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Research paper

Studies on the influence of water filtration on the strength parameters of lime-stabilized soil

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Abstract: The stabilization of cohesive soils intended for use in water-retaining embankments with quicklime is not a popular technology in the hydrotechnical industry. This is associated with the potential for lime to leach from the soil structure, thereby reducing the strength of the material used. An experiment was designed and carried out to force water to flow through cohesive soil compacted at the optimum moisture content. The strength parameters of the soil were determined on the basis of a test in a large-scale direct shear apparatus. Even in its natural form, the tested soil was characterized by high cohesion (average 103.47 kPa) and a high internal friction angle (average 27.05°). As a result of water filtration, a slight average increase in these parameters was observed, by 13.01% (cohesion) and 11.87% (internal friction angle). Between 2.75 and 8.0 dm^3 of water was filtered through the individual samples, and the lime concentrations were low, between 53.7 and 98.9 mg/dm^3. After the soil was stabilized with lime, both analysed parameters increased – cohesion averaged 148.98 kPa and internal friction angle 33.53°. As a result of water filtration through the stabilized soil, the increase in cohesion was inhibited and the average internal friction angle decreased by 16.49%. Between 3.05 and 11.5 dm^3 of water was filtered through the individual samples, and the lime concentrations ranged between 380.8 and 915.4 mg/dm^3. No correlation was found between the amount of lime leached and the maximum shear strength values obtained for a given soil sample. Despite the high water pressure (4.5 meters of water gauge), long filtration time (40 days), and short period between compaction and the start of flow (approx. 3 days), the tests did not confirm any risk of a significant reduction in the strength parameters of the lime-stabilized soil as a result of water impact.

Keywords: hydrotechnical engineering, lime stabilization, soil strength, water filtration

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1. Introduction

Soil stabilization with quicklime is not a new technology. It began to be widely used in civil engineering in the first half of the 20th century to improve the geotechnical parameters of soil [1]. The chemical reactions that occur during soil stabilization with quicklime include hydration (lime slaking in an exothermic reaction), ion exchange (soil flocculation) and, after a longer period of time, pozzolanic reactions and carbonation [2, 3]. These processes lead to an increase in the bearing capacity of the soil, a reduction in plasticity and an improvement in stability and durability. The end result is a structure with characteristics similar to those of weak concrete, which makes the soil more suitable for engineering applications [4, 5]. Lime stabilization of soils is a well-established technique that has been widely adopted for decades to improve the engineering performance of weak and expansive clays [6]. This treatment markedly reduces the plasticity and swell potential of clayey soils while significantly increasing their strength and stiffness [7]. Recent studies have also shown that adding lime has a favorable effect on the compressibility and volume stability of natural clays, leading to substantial gains in load-bearing capacity and long-term stability [8]. Examples of large investments in which lime-stabilized soil has been used include the construction of the Dallas-Fort Worth Airport (USA), where lime was used to stabilize clayey soils under runways and airport aprons. This resulted in a substrate resistant to deformation and water [9]. There are hundreds of similar examples around the world, but the vast majority of these involve roads, motorways or railway lines.

Regardless of the potential benefits, including economic and logistical ones, soil stabilization has not become widely used in hydraulic engineering, and designers in this industry mainly opt for other solutions when developing concepts for embankments or dams. This is primarily justified by the potential risk resulting from the filtration of accumulated water through the embankment, thus the leaching of lime contained therein and a significant deterioration of its parameters, which would threaten the safety of the structure. An example of this is the construction of the Szalejów Górny flood protection reservoir in south-western Poland, where the cohesive soil obtained from the reservoir basin required moisture reduction in order to achieve proper compaction. However, stabilization with quicklime was only used for the core of the dam structure, and despite confirmation of the significant effectiveness of this technology, the designer did not agree to its use on the waterside of the embankment. As a result of this decision and the long process of natural drying of the material, the investment was significantly delayed, which could have been avoided by using the same technology for the waterside as for the core, i.e. drying with quicklime [10].

Less numerous, although existing worldwide, examples of the use of quicklime stabilization of hydraulic embankments do not confirm concerns about the use of this technology for water-retaining soil structures. One example is the Friant-Kern canal in California, where between 1973 and 1977, eroded embankments were reclaimed using 4% quicklime. The effect proved to be permanent – after almost 50 years of constant exposure to water, traces of erosion are minimal and the need for maintenance work is low [11–14]. Another case is the flood embankments on the Mississippi River, damaged during the 1973 floods. Thanks to the use of lime, more than 150 landslides were repaired without the need to demolish the structures or supply new soil [15]. Examples of such solutions can also be found in Europe, e.g.

dry flood reservoirs in the German towns of Rems, Langenneufnach, Engelshofer Bach and Merching, where lime stabilization was used. In addition, with the participation of the Dutch technology institute Deltares, large-scale studies were conducted on the erosion resistance of soil embankments, which confirmed the significant benefits of using stabilized soil [16].

