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THE INFLUENCE OF ALKALIES ON THE PERMEABILITY TO WATER OF COMPACT SOILS

WPŁYW ALKALIDÓW NA WODOPRZEPUSZCZALNOŚĆ GRUNTÓW SPOISTYCH

The consolidation analysis of filtration coefficients of a selected fine clayey soil and mixtures of clayey soil with calcium, potassium and sodium hydroxides is discussed in this paper. The influence of such chemical additives on soil permeability on a time-scale is described and quantified. The consolidation-modulus of compressibility was determined for soil and mixtures with chemical additions. The influence of unitary loads on the filtration characteristics of the original selected soil and its mixtures with selected chemical compounds content was established.

Key words: compact soils, alkalies, mixtures, water permeability

W publikacji opisano edometryczne badania współczynników filtracji wyselekcjonowanego drobnoziarnistego gruntu ilastego oraz mieszanin tego gruntu z domieszkami wodorotlenków wapnia, potasu i sodu. Scharakteryzowano działanie zastosowanych dodatków chemicznych na zmiany wodoprzepuszczalności gruntu w czasie. Wyznaczono edometryczne moduły ściśliwości gruntu i mieszanin z dodatkami chemicznymi. Określono wpływ obciążeń jednostkowych na zmiany współczynników filtracji gruntu rodzimego oraz jego mieszanin z wybranymi związkami chemicznymi.

Do badań laboratoryjnych wyselekcjonowano grunt spoisty, dla którego, po wykonaniu analizy sitowej, otrzymano wykres uziarnienia (rys. l). Na podstawie analizy granulometrycznej oraz uzyskanej charakterystyki uziarnienia, zaliczono wyselekcjonowany grunt do grupy gruntów odpowiednich do budowy gruntowych wykładzin mineralnych (Pisarczyk 2000). Spełnienie kryterium uziarnienia czyniło uzasadnionym przeprowadzenie badań laboratoryjnych dla wyznaczenia współczynnika filtracji gruntu.

Współczynniki filtracji gruntu rodzimego określono metodą edometryczną, stosowaną do gruntów spoistych. Wartości współczynników filtracji, dla początkowego spadku hydraulicznego $i = 30$, obliczono ze wzoru (3) (Pisarczyk 1999; Wiłun 2000). Otrzymane wyniki przeliczono według wzoru (2) na zredukowane wartości współczynników filtracji k_{10}.

Wykresy zmian współczynników filtracji od obciążeń jednostkowych przedstawiono na rysunkach 2 i 3, a graniczne wartości liczbowe zamieszczono w tablicy l.

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Na skutek braku efektywnego oddziaływania w sposób mechaniczny na obniżenie wodoprzepuszczalności badanego gruntu podjęto próby oddziaływania na ten grunt środkami chemicznymi.

W celu określenia wpływu niektórych środków chemicznych na właściwości filtracyjne wybranego gruntu ilastego przygotowano trzy próby mieszanin gruntu rodzimego z 0,5-procentowymi domieszkami w stosunku wagowym do gruntu: wodorotlenku wapnia $Ca(OH)_2$, wodorotlenku potasu — KOH oraz wodorotlenku sodu NaOH. Po upływie doby od sporządzenia mieszanin poddano je edometrycznemu wyznaczaniu współczynników filtracji w sposób analogiczny jak dla próby gruntu rodzimego. Przebiegi zmian wartości współczynników filtracji od obciążeń jednostkowych zobrazowano graficznie w postaci wykresów na rysunku 2, a graniczne wartości współczynników zestawiono w tablicy 1.

Zadanie gruntu ilastego środkami chemicznymi powoduje zainicjowanie procesów z minerałami zawartymi w tym gruncie. Efektem tych procesów są zmiany w strukturze wewnętrznej gruntu, w wyniku czego zmieniają się jego właściwości fizyczne. Istotnym zagadnieniem jest stabilność zachodzących zmian właściwości modyfikowanego gruntu w funkcji czasu. Aby odpowiedzieć na pytanie, jaki wpływ ma czynnik czasu na zmiany zachodzące w gruncie na skutek działania zastosowanych domieszek środków chemicznych oraz czy zaobserwowane zmiany współczynników filtracji mają charakter stabilny czy też podlegają modyfikacjom wraz z upływem czasu powtórzono laboratoryjne badania współczynników filtracji po odpowiednim przygotowaniu uprzednio przebadanych mieszanin.

