GEOLOGIJA. 2014. Vol. 56. No. 3(87). P. 74–86

Influence of aggressive inorganic acids upon the strength parameters of glacial soil

Vytautas Račkauskas

Račkauskas V. Influence of aggressive inorganic acids upon the strength parameters of glacial soil. *Geologija*. Vilnius. 2014. Vol. 56. No. 3(87). P. 74–86. ISSN 1392-110X.

This paper presents a review of monoinfluence of particular inorganic acids – hydrochloric (HCl) and sulphuric (H_2SO_4) acids – upon glacial soil which covers almost a half of the territory of Lithuania. The results of investigations on how inorganic acids influence clayey soil, the object of research and methods are introduced here, as well as the determined background values of strength parameters of glacial soil. The influence of these acids upon the strength parameters of glacial soil is evaluated and an analysis of the influence of chemical pollution by the above mentioned inorganic acids on the change of soil properties is presented.

Key words: moraine soil, hydrochloric acid, sulphuric acid, cohesion, angle of internal friction, undrained shear strength

Received 1 August 2014, accepted 13 October 2014

Vytautas Račkauskas. Department of Hydrogeology and Engineering Geology, Vilnius University, 21/27 M. K. Čiurlionio Street, LT-03101 Vilnius, Lithuania. E-mail: vytautas.rackauskas@gf.vu.lt

INTRODUCTION

Evaluation of the influence of pollution by chemical substances for the building properties of soil becomes an indispensable condition because of increase in engineering economical man's activity intensity and in probability to pollute the soil, both natural and having the destroyed structure, by various technological solutions. Industrial complexes in urbanised territories or nearby usually make bigger chemical effect on ground solid than the total physical effect. One of the most aggressive chemical pollutants are inorganic acids and their monoinfluence upon Lithuanian soils, especially clayey soil, including glacial soils, is almost uninvestigated. Published works on this subject and performed investigations have demonstrated that inorganic acids have clear directions of their effects, while improving or worsening physical mechanical properties of soils. Besides, as it is declared, the forecast on changes of the properties of clayey deposits shall be performed on the ground of experimental data (Dashko, 1984; Ignatavičius, 1984).

REVIEW OF PREVIOUS INVESTIGATIONS

Many previous investigations on how inorganic acids affect soils were committed to research changes in clay properties (Jozefaciuk, Bowanko, 2002; Umesh et al., 2011; Umesha et al., 2012). Changes in moraine soils have been almost uninvestigated. At the same time the moraine soil is heterogenous, an "optimal mix" or close to it by the composition of its separate fractions (Marcinkevičius, 1990), where the fraction of clay amounts to 10–20%. Thus investigations in the field of clay soils research are also important to the analysis of changes in the properties of moraine soils. Determining the influence of inorganic acids on the physical mechanical properties of clayey soils, numerous materials of previous works were collected, but experiments were performed with different litological and mineral variety of soils, various compounds, usually hydrochloric and sulphuric acids, their different concentration and duration of pollution were used.

Foundation soil of industrial buildings and constructions, as well as foundation soil of analogical objects, quite often may be affected by different acid solutions, especially as a compound of waste water, which forms specific technogenic groundwater. At the moment, in most cases it is complicated or sometimes impossible to evaluate critically such changes in the properties of foundation soils. Mostly experimental works and their results are used in order to understand possible changes.

For example, tests have established that the interaction between hydromica montmorillonite quaternary marine clay of Chvalyn and solutions of sulphuric acid turns clay into a fluid state with clear decrease of strength that is conditioned by "chemical spreading" and change in its chemical mineral composition. It is noted that such reduction of strength does not depend on the concentration of acid, besides, cementing material is under destruction (Ziangirov et al., 1981). Alluvial-prolluvial fat clay of the West Pre-Caucasus was analogically investigated under the effect of water and industrial waste water. It was established that during the experiment (4–5 months) under the effect of sulphuric acid (0.1 N) cementing carbonate material of clay, which composition consists mostly of montmorillonite with kaolinite and hydromica admixtures, is destroyed and permeability of soil increases (Monyushko, Kurzina, 1984). After deformation analysis of clayey ground foundation, saturated with water, it was established that intensity of industrial effluent's effect on clayey soils is determined by its chemical composition and duration of influence but not by its quantity. Acid influence on the properties of soils is determined by concentration of solutions and material composition of soils. The most intensive interaction passes when carbonates (compounds of cement and soil) are under destruction and hydromicas or chlorites are changed. Montmorillonite and kaolinite clay changes much less (Dashko, 1984).

V. Ignatavičius (1984; 1986) performed experimental investigations with moraine clayey soils on how they are affected by the total chemical pollution. He investigated the hydromica and kaolinite hydromica loam of the South Lithuania phase marginal moraine till and basal till located in the foundations of the Plant of Calculating Machines in Telšiai. In 15 years of plant operation fresh, hydrocarbonate, non-aggressive to reinforced concrete construction water has turned into mineralised, acid reaction water of technical origin; the water consists of hydrochloric acid, sulphuric, nitric and other acids. Such mineralised kalium and sodium sulphate chloride water of technogenical origin affected the surrounding loam, because there was no carbonate found in it as sodium replaces calcium in hydromica, permeability and moisture of loam increase, strength of soil decreases, especially cohesion (2.5 times), and compressibility of soil increases 1.5 times (Dundulis, Ignatavičius, 1999).

OBJECT OF RESEARCH AND METHODOLOGY

It was calculated that glacial soils cover the area of 26 706.1 km^2 or 41.33% of the territory of Lithuania (Guobytė et al., 2001). In this territory moraine binder soils are like a base for such big towns or industrial and transport centres, such as Šiauliai, Panevėžys, Plungė, Telšiai, etc. (Račkauskas, 2001). For example, at present a constant, and in some places even rather intensive, technogenic, chemical pollution effect covers 4.5% of the Šiauliai area (region) (towns, villages, roads, dumps, etc.) (Račkauskas, 2003).

Possible main polluters by acids are plants and manufactories of electrical engineering, metal manufacturing, tannery, accidents while transporting acids per roads and rails, etc. While foreseeing the potential polluters, the aim to investigate influence of various acids on physical mechanical properties of glacial soils and try to find out causes of possible changes by use of both investigations performed and published works on this subject, according to an example of Šiauliai area, was determined.

The object of research is the Šiauliai area (Nemunas formation, Baltija subformation) marginal and basal till (g^tIIIbl_2, $gIIIbl_2$, g^tIIIbl_1, $gIIIbl_1$) of Middle and South Lithuania phases (Nemunas formation, Baltija subformation) and their changes under the effect of inorganic acids. After selection of typical sections, near existing boreholes pits were made, samples were taken and the following physical properties of moraine soils have been determined by laboratory methods: density of particles (ρ_s), density (ρ), undisturbed moisture content (W), void ratio (e), liquid index (I_L), grain-size distribution (LST EN ISO 14688-2:2006 lt) and strength parameters – cohesion (c), angle of internal friction (φ), undrained shear strength (c_u) (Tables 1, 2). The investigated sandy silty clay (former moraine loam) is one of the most dominant varieties of moraine deposits, especially in the marginal moraine deposits of the Middle Lithuania phase, Baltija subformation (Račkauskas, 2003), and Šiauliai city is set on them.