The issue of leaching of lime or other stabilizers from the soil is not widely discussed in the literature, but there are publications describing some of the effects associated with this. In the paper '*Shear strength and elastic properties of lime-soil mixtures*' [17], it was pointed out that filtering water directly affects the unfavorable change in the lime ratio and pH fluctuations in the stabilized material. It was also noted that the intensity of this phenomenon depends on the soil permeability – the lower the filtration coefficient, the smaller the fluctuations in parameters. The dissertation '*Clay mineralogy effects on long-term performance of Chemically treated expansive clays*' [18] presents studies of soil samples subjected to fourteen 24-hour water flushing cycles. The changes in pH were analysed, and the key observation was a significant reduction in the concentration of lime particles from 610 ppm to 310 ppm after the completion of all cycles. However, it should be noted that the tested soil (classified as highly compressible clay) was not additionally compacted, and its porosity coefficient was $e = 0.856$, which does not reflect the conditions found in a typical hydrotechnical embankment. In the studies described in the publication '*Evaluation of Remolded Field Samples of Lime-Cement-Fly Ash-Aggregate Mixture*' [19], the soil was compacted at an optimum moisture content and subjected to water filtration for 10 days. It was indicated that with such compacted material, only small amounts of stabilizer leached out. The conclusions from the publication '*Leachate Studies on Lime and Portland Cement Treated Expansive Clays*' [20] suggest that even if the stabilizer concentration is lost, the strength of the soil is not reduced. The manuscript '*Performance of lime-treated silty soil under long-term hydraulic conditions*' [21] comprehensively addressed the stage of preparing stabilized soil before filtration, compacting it at an optimum moisture content and leaving it for 25 days before starting the experiment. Its results indicated a decrease in shear strength in the initial period of water circulation, which depended primarily on the accuracy of compaction and permeability of the material. The time between soil compaction and the start of filtration was also crucial in this case. After 25 days, most of the lime was used up in chemical reactions, which reduced the amount of stabilizer leached out. Furthermore, the publication '*Durability and Recuperative Properties of Lime Stabilized Soils*' [22] emphasizes the critical importance of selecting an appropriate lime content relative to the soil mass, as well as the role of moisture exposure following stabilization. In parallel, the findings presented in '*Key Parameters for the Strength Control of Lime Stabilized Soils*' [23] indicate that the strength of lime-stabilized soils is governed not only by the lime content but also by the soil's porosity and its proportion relative to the amount of lime used.

The aim of the research described in this manuscript is: (1) to design and carry out an experiment allowing water to be filtered through homogeneous and compacted cohesive soil, natural or stabilized with lime, (2) to determine the strength parameters of the selected soil (cohesion and internal friction angle) before and after water filtration, (3) to determine the amount of lime leached from the tested soil samples, and (4) to determine whether there is a significant loss of lime from soil exposed to water filtration and whether this has a significant effect on its strength parameters.

2. Materials and methods

The research used cohesive soil obtained from the construction site of the Szalejów Górny flood protection reservoir (in south-western Poland), intended for use in the dam body. The approximate parameters of this soil are summarized in Table 1.

Table 1. Basic parameters of the tested soil [24–26]

Soil (clay)	**Grain size [%]**				**Plasticity index** I_P **[%]**	**Plasticity degree** I_L **[–]**	**Filtration coefficient** k **[m/s]**
	> 2	**2–0.05**	**0.05–0.002**	**< 0.002**			
Natural	19	36	26	18	19.1	0.068	$5.39 \cdot 10^{-9}$
Selected*	10	41	29	20	20.9	0.060	$3.17 \cdot 10^{-9}$

*After partial removal of fractions > 2 mm

First, in order to obtain a relatively homogeneous material, larger pebbles and stones (> 2 mm) were removed from the soil and then crushed and mixed, as shown in Fig. 1.

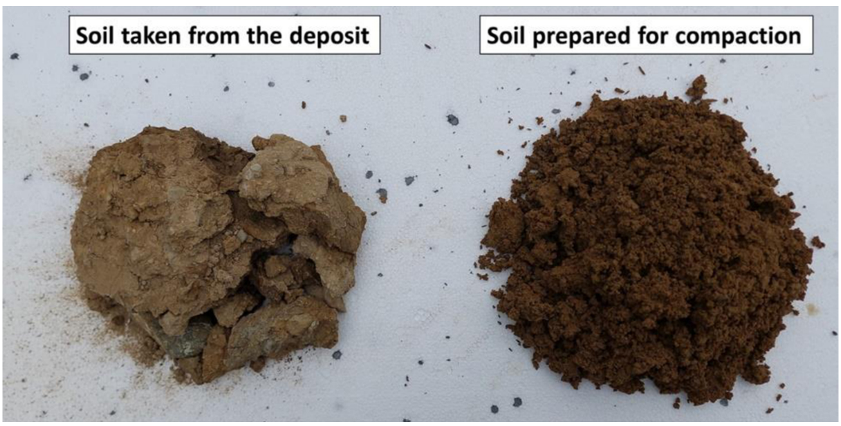

Fig. 1. Photo of the material before and after stone removal, crushing and mixing