W celu przyspieszenia zachodzących w gruncie reakcji chemicznych i zminimalizowania czasu oczekiwania na zakończenie ich trwania, uprzednio opisane mieszaniny gruntu z domieszkami chemicznymi poddano wygrzewaniu w temperaturze 353 K (80°C), ze stałym nawilżaniem, przez okres 12 dni, a następnie określono, w sposób analogiczny jak poprzednio, wartości współczynników filtracji badanych mieszanin. Wyniki badań przedstawiono w sposób graficzny na rysunku 3, a wartości liczbowe współczynników filtracji dla granicznych obciążeń jednostkowych zestawiono w tablicy 1.

Reakcje jakie zachodziły w gruncie na skutek oddziaływania $Ca(OH)_2$ w sposób krótkotrwały spowodowały obniżenie wodoprzepuszczalności mieszaniny, po czym została praktycznie przywrócona pierwotna drożność dla przepływu wody, a efekty działania wprowadzonego do gruntu dodatku wodorotlenku wapnia przestały być widoczne. Stwierdzono natomiast zmniejszenie wartości współczynników filtracji w zależności od obciążeń jednostkowych w mieszaninie gruntu z KOH oraz wzrost wartości współczynników filtracji w mieszaninie gruntu z NaOH w porównaniu do analogicznych wartości uzyskanych w badaniach po upływie jednej doby od sporządzenia tych mieszanin (rys. 2 i 3).

Próbę wytłumaczenia zmian wodoprzepuszczalności mieszanin gruntu ze środkami chemicznymi podjęto na podstawie wyników badań ściśliwości po upływie doby od sporządzenia mieszanin (rys. 4) oraz po upływie 12 dni obróbki termicznej prób (rys. 5). Wartości liczbowe edometrycznych modułów ściśliwości pierwotnej obliczono według wzoru (4) (Myślińska 1998; Pisarczyk 1999; Wiłun 2000). Wyniki obliczeń zamieszczono w tablicy 2.

W efekcie przeprowadzonych badań stwierdzono, że wzrost stopnia zagęszczenia badanego gruntu na skutek zwiększania obciążeń jednostkowych nie powoduje efektywnego zmniejszania jego współczynnika filtracji, zaobserwowano natomiast istotny wpływ zastosowanych alkalicznych domieszek chemicznych na mikrostrukturę badanego gruntu rodzimego.

Słowa kluczowe: grunty spoiste, alkalia, mieszaniny, wodoprzepuszczalność

Symbols

a — cross-sectional area of a glass pipe [m^2],

A — cross-sectional area of a soil sample [m^2],

d — equivalent grain diameter [mm],

h_1 — height of water column at beginning of permeability test [m],

h_2 — height of water column at termination of permeability test [m],

i — hydraulic drop [ratio],

k — filtration coefficient [m/s],

l — height of soil sample [m],

k_{10}— reduced filtration coefficient [m/s],

k_T — filtration coefficient at temperature T [m/s],

M_o— primary compressibility modulus [Pa],

t_1 — time of beginning of permeability test [s],

t_2 — time of termination of permeability test [s],

T — temperature [K],

v — water flow rate [m/s],

ε — relative unitary deformation of a sample [ratio],

σ — set load on a sample [Pa],

$\Delta\sigma$— increase of set load on a sample [Pa].

1. Introduction

Water permeability is one of the most significant parameters affecting decisions about the suitability of soil for construction purposes, e.g. mineral sealing lining (Pisarczyk 2000).

The permeability of soil to water can be measured by its filtration coefficient. Darcy's equation expresses the relationship between the flow rate and the hydraulic drop in compliance with the following formula. (Jarosz 1996; Myślińska 1998; Pisarczyk 1999; Wieczysty 1982; Wiłun 2000):

$$v = k\ i\ [\text{m/s}] \qquad (1)$$

The filtration coefficient for compact soils to be used for mineral sealing linings is $k < 10^{-9}$ m/s (Pisarczyk 2000).