The physical mechanical properties of sandy silty clay (sasiCl) and silty sand (siSa) found in pits, pass the variation range of values of the physical mechanical properties indexes of area moraine soils and are close to the sample means (Bucevičiutė, Račkauskas, 1997; Bucevičiutė et al., 2000). The above mentioned silty sand (Pit No. 29) is similar according to the components of fractions to sandy silty clay (LST EN ISO 14688-2:2006 lt). Except grain-size distribution, some results of physical properties (ρ_s, e) are also similar, though samples of undisturbed soil were taken from moraine soil of different genesis and this provides a possibility to compare them (Tables 1, 2).

The following undisturbed strength parameters of moraine soil were determined during the initial stage of research: angle of internal friction (φ) and cohesion (c). For those purposes direct consolidated drained shear made by a modified VSV-25 device was applied on undisturbed soil samples at a vertical pressure of 0.1, 0.2, 0.3 MPa, shearing at the constant speed. Before this test the soil was pressed by proof load for 24 hours. Often scientists, like R. E. Dashko, A. A. Kagan, V. D. Lomtadze, V. N. Sokolov and others, used mixes (pastes), while investigating strength of clayey soils and its change under the effect of various

Table 1. **Grain-size distribution of the till soils taken from pits**

1 lentelė. **Kasiniuose imtų moreninių gruntų granuliometrinė sudėtis**

Pit (borehole) No.	Depth of sampling, m	Stratigraphical genetic complexes	Soils	Grain-size distribution of the soils					
				Fraction as % by mass					<0.002 by mass of <0.06 mm
				60–2	2–0.06	0.06–0.002	<0.002	<0.06	
1 (21269)	1.15–1.25	$gIIIbl_2$	sasiCl	4.0	49.0	34.5	12.5	47.0	26.6
3 (21271)	1.30–1.40	g^tIIIbl_1	sasiCl	2.5	50.0	34.5	13.0	47.5	27.4
7 (21275)	1.20–1.35	$gIIIbl_2$	sasiCl	4.0	46.5	32.0	17.5	49.5	35.4
9 (21277)	1.20–1.30	g^tIIIbl_2	sasiCl	4.0	54.5	29.5	12.0	41.5	28.9
16 (21284)	1.10–1.25	$gIIIbl_1$	sasiCl	2.5	45.5	36.0	16.0	52.0	30.8
18 (21286)	1.25–1.45	g^tIIIbl_1	sasiCl	3.0	48.0	36.5	12.5	49.0	25.5
29 (25607)	1.60–1.70	g^tIIIbl_2	siSa	3.0	60.5	29.5	7.0	36.5	19.2

Table 2. Physical mechanical properties of the till soils taken from pits

2 lentelė. Kasiniuose imtų moreninių gruntų fizinės mechaninės savybės

Pit No.	Depth of sampling, m	Stratigraphical genetic complexes	Soils	Values of the physical mechanical properties of the soils							
				ρ_s, Mg/m^3	ρ, Mg/m^3	W, %	e	I_L	φ, degr	c, kPa	c_u, kPa
1	1.15–1.25	$gIIIbl_2$	sasiCl	2.69	2.20	10.6	0.352	–0.095	33	37	
3	1.30–1.40	g^tIIIbl_1	sasiCl	2.69	2.25	12.8	0.349	0.121	26	23	620
7	1.20–1.35	$gIIIbl_2$	sasiCl	2.68	2.25	12.2	0.336	0.143	21	71	802
9	1.20–1.30	g^tIIIbl_2	sasiCl	2.70	2.17	13.8	0.416	0.200	13	41	395
16	1.10–1.25	$gIIIbl_1$	sasiCl	2.70	2.17	11.5	0.387	0.018	26	66	
18	1.25–1.45	g^tIIIbl_1	sasiCl	2.70	2.26	12.4	0.343	0.070	22	50	
29	1.60–1.70	g^tIIIbl_2	siSa	2.71	2.24	14.2	0.382	0.315	27	73	

factors (Dashko, Kagan, 1977). Pollutants also often migrate to fill moraine soils. Besides, pebble and gravel (fractions >2 mm), which are found in undisturbed soils, influence the values of strength parameters (c, φ, c_u), and it is desirable to get the most precise values of changes in soil strength applying different sorts of acid solutions. Considering that, mixes (pastes) were tested during the investigations. The soil from undisturbed sample was drained, crushed and sieved using a sieve with perforations 2 mm in diameter. The obtained soil "flour" was mixed with distilled water, when the density of the particles was $\rho_s = 2.70$ Mg/cm^3, the moisture content of the mix was W = 12% and the void ratio was e = 0.375. The moisture content was chosen similar to that of undisturbed soil (Table 2), the void ratio and the density of particles were according to respective general parameters of the area (Bucevičiutė, Račkauskas, 1997; Račkauskas, 2001; 2003).

Influence of acids was modelled under the effect of 3% solutions of hydrochloric (HCl) and sulphuric (H_2SO_4) acids on disturbed moraine soils (pastes). The pastes were made accepting the mentioned ρ_s, W, e values, but instead of distilled water respective solutions of hydrochloric and sulphuric acids were used. Marginal acid quantity (3%) in solutions was taken in accordance with the present and possible pollution of ground water, as well as soil, in cities, areas of industrial objects (Ignatavičius, 1984; Tratsevskiy, 1989), and necessary minimum or maximum quantity of pollutants in order to ensure their obvious physical chemical and chemical absorption, metathesis of ions and etc. (Goncharova, 1973), and the strength of clay soils gets increased or decreased.

Strength of moraine soils affected by hydrochloric and sulphuric acids and its change were also investigated by a vane-test, using a Torvane shear device 26-2261. Both background values of undrained shear strength (c_u) of undisturbed moraine soil and its disturbed mix (paste) and values of undrained shear strength under the effect of hydrochloric and sulphuric acids were determined.

Applying a vane-test method undrained shear strength c_u was determined for 3 sorts of samples which are of different genesis but are moraine soils of the same litological composition (Table 2). The measurement error of undrained shear strength is ~1–12.5 kPa and depends on the diameter of used vane (4.75 cm Ø vane ~1 kPa, 2.5 cm – ~5 kPa, 1.85 cm – ~12.5 kPa). The main quantity of data (c_u values) was established with the 5–12.5 kPa error.

During the initial stage of these investigations undrained shear strength of undisturbed moraine soil was established. The number of tests of monolith from each pit is 27–32. Samples of disturbed soil with distilled water were prepared. Principles of these samples' (pastes') preparation and taken conditions (ρ_s, W, e) were adequate to the above mentioned mixes. 13–17 samples of each sort of soil determined the undrained shear strength of mixes.

A series of tests to evaluate the influence of changed moisture on strength parameters of soil was performed. For that purpose samples of 2 centimetre-height were cut from monolith by rings, mixes (pastes) with distilled water were prepared, and placed into a glass vessel with distilled water so that liquid submerged a half of the ring. In 24 hours the samples were taken out of the liquid and undrained shear strength was determined from both sides of the sample – the contact and distilled water zone – by vane for several times: 2–4 tests from one side according to the composition and consistence of the soil. For each series of tests 19–22 tests of undisturbed soils and 10–12 tests of disturbed soils were performed. At the same time the moisture of undisturbed soil or mixes made of it was measured.