Four containers were designed and constructed in which it was possible to intensively compact the soil, then seal them tightly and pass water through them (and thus through the soil) under high pressure, draining it in a controlled manner and collecting it for further testing. Ultimately, the analysed water samples were collected from only three containers, as the fourth (a prototype) was not equipped with a removable bottom drawer that would have allowed the lime to leach out and deposit at the bottom to be collected for testing. The water used in the experiment was also tested, and its average base lime concentration was determined to be 47.1 mg/dm^3. A drawing of the container in question is shown in Fig. 2.

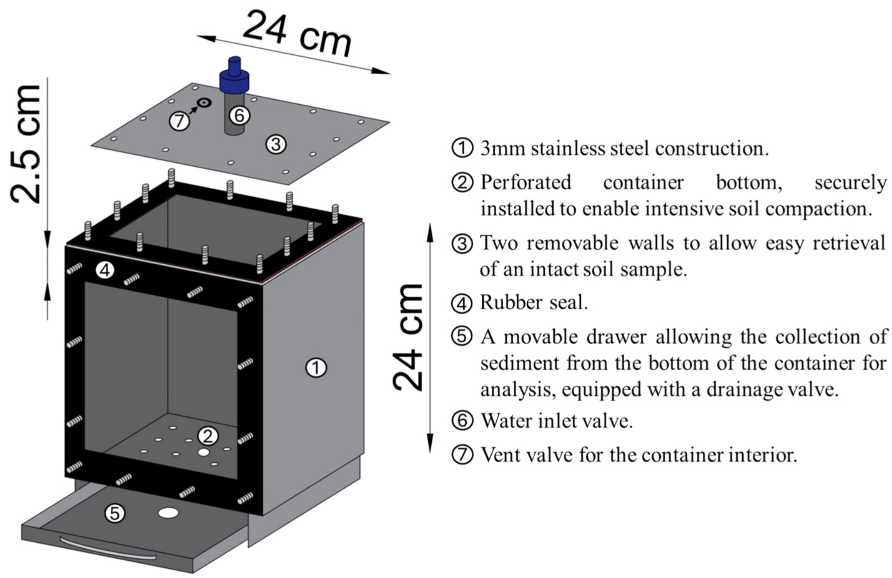

Fig. 2. The design of a container for water filtration through compacted cohesive soil

In order to ensure rational stabilization, the soil was first hydrated to a moisture content of approx. 23%, and then 2% lime (by weight) was added, mixing and grinding the material thoroughly so that the lime particles could penetrate the clay structure. The soil, brought to optimum moisture content (approx. 15% natural, approx. 18% limed) was compacted in the containers, in layers and using a pneumatic drill, to achieve a compaction index Is in the range of 0.97 to 1.01, which was determined by establishing the maximum volume density of the soil skeleton using a Proctor apparatus. This averaged 1.729 and 1.651 g/cm^3 for the natural and stabilized soil, respectively. The rest of the experiment was carried out in the period from April to September, according to the diagram shown in Fig. 3. The atmospheric conditions at this time were typical for south-western Poland, with temperatures averaging between 3 and 26°C. Therefore, there was no freezing, and in order to reduce evaporation, all elements were kept in a shaded area and care was taken to keep the filtered water tanks airtight (they were drilled and rubber water hoses were inserted). The height of the upper tanks, and thus the pressure, was set in such a way as to obtain a measurable amount of water filtered through the soil. Too-low a pressure resulted in insufficient filtration, and water slowly dripping from the soil evaporated, preventing its collection for further testing. Finally, the height difference between the containers and the tanks was set at 4.5 m. Water filtration through the soil began approximately 3 days after its compaction.