As the filtration coefficient depends on temperature, the filtration coefficient k_{10} was determined using reduced water temperature conditions 283 K, (i.e. 10°C) from the formula below (Pisarczyk 1999; Wiłun 2000):

$$k_{10} = \frac{k_T}{0.7 + 0.03T}\ [\text{m/s}] \qquad (2)$$

A compact soil was selected, for which a granulation plot was worked out on the basis of a sieve analysis (Fig. 1). The sandy, dust and clayey fractions constituted up to 98.71% of the soil analysed. The equivalent diameter $d < 0.075$ mm was 64.81%, whereas the gravel fraction was 1.29% and the diameter of its largest grains did not exceed 10 mm.

Based on the grain-size analysis and the plot obtained (Fig. 1), the selected soil was classified as suitable for making mineral linings (Pisarczyk 2000).
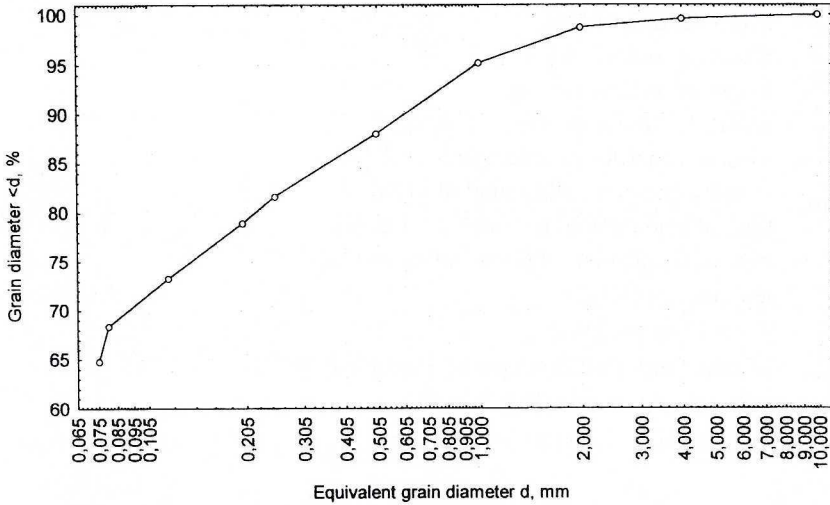
Fig. 1. Chart of soil grain size

Rys. 1. Wykres uziarnienia gruntu

With the granulation criterion satisfied, laboratory tests were conducted to determine the filtration coefficient for the soil.

2. Determination of filtration coefficient for source soil

The filtration coefficients for the original soil were determined by consolidation tests used for compact soils. The filtration coefficients for an initial hydraulic drop $i = 30$ were calculated from the formula (Pisarczyk 1999; Wiłun 2000):

$$k = \frac{al}{A(t_2 - t_1)} \ln \frac{h_1}{h_2} \, [\text{m/s}] \tag{3}$$

The obtained results were re-calculated with the use of the formula (2) for reduced filtration coefficients k_{10}.

In the course of tests, unitary loads exerted on soil samples were increased from 0.0125 MPa to 0.2 MPa (in line with principles governing the consolidation tests) (Myślińska 1998; Pisarczyk 1999; Wiłun 2000). Thus the plot of reduced filtration coefficient trends in the function of unitary loads was obtained (Figs. 2 and 3, line 1). The boundary values of the filtration coefficient in the range of unitary loads analysed are listed in Table 1.

As the soil became progressively compacted, the filtration coefficient changed almost linearly (Figs. 2 and 3, line 1), and the boundary values were $k_{10} = 4.52 \cdot 10^{-6}$ m/s under a unitary load $\sigma = 0.0125$ MPa and $k_{10} = 3.42 \cdot 10^{-6}$ m/s under $\sigma = 0.2$ MPa, respectively.
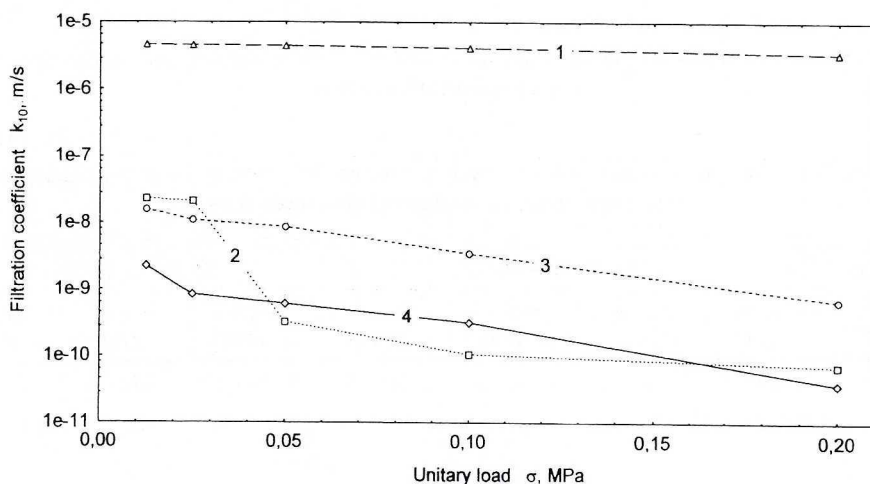
Fig. 2. Patterns of filtration coefficients as a function of unitary loads (test 24 hours after making the mixtures)