Correspondingly, influence of acid solutions upon undisturbed or disturbed moraine soils was investigated. Tests with polluted undisturbed soils are analogical to the tests described above. They were performed by steeping samples in solutions for 24 hours. Tests with mixes of disturbed soil were performed immediately after their production, while using 3% solutions of hydrochloric and sulphuric acids and steeping in these solutions for 24 hours.

84 complex, direct, consolidated drained shear tests and 434 vane tests of undrained shear strength determination altogether with samples of both undisturbed and disturbed moraine soils were performed having established background values and soils affected by acids. The results of shear tests were treated by a method of regressive analysis, while 21 shearing strength (τ) values made a set of tests, and in case of a vane test, 29–148 undrained shear strength (c_u) values made a set of tests.

BACKGROUND VALUES OF STRENGTH PARAMETERS OF MORAINE SOIL

In the process of research, investigation of strength parameters of undisturbed moraine soil and its mix with distilled water was performed, which proved that the strength of the produced mix is similar to the undisturbed strength of soil, and they were compared with strength parameters of samples affected by solutions of hydrochloric and sulphuric acids. Direct shear tests determined that the average cohesion (c) of undisturbed soil equals to ~50 kPa, that of disturbed soil is ~43 kPa, the angles of internal friction (φ) are 25 and 27°, respectively (Figs. 1, 2).

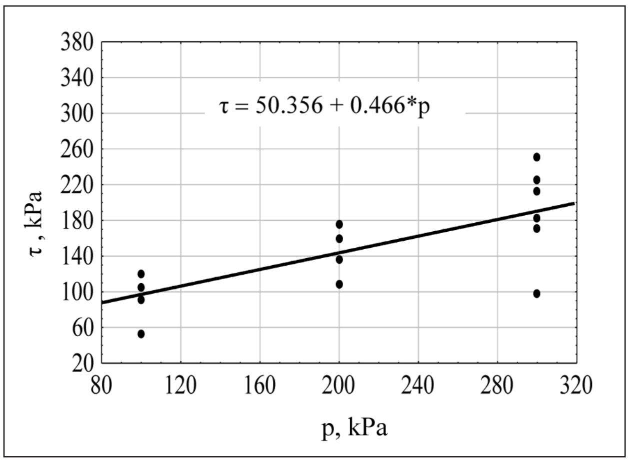

Fig. 1. Diagram of shear strength test of undisturbed samples

1 pav. Natūralios sandaros bandinių kirpimo grafikas

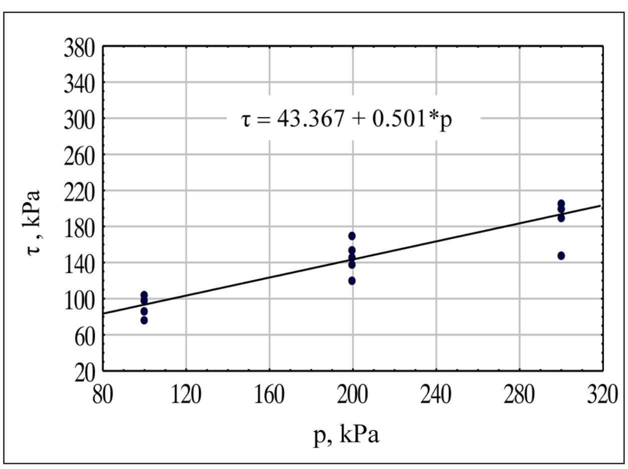

Fig. 2. Diagram of shear strength test of disturbed samples (distilled water)

2 pav. Suardytos sandaros bandinių (distiliuotas vanduo) kirpimo grafikas

R. E. Dashko and A. A. Kagan (1977) maintained that soils resistance to shear depends not only on their granular and mineral composition and denseness but also on the moisture which gets special importance in clayey soils. Thus the undrained shear strength (c_u) of undisturbed soil and its paste with water was investigated by a vane test, while the content of moisture (W) was changing. Besides, a comparison of the change (c_u type) between undisturbed soil and its mix was made. And it was determined that the exponential curve and equation express best the diminution of undrained shear strength (c_u) values, while the soil is moistured additionally (Fig. 3).

The average undrained shear strength of undisturbed moraine soil changes from 910 to 225 kPa (148 tests), while the moisture changes from 10.6 to 17.2%; and that of its paste changes from 480 to 60 kPa (62 tests), while the moisture changes from 11.5 to 17.3% (Fig. 3).

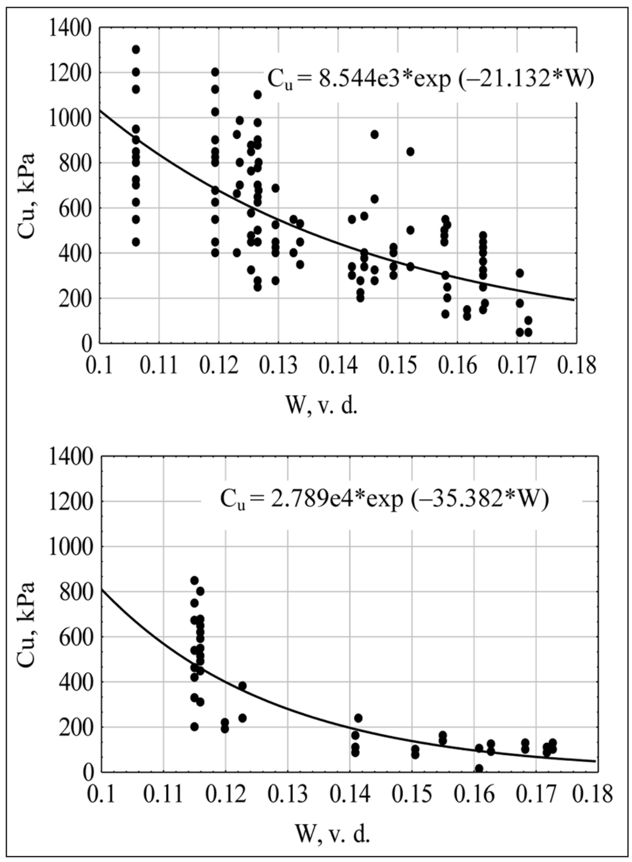

Fig. 3. Diagrams of dependence of undrained shear strength (c_u) of undisturbed (above) and disturbed (below) soils on moisture (W)

3 pav. Natūralios (aukščiau) ir suardytos (žemiau) sandaros grunto tariamosios sankibos (c_u) priklausomybės nuo drėgmės (W) grafikai

A consistent pattern was noticed – if moisture increases gradually, values of the undrained shear strength of undisturbed moraine soil in the initial stage decrease faster, and while the moisture content of soil is increasing, decrease of intensity of its c_u values is getting slower. A wide range of c_u values of undisturbed soil is because soil monolith is not solid and the least strength of soil is in places where there are defects and inclusions, and the largest strength is in monolith areas and where particles exceed 2 mm.