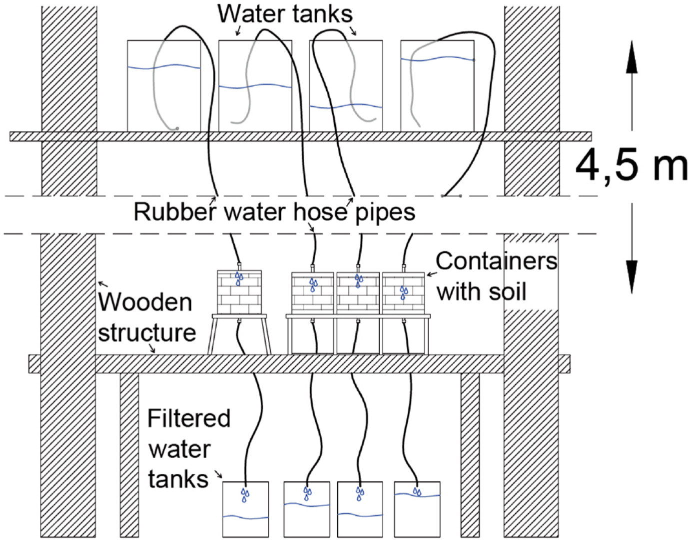

Fig. 3. Diagram of the experiment

The material was filtered for 40 days, then the water supply was cut off, the containers were opened and a soil sample with an intact structure was taken using cubic samplers measuring 15×15×15 cm. These samplers were cut appropriately to allow the extraction of an intact sample of material. The soil was left to partially dry until it reached a moisture content of approx. 11% for natural soil and 15% for stabilised soil, which was intended to reflect the partial but not complete drying of the material built into a hypothetical embankment. The samples thus prepared were placed in a SHEARMATIC 300 large-format direct shear apparatus to determine the strength parameters, i.e. cohesion and internal friction angle. Each test was carried out on 4 soil samples subjected to shear with a vertical pressure of 100, 150, 200 or 250 kPa. The following analyses were carried out:

- Testing of the strength parameters of compacted natural soil, not filtered (2 tests, 4 samples each).
- Testing of the strength parameters of compacted soil stabilized with quicklime, not filtered (2 tests, 4 samples each).
- Testing of the strength parameters of compacted natural soil, filtered (2 tests with 4 samples each).
- Testing of the strength parameters of compacted soil stabilized with quicklime, filtered (2 tests with 4 samples each).
- Testing of lime concentration in water filtered through natural soil (2 tests from 3 filtration containers, after 20 and 40 days of filtration).
- Testing of lime concentration in water filtered through soil stabilized with quicklime (3 tests from 3 filtration containers, after 15, 25 and 40 days of filtration).

3. Results and discussion

Figure 4 and Table 2 present the results obtained for natural soil, dried to a moisture content of approx. 11%, previously compacted at an optimum moisture content and not subjected to water filtration.

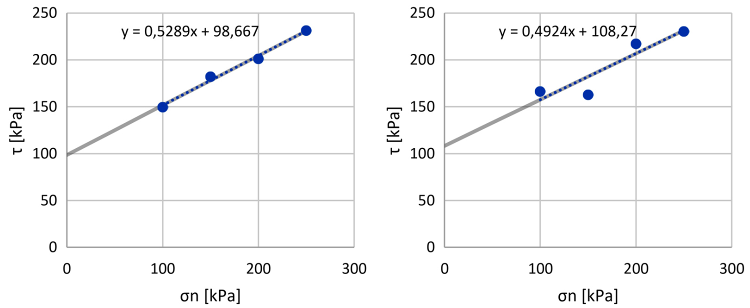

Fig. 4. Maximum shear strength τ at a given pressure σ_n for natural soil, not subjected to water filtration, tests No. 1 and 2

Table 2. Cohesion and internal friction angle values for natural soil, not subjected to water filtration

Test number	**Cohesion *c* [kPa]**	**Angle of internal friction ϕ [°]**
1	98.67	27.87
2	108.27	26.22

The results obtained allow the tested natural material (without additional stabilization) to be classified as hard plastic clay with high structural cohesion and relatively high shear strength [27, 28]. These results are the starting point for further analyses in which the same soil was stabilized or filtered.

Figure 5 and Table 3 present the results obtained for soil stabilized with quicklime (2% by weight), dried to a moisture content of approx. 15%, compacted at an optimum moisture content and not subjected to water filtration.

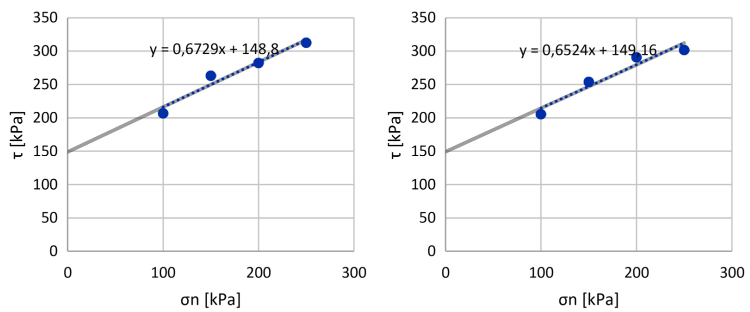

Fig. 5. Maximum shear strength τ at a given pressure σ_n for stabilised soil, not subjected to water filtration, tests No. 3 and 4

Table 3. Cohesion and internal friction angle values for stabilised soil, not subjected to water filtration

Test number	Cohesion c [kPa]	Angle of internal friction ϕ [°]
3	148.80	33.94
4	149.16	33.12

The results obtained are consistent with other studies available in the literature [8,13,29]. The cohesion of the soil increased significantly and would probably continue to increase gradually if the material were left to dry longer, allowing for longer chemical transformations and pozzolanic reactions in the clay [21,30]. An increase in the internal friction angle was also noticeable in this case, which further indicates an improvement in the strength of the material after stabilization.