1 — original soil, 2 — original soil + Ca(OH)$_2$, 3 — original soil + KOH, 4 — original soil + NaOH

Rys. 2. Zależność zmian współczynników filtracji od obciążeń jednostkowych (badanie po 1 dniu od sporządzenia mieszanin)

1 — grunt rodzimy, 2— grunt rodzimy + Ca(OH)$_2$, 3 — grunt rodzimy + KOH,
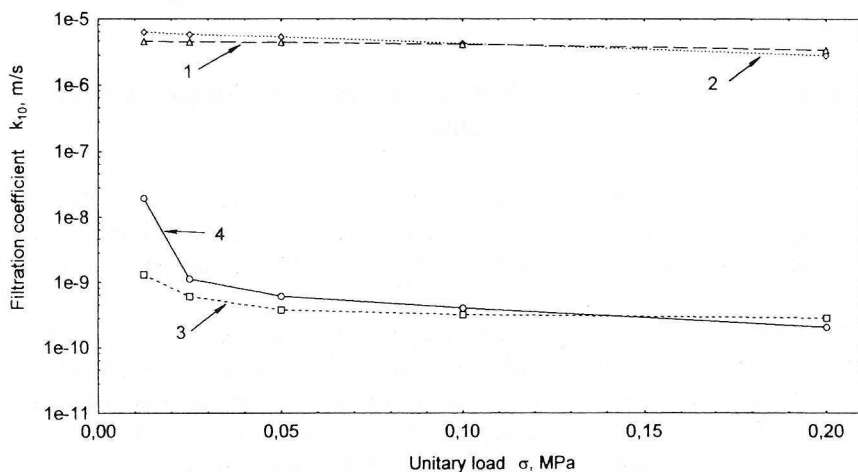4 — grunt rodzimy + NaOH

Fig. 3. Patterns of filtration coefficients as a function of unitary loads (test 12 days after making the mixtures)

1 — original soil, 2 — original soil + Ca(OH)$_2$, 3 — original soil + KOH, 4 — original soil + NaOH

Rys. 3. Zależność zmian współczynników filtracji od obciążeń jednostkowych (badanie po 12 dniach od sporządzenia mieszanin)

1 — grunt rodzimy, 2— grunt rodzimy + Ca(OH)$_2$, 3 — grunt rodzimy + KOH,
4 — grunt rodzimy + NaOH

List of boundary values of reduced filtration coefficients k_{10} for source soil and soil mixtures with chemical additives [m/s]

Zestawienie granicznych wartości zredukowanych współczynników filtracji k_{10} gruntu rodzimego oraz mieszanin gruntu ze środkami chemicznymi [m/s]

Unitary load σ [MPa]	Test after 24 hrs				Test after 12 days		
	Original soil	Soil + + Ca(OH)$_2$	Soil + + KOH	Soil + + NaOH	Soil + + Ca(OH)$_2$	Soil + + KOH	Soil + + NaOH
0.0125	4.52e − 6	2.31e − 8	1.58e − 8	2.24e − 9	6.29e − 6	1.32e − 9	1.97e − 8
0.2	3.42e − 6	7.13e − 11	6.79e − 10	3.75e − 11	2.82e − 6	2.84e − 10	2.05e − 10

The coefficients of filtration for the original soil were too great and the soil was judged to be unsuitable for construction purposes without any pre-treatment (Pisarczyk 2000).

The influence of compression loads on the filtration coefficient of the analysed soil was small. The consolidation method did not suffice to lower the permeability of the original soil to water sufficiently, even if considerable loads were applied.

In the lack of an efficient mechanical consolidation method to lower water permeability, attempts were made to treat the clayey soil with chemicals.