The undrained shear strength of disturbed moraine soil decreases, while the moisture content is increasing in the same proportions like in the undisturbed soil case but values of undrained shear strength are a bit less, because structural bounds that exist in undisturbed soil (Marcinkevičius, 1974; 1990) and provide it extra strength are partially damaged.

Comparison of sample values of the undrained shear strength of undisturbed and disturbed soil (paste), according to the exponential curves, allows to determine that if moisture increases from 11.5 to 17.2%, the undrained shear strength of paste decreases from 1.56 to 3.46 times (if W = 12%, it decreases 1.7 times). Thus, if soil moisture increases, its disturbed soil analogue has lower value of undrained shear strength.

INFLUENCE OF ACIDS UPON STRENGTH PARAMETERS OF MORAINE SOIL

Having analysed the share data of disturbed soil, polluted by 3% solution of hydrochloric acid, and the regressive equation, it was established that in comparison with background values (Fig. 2) the average cohesion and angle of internal friction are less. Cohesion diminishes to 29 kPa (–33%) and the value of the angle of internal friction is 26° (–4%) (Fig. 4).

Having analysed the share data of disturbed soil, polluted by 3% solution of sulphuric acid, and the regressive equation, it was established that in comparison with background values (Fig. 2) the average cohesion increased (+27%) and was 55 kPa; the angle of internal friction remained unchanged – 27° (Fig. 5).

Figures 6 and 7 present values of the undrained shear strength in undisturbed soil saturated by distilled water and polluted by solutions of hydrochloric and sulphuric acids. The exponential curve of c_u change of undisturbed soils, saturated by distilled water, was made by use of 60 c_u values.

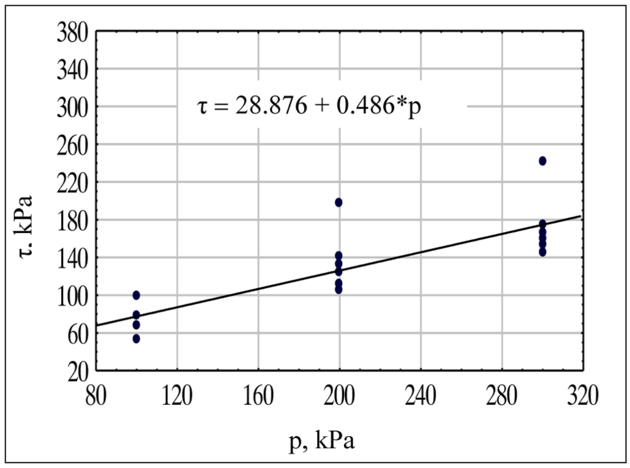

Fig. 4. Diagram of shear strength test of disturbed samples polluted by hydrochloric acid (HCl)
4 pav. Suardytos sandaros bandinių, užterštų druskos rūgštimi (HCl), kirpimo grafikas

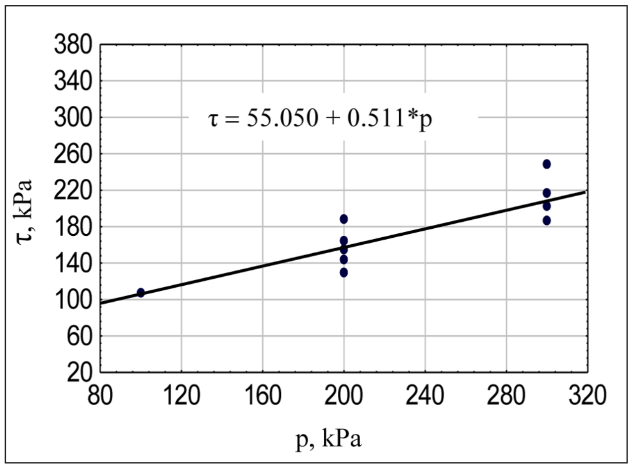

Fig. 5. Diagram of shear strength test of disturbed samples polluted by sulphuric acid (H_2SO_4)
5 pav. Suardytos sandaros bandinių, užterštų sieros rūgštimi (H_2SO_4), kirpimo grafikas

While saturating by solutions of hydrochloric acid (initial concentration 3%) for 24 hours and changing moisture content from 12.2 to 16.9%, the average undrained shear strength of undisturbed soil changes from 550 to 120 kPa (29 tests) (Fig. 6).

In comparison with background values, the change of undrained shear strength value if moisture content increases in soil according to exponential curves has common trend: the strength of undisturbed

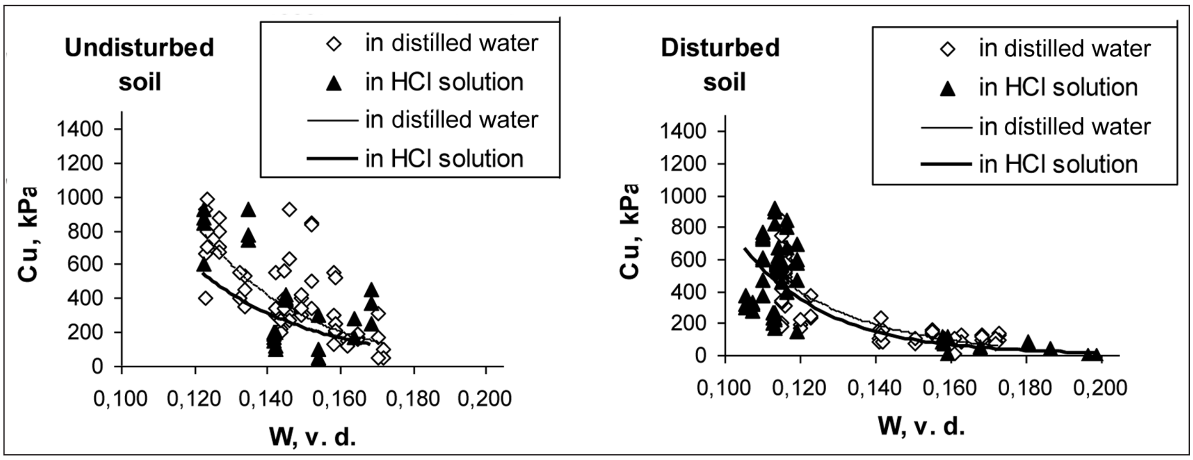

Fig. 6. Diagrams of undrained shear strength (c_u) changes of undisturbed and disturbed soil, saturated by distilled water and polluted by hydrochloride acid (HCI) solution

6 pav. Natūralios ir suardytos sandaros grunto tariamosios sankibos (c_u) kaitos, sotinant distiliuotu vandeniu ir teršiant druskos rūgšties (HCl) tirpalu, grafikai

moraine soil is decreasing more than in distilled water environment, while soil is treated by solution of hydrochloride acid. While the total moisture content is increasing and the strength of soil is decreasing, this difference is getting less (Fig. 6). The average undrained shear strength of undisturbed soil, polluted by solution of hydrochloride acid, decreases from 1.45 to 1.25 times if moisture content increases from 12.3 to 16.9%. The exponential equations of undrained shear strength dependence on moisture (Table 3) are established for figures demonstrating this difference. According to these equations, when moisture of soil equals to 12%, the undrained shear strength of undisturbed soil (~585 kPa) decreases 1.47 times in comparison with the background value (~860 kPa). Moraine soils which have higher content of clay fractions (Pit No. 7) are more resistant to the influence of hydrochloride acid (Table 1).