Figure 6 and Table 4 show the results obtained for natural soil compacted at an optimum moisture content, subjected to water filtration for 40 days and then dried to a moisture content of approx. 11%.

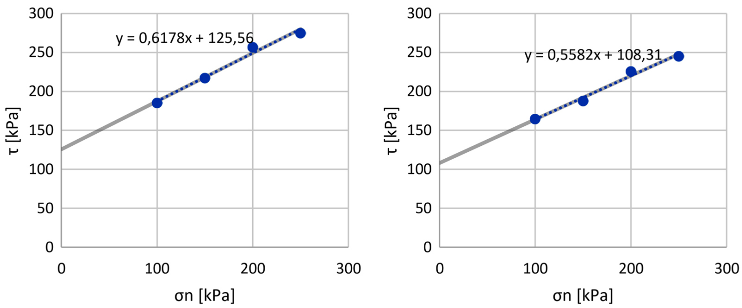

Fig. 6. Maximum shear strength τ at a given pressure σ_n for natural soil subjected to water filtration, tests No. 5 and 6

Table 4. Cohesion and internal friction angle values for natural soil subjected to water filtration

Test number	Cohesion c [kPa]	Angle of internal friction ϕ [°]
5	125.56	31.94
6	108.31	29.17

The results obtained indicate higher values of cohesion and internal friction angle for natural soil subjected to water filtration. When comparing the average values, these parameters increased by 13.01% and 11.87%, respectively. However, it should be emphasized that the results are very similar in tests No. 2 and No. 6, and the higher strength parameters for the samples in test No. 5 may result, for example, from relatively more intensive drying of the material, which in the case of cohesive soils has a significant impact on the results of tests in a direct shear apparatus [31]. In addition, the soil subjected to water filtration under high pressure pressing on the upper surface of the sample may have become further compacted, but due to the good consolidation of the material even before the flow was started, this phenomenon should not have had a significant impact on the results obtained.

Table 5 and Fig. 7 present the results of tests on the amount of lime leached from the natural soil (without lime addition). The water samples analysed were taken during test No. 5. Samples 1–3 correspond to those later placed in the direct shear apparatus with a vertical pressure of 100 kPa (sample 1), 150 kPa (sample 2) and 200 kPa (sample 3), respectively.

Table 5. Amounts of filtered water and lime leached from natural soil

Sample number	Filtration duration [days]	Volume of water filtered through the sample [dm^3]	Lime concentration in filtered water [mg/dm^3]	Amount of lime in filtered water [g]	Amount of lime leached from soil* [g]	Total amount of leached lime [g]
1	0–20	0.5	93.6	0.047	0.02	0.12
	20–40	2.25	88.3	0.199	0.09	
2	0–20	3.0	53.7	0.161	0.02	0.16
	20–40	5.0	75.5	0.378	0.14	
3	0–20	2.0	98.9	0.198	0.10	0.13
	20–40	1.8	63.3	0.114	0.03	

* The average base amount of lime in the water was subtracted – concentration 47.1 mgCa/dm^3.