3. Analysis of filtration coefficients for original soil samples with chemical additions

To determine the influence of some chemicals on the filtration properties of the selected clayey soil, there three samples of mixed soils with 0.5% admixtures (wt.): calcium hydroxide Ca(OH)$_2$, potassium hydroxide KOH and sodium hydroxide NaOH were prepared.

After 24 hrs the mixture was subjected to consolidation tests and filtration coefficients were determined in a similar way as for the original soil samples.

The patterns of filtration coefficients as a function of applied loads are represented graphically in Fig. 2, and the boundary coefficients given in Table 1.

Although small quantities all chemical additives were present, the filtration coefficients for the mixtures were lower than for the original soil. The least change was observed for soil with potassium hydroxide (Fig. 2, curve 3). The filtration coefficient declined to $k_{10} = 1.58 \cdot 10^{-8}$ m/s for $\sigma = 0.0125$ MPa to $k_{10} = 6.79 \cdot 10^{-10}$ m/s for $\sigma = 0.2$ MPa (Table 1). Larger changes were observed for soils with calcium hydroxide (Fig. 2, curve 2) $k_{10} = 2.31 \cdot 10^{-8}$ m/s for $\sigma = 0.0125$ MPa to $k_{10} = 7.13 \cdot 10^{-11}$ m/s for $\sigma = 0.2$ MPa, and with sodium hydroxide (Fig. 2, curve 4) $k_{10} = 2.24 \cdot 10^{-9}$ m/s for $\sigma = 0.0125$ MPa to $k_{10} = 3.75 \cdot 10^{-11}$ m/s for $\sigma = 0.2$ MPa (Table 1).

A diversified influence of the consolidation processes on the filtration coefficient was observed, depending on the chemical additive used. For original soil with KOH and NaOH, the filtration coefficient changed under the loads almost linearly (Fig. 2, curves 3 and 4). For soils with $Ca(OH)_2$ (Fig. 2, curve 2) the change was negligible with loads ranging from 0.0125 to 0.025 MPa. When the load was increased by 0.05 MPa, the coefficient's value fell drastically, and when this value was exceeded, the filtration coefficient was observed to stabilise.

The filtration coefficient for the mixtures was lower than the required value for a mineral sealing lining (Pisarczyk 2000): for soils with sodium hydroxide — over $\sigma = 0.025$ MPa (Fig. 2, curve 4), with calcium hydroxide — over $\sigma = 0.05$ MPa (Fig. 2, curve 2), with potassium hydroxide — over $\sigma = 0.2$ MPa (Fig. 2, curve 3). The smallest effect on the permeability was observed in the case of KOH. whereas the strongest impact was observed for NaOH and $Ca(OH)_2$ admixtures. After introducing chemicals to the clayey soils, interactions with the minerals of which the original soil was made were stimulated. The soil's inner structure and its physical properties changed. The most important consideration here was the stability of changes taking place in the modified soil as a function of time.

4. Analysis of filtration coefficient for soil mixtures with chemical additions over time

Laboratory measurements of filtration coefficients were repeated after prior pre-paration of the mixtures. The purpose of this was to examine how the changes in the chemically treated soils progressed as time elapsed and whether the chemical additives produced a stabilised filtration coefficient.

To accelerate the chemical reactions taking place in the soil and minimize their duration time, the soil mixtures with chemical additives were exposed to low--temperatures 353 K (80°C) and constant wetting for 12 days. The filtration coefficient was then determined in a similar way as in the first experiment. The results are presented graphically in Fig. 3 (curves 2, 3 and 4) and the respective figures are listed in Table 1. To enable comparative studies, the plot of filtration coefficients for original soil as a function of loadings was plotted (curve 1).

The analysis of the results shows significant changes in the filtration coefficients for mixtures as compared to the data for original soil. The filtration coefficient for soils with calcium hydroxide (Fig. 3, curve 2) increased to the level of the original soil (Fig. 3, curve 1). This signifies that both reactions taking place under the influence of $Ca(OH)_2$ caused a short-term lowering of the water permeability of the mixture. Then the original permeability returned, and the influence of the calcium hydroxide ceased.