Under the circumstances when moisture content changes from 10.5 to 19.9%, the average undrained shear strength of disturbed moraine soil's mix, saturated by solution of hydrochloride acid, changes from 675 to 10 kPa (57 tests) (Fig. 6).

Comparison of exponential curve values of the undrained shear strength of disturbed moraine soil with background values provides the possibility to determine that the undrained shear strength of polluted mixes, as in case with undisturbed soil, always is less than the background values. Differently than in cases with polluted undisturbed soil, the c_u exponential curve of polluted mix gradually and in parallel repeats the exponential curve of background values, and if moisture content increases from 11.5 to 17.3%, equation values of undrained shear strength decrease from 1.10 to 1.76 times. When soil moisture content is 12%, c_u (~350 kPa) of the mix, polluted by solution of hydrochloride acid, decreases 1.14 times in comparison with the background value (~400 kPa). Besides, mixes of moraine soils, which volume of silt fractions is higher (Pit No. 3), are less resistant to the negative influence of hydrochloride acid (Table 1).

Strength comparison of undisturbed and disturbed soils that are affected by a weak solution of hydrochloride acid with analogical tests using distilled water provides a possibility to maintain that tests with mixes highlighted an obvious common trend of strength diminution in undisturbed soil (Fig. 6). However, while moisture content increases from 12.2 to 16.9%, values of the average undrained shear strength of disturbed moraine soil (mix), polluted by 3% solution of hydrochloride acid, are from 1.72 to 3.00 times less in comparison with c_u values of the undisturbed soil affected by the same solution of hydrochloride acid. The negative effect of hydrochloride acid on undisturbed soil is stronger than on the mix, probably because of there existing structural bounds which mostly are carbonate type and under the effect of the solution of hydrochloride acid they decompose, thus cohesion of soil considerably diminishes.

Table 3. **Exponential equation of dependence of undrained shear strength of undisturbed and disturbed moraine soils on moisture**

3 lentelė. **Natūralaus ir suardytos sandaros moreninio grunto tariamosios sankibos (c_u) priklausomybės nuo drėgmės eksponentinės lygtys**

Soil saturating substance	Structure of moraine soil	
	Undisturbed soil	Disturbed soil
Water	c_u = 8.544e3*exp (–21.132*W) (148)	c_u = 2.789e4*exp (–35.382*W) (62)
HCl 3% solution	c_u = 2.742e4*exp (–32.047*W) (29)	c_u = 6.841e4*exp (–43.979*W) (57)
H_2SO_4 3% solution	c_u = 1.593e4*exp (–24.439*W) (58)	c_u = 4.374e4*exp (–38.24*W) (80)

Note: In brackets – c_u values set of tests, according to which the exponential equations were derived.

While saturating by solutions of sulphuric acid (initial concentration 3%) for 24 hours and changing moisture content from 13.2 to 18.4%, the average undrained shear strength of undisturbed soil changes from 630 to 180 kPa (58 tests) (Fig. 7).

Change of the undrained shear strength value in comparison with background values in accordance with exponential curves is favourable when moisture content in soil increases, i. e. the strength of undisturbed moraine soil increases under the effect of solution of sulphuric acid compared with distilled water environment (Fig. 7). Under the circumstances when moisture content increases from 13.2 to 17.2%, the average undrained shear strength of undisturbed moraine soil, polluted by solution of sulphuric acid, increases from 1.13 to 1.78 times. In accordance with exponential equations (Table 3), if the moisture of soil is 12%, the undrained shear strength (~850 kPa) of undisturbed moraine soil almost equals to the background value (~860 kPa) and is a bit less.

Under the circumstances when moisture content changes from 11.3 to 20.3%, the average undrained shear strength of disturbed moraine soil's mix, saturated by solution of sulphuric acid, changes from 580 to 20 kPa (80 tests) (Fig. 7).

Comparison of exponential curve's values of the undrained shear strength of disturbed moraine soil (mix), polluted by solution of sulphuric acid, with background values provides the possibility to determine that the undrained shear strength of polluted mixes, differently than in case with undisturbed soil, is higher than the background values only when moisture content is little (~12%), and while moisture content increases (>14.5%), it is coincident with background values. It means that the water influence upon the strength of mix is much higher than the influence of sulphuric acid. If the

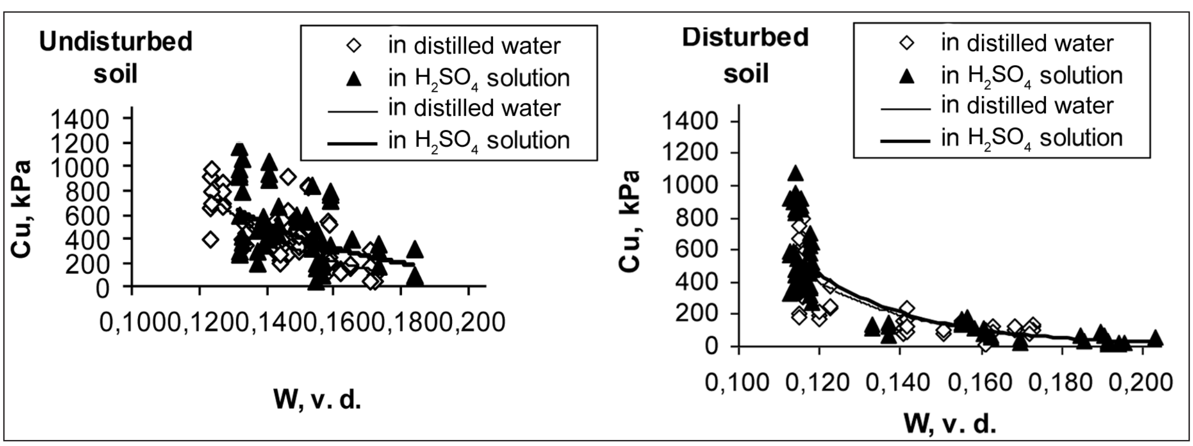

Fig. 7. Diagrams of changes in the undrained shear strength (c_u) of undisturbed and disturbed moraine soils saturated by distilled water and polluted by sulphuric acid (H_2SO_4) solution

7 pav. Natūralios ir suardytos sandaros grunto tariamosios sankibos (c_u) kaitos, sotinant distiliuotu vandeniu ir teršiant sieros rūgšties (H_2SO_4) tirpalu, grafikai moisture content increases from 11.5 to 14.5%, curve's values of undrained shear strength increase from 1.13 to 1.03 times. When the soil moisture content is 12%, c_u (~445 kPa) of the mix, polluted by solution of sulphuric acid, increases 1.11 times in comparison with the background value (~400 kPa).

