport TB25©. The 5% admixture’s average value is influenced by the P2 sample, which might have suffered some alterations independent from freeze-thaw cycles. Otherwise if we eliminate that result we have a slight improvement against the 3% admixture. More tests should be carried out on this recipe too.
4. Conclusions
The experimental protection system on Căpuș river behaves differently from one embankment to the other, largely eight months after constructions. The structures were built in October 2018, and were left exposed to the winter conditions of 2018. A visit in June 2019 revealed erosion problems on the right embankment, where Dorosol was mixed with a clayey type soil, as presented in figures 8 and 9.

Having different soils on the embankments, stabilized with two kinds of hydraulic binder raises a sum of uncertainties in interpreting the different behavior of the structures exposed to the same enviroment and conditions.

A freeze thaw sensibility potential revealed by laboratory tests on the right embankment stabilized with Dorosol C30© can be an explanation, however more tests would be required to draw long term conclusions, including swelling index determination.

An internal study of the Lafarge Holcim Group revealed that less aggressive cycles of freeze-thaw have much lower effect on freeze-thaw sensibility. At the factory freezing cycles of 7 days were applied, maintaining a temperature of -8°C. Only after this period were the samples sunk in water, and a number of 12 wet-dry cycles performed afterwards. This opens a discussion about the actuality of the Romanian standard. The American standard [8] also sets a different timing for the cycles, having 24 hours of freezing followed by 24 hours of immersing in water. The rapid changes of temperature and humidity in the testing procedure of the Romanian standard may cause more damage to the samples than other acknowledged testing procedures. Stabilized soil admixtures are not designed to be left exposed to the elements, as they are usually included in road bed structures. The damage of the embankment of the experimental sector shows that a protective layer is necessary over the stabilized soil structures. Considering the economy caused by using local soil, and the fact that grassing would be the cheapest and most expedient method of protection, this method of riverbank consolidation is considerably “greener” than conventional structures used today.
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