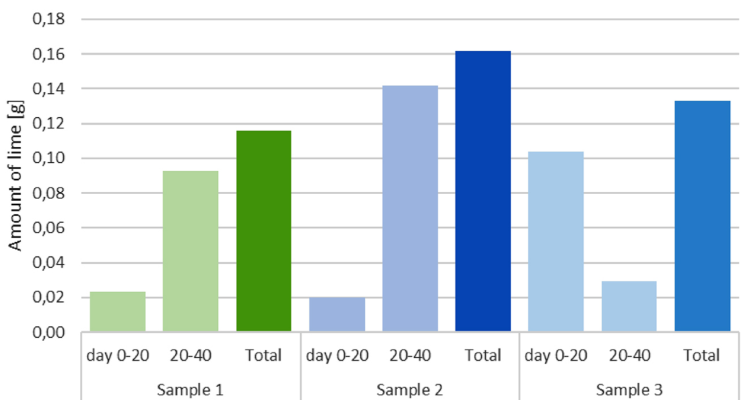

Fig. 7. Amount of lime leached from natural soil

Soil samples 1, 2 and 3 were filtered through 2.75, 8.0 and 3.8 dm^3 of water, respectively, in which the lime concentration ranged between 53.7 and 98.9 mg/dm^3. Since macroscopically homogeneous soil was used for all samples, an identical water pressure and the same compaction method were used for all samples, the difference in the amount of filtered water may result from a heterogeneous microporous structure, local microcracks, as well as disruptions or differences in the distribution of clay particles (which affects the size of pores) [27,28]. These circumstances are typical of fine-grained soils and mean that, on a laboratory scale, even small differences in microstructure can lead to noticeable differences in the amount of filtered water, even though the macroscopic parameters of the samples remain the same [5]. A similar phenomenon was reported in a study of laboratory-densified clays, where it was shown that even with identical density and sample preparation methods, microstructural differences in pore arrangement led to noticeably different air permeability values [32]. Analogous circumstances may have influenced the different concentrations of lime in the filtered water and, in addition, the lime may have formed seemingly imperceptible local clusters (aggregates), where solubilisation and leaching were more intense at different times during the experiment [33]. Subtracting the average lime concentration in the water used in the experiment (47.1 mg/dm^3), it was found that small amounts of lime were leached from the samples, i.e. 0.12, 0.16 and 0.13 g. This is most likely due to the natural occurrence of lime in the soil, mainly in the form of calcium carbonate (calcite $CaCO_3$) [27, 28]. When comparing the amount of filtered water and leached lime to the tests performed in a direct shear apparatus (test No. 5), no correlation was found between these amounts and the maximum shear strength values obtained for a given soil sample.

Figure 8 and Table 6 present the results obtained for soil stabilized with quicklime (2% by weight), compacted at an optimum moisture content, filtered with water for 40 days and then dried to a moisture content of approx. 15%.

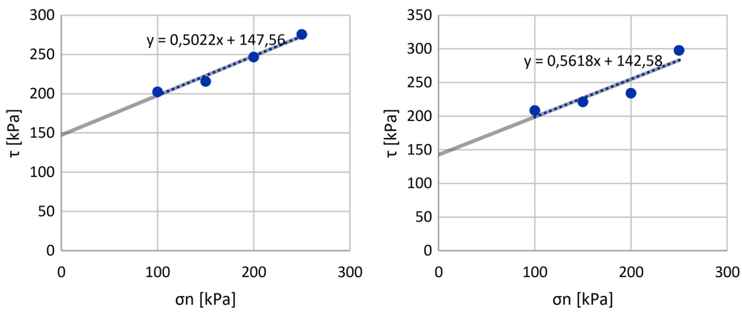

Fig. 8. Maximum shear strength values τ at a given pressure force σ_n for stabilised soil subjected to water filtration, tests No. 7 and 8

Table 6. Cohesion and internal friction angle values for stabilised soil subjected to water filtration

Test number	**Cohesion c [kPa]**	**Angle of internal friction ϕ [°]**
7	147.56	26.67
8	142.58	29.33

The results obtained indicate very similar cohesion values and slightly lower internal friction angle values for stabilized soil subjected to water filtration. When comparing the average values, these parameters were lower by 2.62% and 16.49%, respectively. Since the cohesion values should be noticeably higher approximately 50 days after stabilisation [8, 12, 29] than a few days after (as in tests No. 3 and 4), it should be concluded that complete soil hydration, filtration and partial leaching of lime caused the cessation of chemical reactions increasing the cohesion of the material. Slightly lower internal friction angle values may suggest a slight effect on the change in soil stiffness. Regardless of this, it should be noted that, in general, the soil retained its high strength parameters, in particular those related to cohesion, which may mean that despite the short period from stabilization to the start of filtration (approx. 3 days), the chemical reactions were sufficient to maintain the compact structure of the soil.

Table 7 and Fig. 9 present the results of tests on the amount of lime leached from the soil stabilized with quicklime. The water samples analysed were taken during test No. 7. Samples 1–3 correspond to those later placed in the direct shear apparatus with a vertical pressure of 100 kPa (sample 1), 150 kPa (sample 2) and 200 kPa (sample 3), respectively.

Table 7. Amounts of filtered water and lime leached from stabilised soil

Sample number	Filtration duration [days]	Volume of water filtered through the sample [dm^3]	Lime concentration in filtered water [mg/dm^3]	Amount of lime in filtered water [g]	Amount of lime leached from soil* [g]	Total amount of leached lime [g]
1	0–15	4.5	714.5	3.215	3.00	6.84
	15–25	2.0	642.5	1.285	1.19	
	25–40	5.0	575.5	2.878	2.64	
2	0–15	0.8	730.7	0.585	0.55	1.34
	15–25	0.25	557.9	0.139	0.13	
	25–40	2.0	380.8	0.762	0.67	
3	0–15	0.8	737.4	0.590	0.55	5.31
	15–25	0.7	639.4	0.448	0.41	
	25–40	5.0	915.4	4.577	4.34	

* The average base amount of lime in the water was subtracted – concentration 47.1 mgCa/dm^3.