Strength comparison of undisturbed and disturbed soils that are affected by a weak solution of sulphuric acid with analogical tests using distilled water provides a possibility to maintain that while the moisture content is little (~12%), both undisturbed soil and the mix under the effect of sulphuric acid become firmer. But if the moisture content is increasing and undisturbed soil is still getting firmer, the tendency of mix strengthening is decreasing until reaches the strength of undisturbed mix – the effect of water eliminates the effect of sulphuric acid. While the moisture content increases from 13.2 to 18.4%, values of the average undrained shear strength of disturbed moraine soil (mix), polluted by 3% solution of sulphuric acid, are from 2.25 to 4.50 times less in comparison with c_u values of the undisturbed soil affected by the same solution of sulphuric acid.

ANALYSIS OF CHANGES IN SOILS' PARAMETERS UNDER POLLUTION OF INORGANIC ACIDS

In order to establish the causes of changes in soil, one or another way of interaction was analysed: according to the analysed medium of interaction, possible characters of interaction, their variants and consequences are interpreted and their comparison with the established results allows us to make the following conclusions, which confirm or deny probable characters of interaction and consequences, in many cases they are determined by chemical equations (Račkauskas, 2003).

While hydrochloric acid and its solutions treat moraine soil, carbonate is disturbed; carbonate structural relations decompose and soil strength decreases down (Fig. 8). This statement was proved by the results of plain shear strength and vane tests as well as by the grain-size distribution test of disturbed soil before and after its reaction to solution of hydrochloride acid (Table 4). Direct disturbing of carbonate silt and sand is probable as well.

There is no change in the clay fraction, because a radiostructural analysis has not showed any remarkable changes in the composition of clay minerals or their quantity (Račkauskas, 2003). Only regular diminution, sometimes within the range of error (0.5%) of the silt fraction, was observed. This provides a possibility to make a presumption that hydrochloric acid mostly influences both particles themselves and carbonate. Also, melting of particles was noted in the sand fraction (sample from Pit No. 7).

If moraine soil is polluted by sulphuric acid and its solutions, then calcium carbonate and disperse particles become gypsum, which cement the soil particles, and due to it soil becomes firmer (Fig. 9). The strength improvement and availability of calcium carbonate are determined by tests. There are other ways to cement soil particles that must be

Table 4. **Grain-size distribution of sandy silty clay mix (fractions <2 mm) and this mix, affected by 3% solution of hydrochloric acid (HCl)**

4 lentelė. **Smėlingo dulkingo molio mišinio (dalelės <2 mm) ir šio mišinio, paveikto druskos rūgšties (HCl) 3 % tirpalu, granuliometrinė sudėtis**

Pit No.	Depth, m	Soil or type of its mix	Grain-size distribution of the soils				
			Fraction as % by mass				<0.002 by mass of <0.06 mm
			60–2	2–0.06	0.06–0.002	<0.002	
1	1.15–1.25	Mix	–	51.0	37.5	11.5	23.47
		Mix + HCl	–	52.0	34.5	13.5	28.13
3	1.30–1.40	Mix	–	51.0	36.0	13.0	26.53
		Mix + HCl	–	52.5	33.5	14.0	29.47
7	1.20–1.35	Mix	–	53.0	35.0	12.0	25.53
		Mix + HCl	–	50.0	34.5	15.5	31.00
9	1.20–1.30	Mix	–	56.0	31.0	13.0	29.55
		Mix + HCl	–	58.0	30.5	11.5	27.38

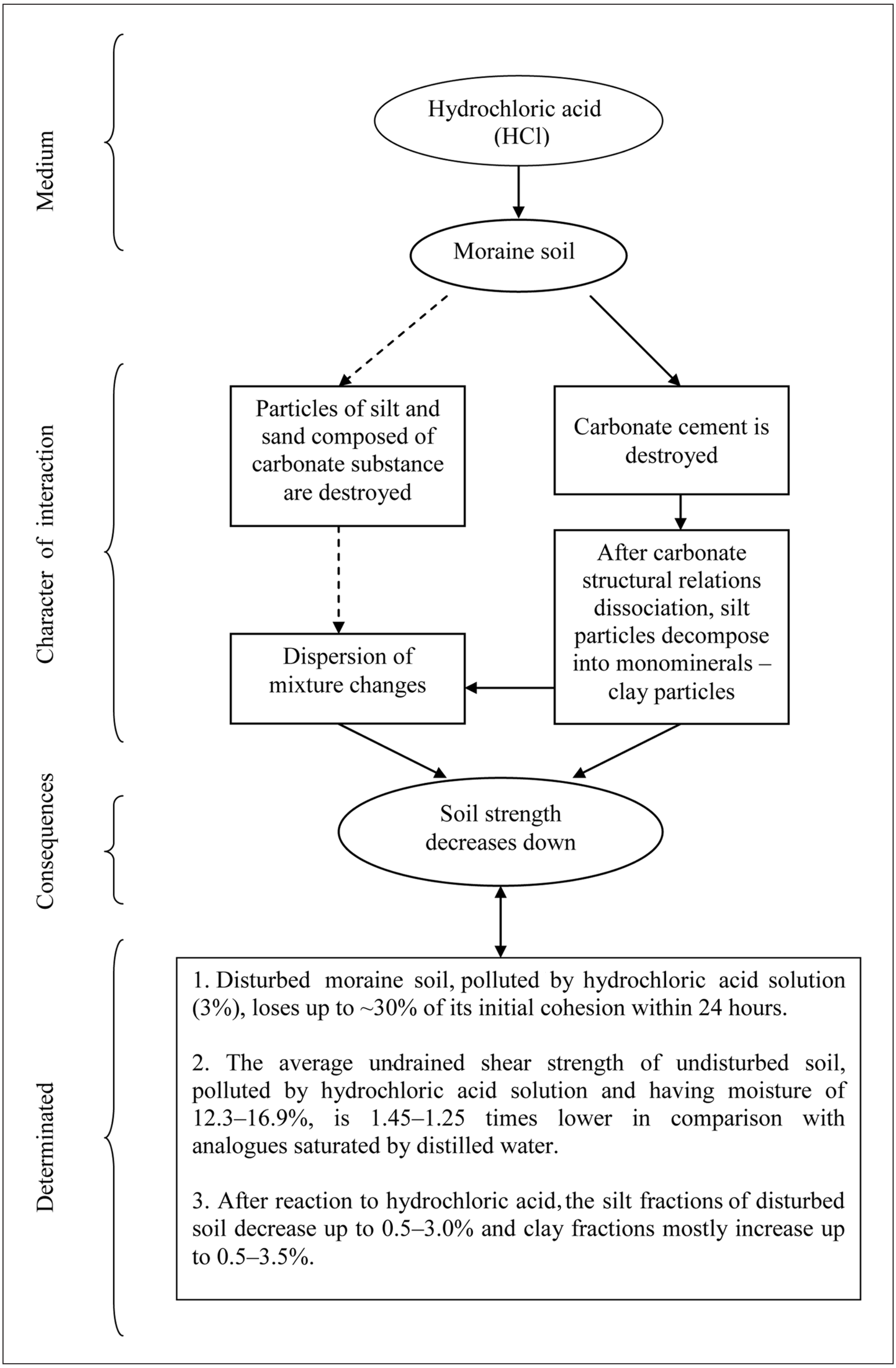

Fig. 8. Influence of hydrochloric acid upon moraine soil strength: process and consequences
8 pav. Druskos rūgšties poveikis moreninio grunto stiprumui: procesas ir pasekmės