Similar effects with additions of potassium hydroxide (Fig. 3, curve 3) and of sodium hydroxide (Fig. 3, curve 4) on the filtration properties of soil mixtures were observed. The filtration coefficients obtained for the mixed samples (24 hrs after mixing) changed considerably (Fig. 2, Table 1). Filtration coefficients obtained after 12 days were

comparable: $k_{10} = 1.32 \cdot 10^{-9}$ m/s for $= 0.0125$ MPa to $k_{10} = 2.84 \cdot 10^{-10}$ m/s for $\sigma = 0.2$ MPa for soil with KOH admixture, and $k_{10} = 1.97 \cdot 10^{-9}$ m/s for $\sigma = 0.0125$ MPa to $k_{10} = 2.05 \cdot 10^{-10}$ m/s for $\sigma = 0.2$ MPa for soil with NaOH admixture (Table 1). When the loads exceeded $\sigma = 0.05$ MPa, the filtration coefficient for both mixtures stabilised for $k_{10} \in [10^{-10}; 10^{-9}]$ m/s, i.e. below the permissible value for a mineral sealing lining (Pisarczyk 2000).

The filtration coefficients fell under the set loads in soil with KOH, and increased in soils with NaOH. This was compared to the analogous values obtained 24 hrs. from making up the mixture (Figs. 2 and 3, Table 1).

5. Compressibility tests on source soil and its mixtures with chemical additives

The interpretation of permeability trends in the chemically treated soil mixtures was based on the results of compressibility tests 24 hrs after making the mixture (Fig. 4) and 12 days of thermal treatment (Fig. 5).

The primary compressibility moduli were calculated from the formula (Myślińska 1998; Pisarczyk 1999; Wiłun 2000):

$$M_o = \frac{\Delta\sigma}{\varepsilon}, \text{ Pa} \tag{4}$$
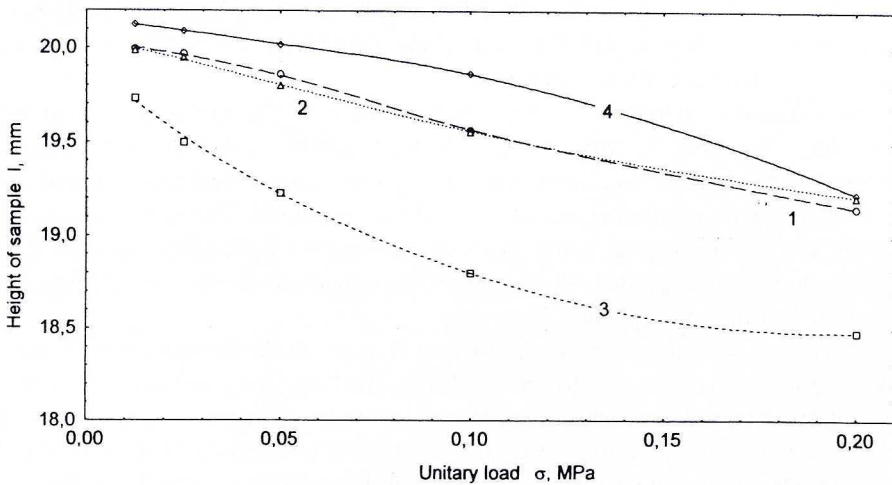
The results of calculations are given in Table 2.

Fig. 4. Curves of soil compressibility (test after 24 hours from making the mixtures)
1 — original soil, 2 — original soil + Ca(OH)$_2$, 3 — original soil + KOH, 4 — original soil + NaOH

Rys. 4. Krzywe ściśliwości gruntu (badanie po 1 dniu od sporządzenia mieszanin)
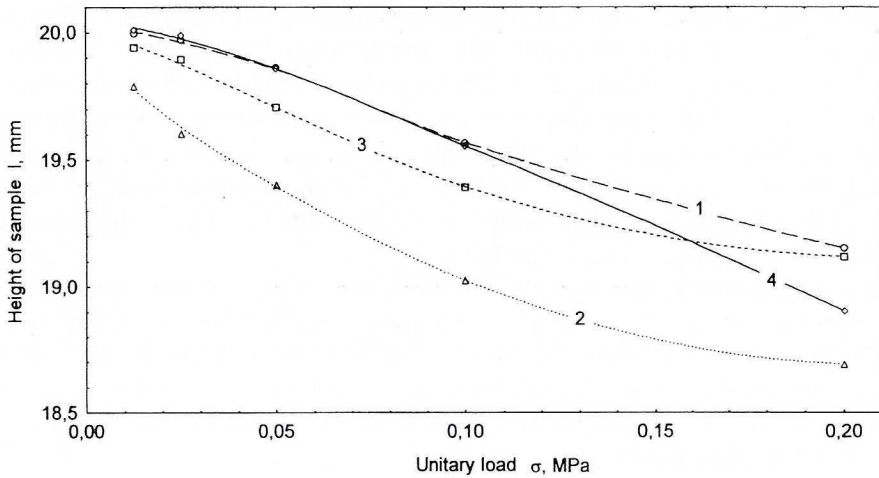1 — grunt rodzimy, 2 — grunt rodzimy + Ca(OH)$_2$, 3 — grunt rodzimy + KOH,
4 — grunt rodzimy + NaOH