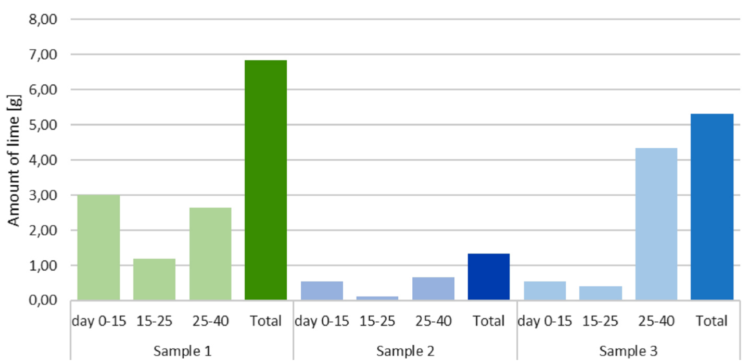

Fig. 9. Amounts of lime leached from stabilised soil

Soil samples numbered 1, 2 and 3 were filtered through 11.5, 3.05 and 6.5 dm^3 of water, respectively, in which the lime concentration ranged from 380.8 to 915.4 mg/dm^3. The difference compared to the concentrations determined for water filtered through natural soil is therefore clear. In line with other studies, the permeability of limed soil is slightly higher [12], which in the short term after stabilization may be characterized by a higher filtration coefficient, gradually decreasing a long time after the addition of lime [21]. An intensification of filtration over time is also noticeable, with the highest amounts of filtered water recorded for all samples between 25 and 40 days. This may be due to the fact that lime particles moving with the water lead to the formation of additional water flow paths, and filtration may also lead to internal erosion of the material, expanding the pores and creating microchannels that further increase the permeability of the soil [27, 28]. Subtracting the average lime concentration in the water used in the experiment (47.1 mg/dm^3), it was found that significant amounts of lime were leached from the samples, i.e. 6.84, 1.34 and 5.31 g. Due to the relatively short period of time between soil compaction and the start of filtration (approx. 3 days), it is most likely that some of the quicklime failed to convert into the insoluble form of calcium hydroxide $Ca(OH)_2$, and leaving the samples to dry for longer could have resulted in a reduction in the amount of stabilizer leached out [21, 30]. Furthermore, when comparing the amount of filtered water and leached lime to the tests in the direct shear apparatus (test No. 7), despite a significant difference between the amount of lime leached from samples 2 and 1 compared to 3, no correlation was found between these amounts and the maximum shear strength values obtained for a given soil sample. The results are close to the trend line, with no significant deviations that could be related to the difference in the amount of stabilizer lost. Fig. 10 shows a graph comparing the average amounts of water filtered and lime washed, as well as the results of cohesion and angle of internal friction for the different research variants, taking into account the differences between these values.

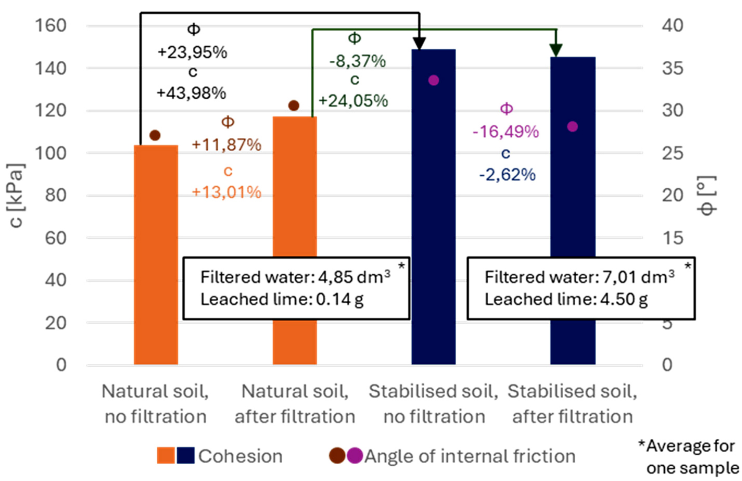

Fig. 10. Summary of the average results for the different research variants

When discussing the results obtained, it should first be noted that they were obtained for a specific variant of the experiment, taking into account the specified initial conditions and input parameters. There are many possibilities for modifying the tests in question, including:

- Using a different type of soil with a different grain size distribution.
- Increasing or decreasing the dose of quicklime.
- Reducing the initial soil compaction.
- Changing the length of time between soil compaction and the start of filtration.
- Changing the length of the water filtration period.
- Changing the moisture content of the soil samples being tested, e.g. drying them more thoroughly.
- Using cycles that include alternating periods of filtration and no filtration.
- Conducting additional laboratory tests, e.g. in a triaxial shear apparatus.

It is also important to emphasize that the experiment used high water pressure resulting from the height of the water gauge (4.5 m) and a long filtration time (40 days), which is not typical for embankments such as flood protection embankments or dry reservoir dams. The lack of significant changes in the strength parameters demonstrated in the experiment may suggest that under milder initial conditions occurring for the structures mentioned in the previous sentence, there is no risk associated with the use of lime-stabilized soil for their formation. In the case of high embankments that constantly accumulate water, such as retention reservoirs, this risk may not be significant either, but in this case, it would be advisable to carry out tests similar to those described in this article, taking into account the initial conditions and parameters corresponding to the design assumptions of the structure in question.