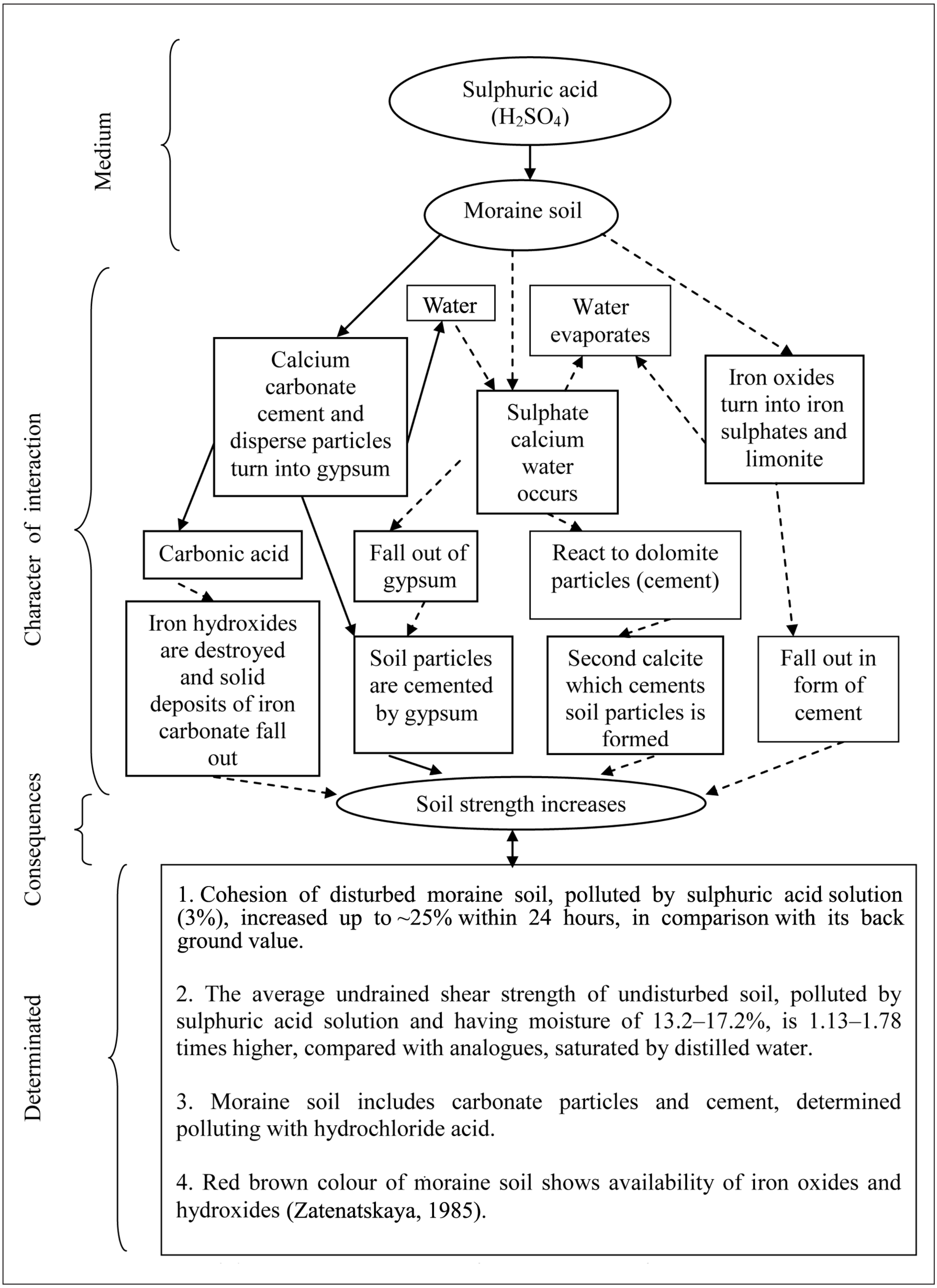

Fig. 9. Influence of sulphuric acid upon cementation of moraine soil particles and soil strength: process and consequences

9 pav. Sieros rūgšties poveikis moreninių gruntų dalelių cementacijai ir grunto stiprumui mentioned: turning of iron oxides and hydroxides into sulphates and carbonates, and their fall out of the undisturbed solution in the form of cement under the favourable condition. In case of the favourable condition (numerous inflow of meteogenous water unsaturated with calcium sulphate or chemical materials that decomposes gypsum) and during long-time influence, gypsum cement may be eliminated and strength of soil decreases down.

CONCLUSIONS

1. Under the effect of hydrochloric acid distinct changes of strength parameters via diminution are observed and soil cohesion decreases up to 33% of its background value, on the average. Strength parameters improve under the effect of sulphuric acid. On the average, cohesion increases up to 27% of its background value. The angle of internal friction of soil remains the same (in cases with sulphuric acid) or slightly changes (in cases with hydrochloric acid – 4%).

2. Decrease of soil strength under the pollution of hydrochloric acid solution is determined by its reaction to carbonate cement and carbonate particles available in the silt fraction – soil dispersion changes and structural relations are eliminated partially; and improvement of soil strength under the pollution of sulphuric acid solution is determined by the above-mentioned reaction to carbonate cement and formation of new gypsum as well as cement of iron compounds.