Fig. 5. Curves of soil compressibility (test after 12 days from making the mixtures)
1 — original soil, 2 — original soil + $Ca(OH)_2$, 3 — original soil + KOH, 4 — original soil + NaOH

Rys. 5. Krzywe ściśliwości gruntu (badanie po 12 dniach od sporządzenia mieszanin)
1 — grunt rodzimy, 2— grunt rodzimy + $Ca(OH)_2$, 3 — grunt rodzimy + KOH,
4 — grunt rodzimy + NaOH

TABLE 2

List of primary compressibility moduli M_o for source soil and soil mixtures with chemical additives [MPa]

TABLICA 2

Endometryczne moduły ściśliwości pierwotnej M_o gruntu rodzimego oraz mieszanin gruntu ze środkami chemicznymi [MPa]

Applied load σ [MPa]	After 24 hrs				After 12 days		
	Original soil	Soil + + $Ca(OH)_2$	Soil + + KOH	Soil + + NaOH	Soil + + $Ca(OH)_2$	Soil + + KOH	Soil + + NaOH
0.0125—0.025	9.61	6.84	1.07	6.71	1.33	5.19	11.63
0.025—0.05	4.62	3.38	1.81	7.02	2.42	2.66	3.81
0.5—0.1	3.37	4.07	2.25	6.65	2.59	3.15	3.27
0.1—0.2	4.73	5.68	5.85	3.11	5.69	7.08	3.01

Original soil + 0.5% $Ca(OH)_2$

It follows from the data obtained that the primary compressibility moduli for the original soil were comparable, therefore the compressibility curve for soil with

a Ca(OH)$_2$ addition (Fig. 4, curve 2) nearly overlapped the respective curve for original soil (Fig. 4, curve 1). In consolidation/settlement tests the initial height was reduced by ca. 4.23% for soil sample, and by ca. 3.92% for soil with Ca(OH)$_2$ admixture under a set load of 0.2 MPa. Despite the similar course of the consolidation/settlement test, the filtration coefficients significantly varied for soil and soil mixtures (Fig. 2, curves 1 and 2, Table 1). The considerable lowering of the water permeability of soil with Ca(OH)$_2$ admixture was not due to the sample consolidation but to the influence of calcium hydroxide on the clayey minerals.

Calcium hydroxide caused partial dehydration of the clayey components of the soil. The increasing volume of water bound by clayey minerals enhanced the soil-con-solidation processes. The change of compressibility of soil with an alkaline substance [Ca(OH)$_2$] was mainly caused by the removal of water from clayey soils under load.

Under the influence of Ca(OH)$_2$, hydrated calcium silicates were formed. They cemented the grains together.

Quite a different trend was obtained for such soils after 12 days of thermal treatment (Fig. 5, curve 2). The compressibility moduli of the mixture were significantly lower than in the first test (Table 2) which tends to a greater degree of compaction under greater loads. The lowering of the initial height of the sample under the final load $\sigma = 0.2$ MPa was 6.54%, i.e. 1.67 times larger than the untreated sample. Such big changes in the consolidation intensity of the sample analysed may be evidence of such states as increased porosity of the mixture. Bigger loads exerted on the sample resulted in the closing of free spaces in the soil and higher consolidation.

The filtration properties of the mixture were nearly restored to the original state of the source soil (Fig. 3, curves 1 and 2, Table 1). Filtration coefficients of the mixture were slightly higher than for the source soil under small loads, when the pores were not reduced, and at slightly higher loads (over 0.1 MPa) when the flow-capacity in the soil was reduced.