4. Summary

A comparative analysis of the influence of water filtration on the strength parameters of natural and lime-stabilized soil (2% by weight) was carried out. In the described experiment, the results indicated that the tested soil, even in its natural form after compaction, was characterized by high structural cohesion and shear strength, as evidenced by the cohesion parameters (average 103.47 kPa) and internal friction angle (average 27.05°). As a result of water filtration through the natural soil, in relation to its original parameters, there was an average increase of 13.01% (cohesion) and 11.87% (internal friction angle), which may result from the problem of achieving identical soil moisture in each test or additional compaction of the material as a result of water pressure. Between 2.75 and 8.0 dm^3 of water was filtered through each sample, with low lime concentrations in the recovered water, ranging between 53.7 and 98.9 mg/dm^3 (with an average base concentration of the water used equal to 47.1 $mgCa/dm^3$). No correlation was found between the amounts of filtered water and the maximum shear strength values obtained for a given natural soil sample.

After the soil was stabilized with lime, both analysed parameters increased – cohesion averaged 148.98 kPa and internal friction angle 33.53°. As a result of water filtration through stabilized soil, in relation to its original parameters, the increase in cohesion (which should occur when the soil is left to dry) was inhibited and the average internal friction angle decreased by 16.49%, indicating the possibility of a slight reduction in the stiffness of the soil skeleton. Between 3.05 and 11.5 dm^3 of water was filtered through the individual samples, and the lime concentrations in the recovered water ranged between 380.8 and 915.4 mg/dm^3 (with an average base concentration of the water used equal to 47.1 $mgCa/dm^3$). The large amount of leached lime may result from the fact that the water filtration was started relatively soon after stabilization (approx. 3 days), which is related to the disruption of ongoing chemical reactions and a higher filtration coefficient. Regardless of this circumstance, it should be noted that the material retained its high strength. No correlation was found between the amount of lime leached and the maximum shear strength values obtained for a given soil sample.

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Studia nad wpływem filtracji wody na parametry wytrzymałościowe gruntu stabilizowanego wapnem palonym

Słowa kluczowe: filtracja wody, hydrotechnika, stabilizacja wapnem, wytrzymałość gruntu

Streszczenie:

Stabilizacja wapnem palonym gruntów spoistych, przeznaczonych do zabudowy w nasypy piętrzące wodę, nie jest technologią popularną w branży hydrotechnicznej. Wiąże się to z potencjalnym wypłukiwaniem wapna z konstrukcji ziemnej, a tym samym obniżenie wytrzymałości użytego materiału.

Zaprojektowano i wykonano eksperyment polegający na wymuszeniu przepływu przez grunt spoisty, zagęszczony przy wilgotności optymalnej. Dokonano pomiaru stężenia wapna w przefiltrowanej wodzie, na podstawie czego określono ilość wypłukanego stabilizatora. Parametry wytrzymałościowe gruntu ustalono w oparciu o badanie w wielkoformatowym aparacie bezpośredniego ścinania. Już w formie naturalnej badany grunt cechował się wysoką kohezją (średnio 103,47 kPa) i kątem tarcia wewnętrznego (średnio 27,05°). W wyniku filtracji wody odnotowano nieznaczny średni wzrost tych parametrów o 13,01% (kohezja) i 11,87% (kąt tarcia wewnętrznego). Przez poszczególne próbki przefiltrowano od 2,75 do 8,0 dm^3 wody, a stężenia wapna były niewielkie – między 53.7, a 98.9 mg/dm^3. Po stabilizacji gruntu wapnem nastąpił wzrost obu analizowanych parametrów – kohezja wynosiła średnio 148,98 kPa, kąt tarcia wewnętrznego 33,53°. W wyniku filtracji wody przez grunt stabilizowany nastąpiło zahamowanie wzrostu kohezji i spadek średniego kąta tarcia wewnętrznego o 16,49%. Przez poszczególne próbki przefiltrowano od 3,05 do 11,5 dm^3 wody, a stężenia wapna wynosiły między 380.8, a 915.4 mg/dm^3. Niezależnie od tej okoliczności należy stwierdzić, że materiał zachował swoją wysoką wytrzymałość. Nie wykazano korelacji między ilością wypłukanego wapna, a wartościami maksymalnej siły ścinającej uzyskanymi dla danej próbki gruntu. Mimo wysokiego ciśnienia wody (4,5 m słupa cieczy), długiego czas filtracji (40 dni) i krótkiego okresu od zagęszczenia do rozpoczęcia przepływu (ok. 3 doby) – badania nie potwierdziły ryzyka znacznego obniżenia parametrów wytrzymałościowych gruntu stabilizowanego wapnem w wyniku oddziaływania wody.

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