REFERENCES

1. Bucevičiūtė S., Marcinkevičius V., Račkauskas V. 2000. The engineering geological conditions of Šiauliai area. In: M. Mets (eds.). *Proceedings of the Ninth Baltic Geotechnical Conference. Baltic Geotechnics IX 2000.* Akadeemia Trükk. Tallinn. 44–51.
2. Bucevičiūtė S., Račkauskas V. 1997. *Specialus geologinis kartografavimas 1: 50 000 masteliu Šiaulių plote. V tomas. Inžinerinė geologija. 1 dalis.* Aiškinamasis raštas ir tekstiniai priedai. Vilnius: Lietuvos geologijos tarnyba. 134 p.
3. Dashko R. E. 1984. Priroda deformatsiy vodonosyshchennykh glinistykh porod v osnovanii sooruzheniy. *Zapiski Leningradskogo gornogo instituta* **100**: 40–47 [in Russian].
4. Dashko R. E., Kagan A. A. 1977. *Mekhanika gruntov v inzhenerno-geologicheskoy praktike.* Nedra. Maskva. 237 p. (188–195) [in Russian].
5. Dundulis K., Ignatavičius V. 1999. The contamination of soils and changes of geotechnical conditions. In: R. N. Yong, H. R. Thomas (eds.). *Geoenvironmental Engineering. Ground Contamination: Pollutant Management and Remediation.* Thomas Telford. London. 163–169.
6. Goncharova L. V. 1973. O*snovy iskustvennogo uluchsheniya gruntov* (*tekhnicheskaya melioraciya gruntov*). Izdatel'stvo Moskovskogo universiteta. Moskva. 376 p. [in Russian].
7. Guobytė R., Aleksa P., Satkūnas J. 2001. Lietuvos paviršiaus genetinių, litologinių ir stratigrafinių tipų gruntų paplitimo analizė. *Geografijos metraštis* **34(2)**: 57–67.
8. Ignatavičius V. 1984. *Issledovaniye vliyaniya khimikatov na svoystva grunta osnovaniya Tel'shyayskogo ZSM i razrabotka predlozheniy po usileniyu zdaniy.* Vil'nyuskiy inzhenerno stroitel'nyy institut. Vilnius. 42 p. [in Russian].
9. Ignatavičius V. 1986. Moreninių priemolių fizikinių ir mechaninių savybių keitimasis dėl techninės kilmės vandens poveikio. *Geologija* **7**: 122–129.
10. Jozefaciuk G., Bowanko G. 2002. Effect of acid and alkali treatments on surface areas and adsorption energies of selected minerals. *Clays and Clay Minerals* **50(6)**: 771–783.
11. *LST EN ISO 14688-2:2006 lt. Lietuvos standartas. Geotechniniai tyrinėjimai ir bandymai – Grunto atpažintis ir klasifikavimas. 2 dalis: Klasifikavimo principai* (*ISO 14688-2:2004*). Vilnius: Lietuvos standartizacijos departamentas. 15 p.
12. Marcinkevičius V. 1974. *Formirovaniye fiziko-mekhanicheskikh svoystv morennykh otlozheniy poslednego oledeneniya na territorii Srednej Litvy.* Avtoreferat dissertatsii na soiskaniye uchenoj stepeni kandidata geologo-mineralogicheskikh nauk. Leningradskiy gornyy institut imeni G. V. Plekhanova. Leningrad. 21 p. [in Russian].
13. Marcinkevičius V. 1990. Formirovaniye fiziko-mekhanicheskikh svoystv morennykh otlozheniy poslednego oledeneniya Sredney Litvy. *Geologija* **11**: 87–98 [in Russian].
14. Monyushko A. M., Kurzina E. V. 1984. Ocenka izmeneniya fiziko-mekhanicheskikh svoystv chetvertichnykh kontinental'nykh glin zapadnogo Predkavkaz'ya pod vliyaniem obvodneniya i promstokov. *Processy podtopleniya zastroyennykh territoriy gruntovymi vodami. Tezisy dokladov Vsesoyuznogo Soveshchaniya. Ch 2.* PNIIIS Gosstroya SSSR. Novosibirsk. 80–82 [in Russian].
15. Račkauskas V. 2001. Šiaulių regiono glacialinių nuogulų stiprumo savybės ir jų kitimas teršiant įvairiomis cheminėmis medžiagomis. In: K. Kilkus (moks. red.). *Mokslas Gamtos mokslų fakultete.* Fakulteto antrosios mokslinės konferencijos, įvykusios 2001 m. spalio 10 d., pranešimai. Vilnius: Vilniaus universiteto leidykla. 172–182.

16. Račkauskas V. 2003. *Influence of Pollution by Chemical Substances Upon the Strength Parameters of Glacial Soil (Siauliai Area).* Abstract of Doctor's Thesis. Vilniaus universiteto leidykla. Vilnius. 34 p.
17. Tratsevskiy G. D. 1989. Gidrogeokhimicheskaya i gazovaya zonal'nost'. In: V. I. Juodkazis (eds.). *Regional'naya gidrogeologiya Pribaltiki.* Mokslas. Vilnius. 180–186 [in Russian].
18. Umesha T. S., Sharma H. D., Dinesh S. V., Sivapullaiah P. V., Basim Swamy C. 2011. Physicochemical changes in soil due to sulphuric acid contamination. In: *Proceedings of Indian Geotechnical Conference, December 15–17, 2011, Kochi.* Kochi. 765–768.
19. Umesha T. S., Dinesh S. V., Sivapullaiah P. V. 2012. Effects of acids on geotechnical properties of black cotton soil. *International Journal of Geology* **6(3)**: 69–76.
20. Zatenatskaya N. P. 1985. Rastvoreniye, vyshchelachivaniye i zasoleniye gruntov. In: E. M. Sergeev (ed.). *Teoreticheskiye osnovy inzhenernoy geologii. Fiziko-khimicheskiye osnovy*. Nedra. Maskva. 95–100 [in Russian].
21. Ziangirov R. S., Lavrova I. A., Oknina N. A. 1981. Izmeneniye prognostnykh i deformacionnykh svoystv glinistykh porod pri vzaimodeystvii s kislymi i shchelochnymi rastvorami. *Izmeneniye svoystv gruntov pod vliyaniyem prirodnykh i antropogennykh vozdeystviy.* Stroyizdat. Moskva. 3–16 [in Russian].

Vytautas Račkauskas

AGRESYVIŲJŲ NEORGANINIŲ RŪGŠČIŲ ĮTAKA GLACIALINIŲ GRUNTŲ STIPRUMO PARAMETRAMS

Santrauka

Esant taršai cheminėmis medžiagomis, viena iš aktualiausių problemų dėl žmogaus ūkinės veiklos tampa gruntų statybinių savybių pokyčiai. Tirtas konkrečių neorganinių rūgščių – druskos (HCl) ir sieros rūgščių (H_2SO_4) – monopoveikis Lietuvos Šiaulių regiono glacialiniams gruntams. Nustatyta, kad gruntas, veikiamas rūgščių, skirtingai reaguoja į jų poveikį. Druskos ir sieros rūgšties poveikis moreniniam gruntui yra priešingas (bent pradiniame etape). Tai patvirtina tiek plokščio konsoliduoto drenuoto kirpimo metodu atlikti bandymai su suardytos sandaros gruntais, tiek mentelių metodu atlikti bandymai su natūralios ir suardytos sandaros gruntais.

Teršiant druskos rūgšties tirpalu (3 %) pastebimi ryškūs stiprumo parametrų mažėjimo pokyčiai, grunto sankabumas vidutiniškai sumažėja iki 33 % foninės vertės. Veikiant sieros rūgšties tirpalu (3 %) stiprumo parametrai pagerėja. Sankabumas vidutiniškai padidėja iki 27 % foninės vertės. Gruntų vidinės trinties kampas lieka nepakitęs (sieros rūgšties atveju) arba šiek tiek sumažėja (druskos rūgšties atveju – –4 %). Grunto stiprumo sumažėjimą teršiant druskos rūgšties tirpalu lemia jos reakcija su karbonatiniu cementu ir karbonatinėmis dalelėmis, esančiomis dulkio frakcijoje, – keičiasi grunto dispersiškumas ir iš dalies suardomi struktūriniai ryšiai, o grunto stiprumo padidėjimą teršiant sieros rūgšties tirpalu lemia anksčiau minėta reakcija su karbonatiniu cementu ir naujo gipso bei geležies junginių cemento susidarymas.

Atlikti tyrimai padeda įvertinti esamus ir galimus (katastrofinius) glacialinio grunto stiprumo pokyčius teršiant agresyviomis druskos ir sieros rūgštimis tiek jam slūgsant natūraliai, tiek projektuojant ar statant žemės statinius. Esant moreninių gruntų taršai rūgštimis, būtina prognozuoti pasekmes.

Raktažodžiai: moreninis gruntas, druskos rūgštis, sieros rūgštis, sankiba, vidinės trinties kampas, tariamoji sankiba