Original soil + 0.5% KOH

Comparing of low compressibility moduli for the mixture and the analogous data for the original soil (Table 2), the consolidation intensity of the mixture (Fig. 4, curve 3) increased in comparison to its source counterpart (Fig. 4, curve 1) when treated with potassium hydroxide. The lowering of the initial height of the sample was ca. 7.5% under the final load $\sigma = 0.2$ MPa.

Incorporation of low-hydration energy clayey cations K$^+$ led to the removal of water from the porous spaces. This resulted in the reduction of the molar volume of the substance. Compaction of the clayey minerals caused profound changes in the porous system of the mixture.

As a result of increased loads, the free spaces in the soil were deformed and the permeability dropped (Fig. 2, curve 3).

After re-testing 12 days later, a significant lowering of the consolidation intensity was observed as compared to the thermally untreated sample. The original height of the

sample was reduced by ca. 4.4% under the final set load $\sigma = 0.2$ MPa, i.e. 1.7 times less than in the case of the sample tested after 24 hrs. This may signify that compounds were formed. They then filled the free spaces and lowered the consolidation intensity of the soil. The structure was sealed and water-permeability stabilised in a narrow range of filtration coefficient values (Fig. 3, curve 3, Table 1), similar to the state before thermal treatment (Fig. 2, curve 3, Table 1).

Original soil + 0.5% NaOH

After treating original soil with sodium hydroxide, the clayey materials started to swell. A graphical representation of the swelling processes was obtained on the compressibility plot (Fig. 4, curve 4). In the course of the consolidation tests, the maximum increase of initial height of the sample by ca. 0.06% under a set load of $\sigma = 0.0125$ MPa was obtained. The swelling of the soil mixture was stopped under a load of $\sigma = 0.025$ MPa. Swelling of the clayey materials in the soil efficiently reduced the permeability of the soil with NaOH content (Fig. 2, curve 4, Table 1) as compared to the permeability of original soil (Fig. 2, curve 1, Table 1) — even under small loads.

Another effect of the swelling was the lowering of the tendency to consolidate (increasing tendency under a unitary load of $\sigma = 0.2$ MPa (Table 2). As a consequence, the lowering of the initial height of the sample was ca. 3.85% under the final load of $\sigma = 0.2$ MPa.

No swelling was observed in soil samples with NaOH content after being exposed to 353 K for 12 days. The consolidation intensity (Fig. 5, curve 4) was similar to the consolidation intensity of original soil (Fig. 5, curve 1), especially under small loads. It was much greater in comparison to the consolidation intensity of a mixture untreated thermally (Fig. 4, curve 4), which could be shown by compressibility moduli (Table 2). Finally, the sample was lowered by ca. 5.47% in height (1.42 times numerically greater than in the case of an untreated sample).

As a consequence, the disappearance of the swelling effect caused a fall in the sealing parameters. The filtration coefficient for the thermally treated mixture increased as compared with its untreated counterpart (Table 1). At the same time, the range of filtration variations for the soil mixture narrowed and the curve of filtration in the function of load flattened (Fig. 3, curve 4) as compared with a similar relationship for soil with sodium hydroxide content after 24 hrs. (Fig. 2, curve 4). Low filtration coefficients were maintained, which signifies that the structure was sealed by the processes taking place within it.

Conclusions

1. Increase of density of the original soil sample under increasing applied loads does not efficiently reduce the filtration coefficient.

2. Even small (0.5% wt) admixtures of selected chemicals to the original clayey soil had a significant impact on the filtration properties of the mixtures.

3. The addition of calcium hydroxide initially causes a considerable drop of the filtration coefficient. This disappears with time; filtration properties are restored as in the original soil.

4. Clayey soils with potassium hydroxide and sodium hydroxide content first show a lowering of permeability, then maintain the stability of filtration properties in the time-span analysed.

5. Over a period of time, potassium hydroxide and sodium hydroxide lower the amplitude of changes of the filtration properties under applied loads. The compression loads have a lesser influence on the filtration coefficients.

6. The influence of chemical additions on the microstructure of the original soil was experimentally proven.

7. Alkalies, comprising 0.5% by weight, start the decomposition of granular aggregates and the formation of new amorphous phases which influence the properties of the porous soil system.

8. The transformation of clayey minerals under the influence of alkaline additives takes place slowly. The reaction was accelerated by low-temperature treatment over 12 days.

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