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A study on the relationship between geotechnical properties and clay mineral composition of Hanoi soft soils in saline media

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Abstract

Soft soil in Hanoi, Vietnam, is mainly originated from lacustrine and shallow-sea sediment. This is the youngest formation with around 3000 years of age. To serve the research purpose, clayey soil samples at ten areas in Hanoi and some places in the RRD are prepared. Mineral composition of soils determined by X-ray diffraction analysis shows that clay minerals are predominated by Illite, Kaolinite, Chlorite, and Montmorillonite respectively. Many previous researches indicated that in saline-saturated condition, types of cation in saline water and types of clay mineral in soil layers, as well as their predomination decide the changing process of geotechnical properties in other manner. In this paper, the initial relationship between geotechnical properties and clay mineral composition of Hanoi soft soils in saline-saturated media is established.

Keywords: Hanoi soft soils, clay mineral, saline soils, saline media, geotechnical properties

1. Introduction

Most of surface area of the Red River Delta (RRD) which includes Hanoi is covered by sediment formation. The youngest formation with around 3000 years of age is mainly original from lacustrine and shallow-sea sediment. In Hanoi area, their highest thickness reaches around 30 m; the sediment formations are predominated by soft soils.

In the coastal area of Vietnam, sea level rise related to global warming is recorded and that is the main reason leading to saline intrusion of the soil layers. As the intrusion of seawater into soil layers occurs, the interaction between cations in seawater and ions in clay minerals may cause geotechnical properties changed in different manners. Based on that background, it is required to evaluate vulnerability of soft soil layers in the Red River delta as the infrastructure. Hanoi area is considered as a case study.

2. Clay mineral composition in Hanoi soft soils

2.1. Objective

When sea level rises, inland areas are gradually intruded by saline water. The coastal region of the RRD is a typical case. Although soil layers in Hanoi have not been affected by seawater yet but that is the ideal condition for studying. Samples in Hanoi and some places in the RRD are collected, and the laboratory experiments are conducted with artificial seawater at different concentration of salt to simulate gradual saline intrusion of brine to soil layers. The experiment results give facility of establishing relationship between geotechnical properties and clay mineral composition of Hanoi soft soils in saline-affected condition. The research areas are given in Fig. 1.

2.2. Samples

Sampling in Hanoi area is carried out at ten different sites in inner city and surroundings that spread two sides of the Red River and the rest one is conducted in the provinces along the coast of the delta included Nam Dinh, Thai Binh, and Hai Phong (Fig. 1). Samples are taken in the boreholes of geotechnical investigation works. Clayey soils are the object of the study. Undisturbed samples taken from the borehole at 2.0÷8.0 m deep are in medium state with value N_{30} in Standard Penetration test (SPT) from 4 to 8. Sampling locations and some fundamental properties of Hanoi soft soil are given in the table 1.

2.3. Experiment

The analysis of clay mineral composition of Hanoi and some places in the RRD's soft soils is conducted by X-ray diffractometer D8-ADVANCE apparatus. Before analysing,

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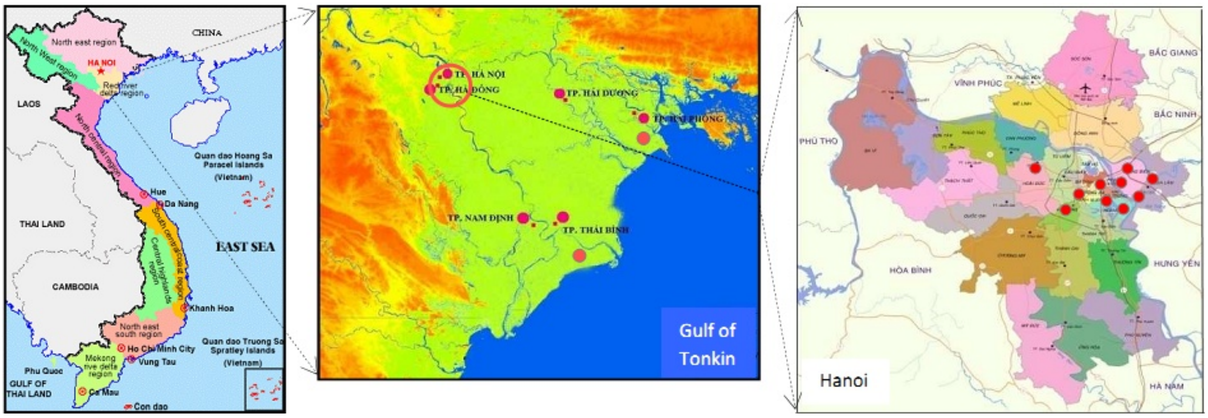

Fig. 1. Distribution of the youngest sediment formation in RRD (🟩) and the research areas (🔴)

Table. 1. Location and fundamental properties of soil samples in Hanoi area

Location	Description	Particle density (g/cm^3)	Natural water content (%)	Unit weight (g/cm^3)
Hoai Duc	Silty clay	2.61	39.15	1.820
Ha Dong	Silty clay	2.63	32.40	1.880
Thanh Xuan	Silty clay	2.64	40.00	1.841
Hai Ba Trung	Silty clay	2.55	47.92	1.750
Hoan Kiem	Silty clay	2.55	41.82	1.770
Hoang Mai	Silty clay	2.57	38.45	1.731
Long Bien I	Silty clay	2.52	36.92	1.821
Long Bien II	Silty clay	2.53	35.42	1.920
Highway № 5	Silty clay	2.50	59.86	1.643
Gia Lam	Silty clay	2.62	36.91	1.998

soil specimens were absolutely made saturation by artificial seawater (solution of sodium chloride) at the concentration of 0.0‰, 9.9‰, 19.8‰ and 33.0‰. These concentrations of sodium chloride solution are chosen because the medium salinity of seawater in Vietnam is 33‰; it is considered as 100%. Thus, the above salinities are equivalent to 0, 30, 60, and 100%. The saturated duration of soil specimens is 10 days. Basic chemical component and the content of salt served saturating is NaCl (≥ 92%), SO_4^{2-} (≤ 2.7%), Mg^{2+} (≤ 1.3%), Ca^{2+} (≤ 0.65%). To analyse clay mineral composition, after saturation process, soil specimens are made dry. Two grams of soil powder with grain size diameter under 0.074 millimetres are prepared for.

In addition to analysing clay mineral composition, the experiments on hydraulic conductivities (in accordance with ASTM D 2434), one-dimensional compression test (ASTM D 2435), and direct shear test (ASTM D 3080) after saturation were carried out to compare the variability of geotechnical properties of soil at different salinity of pore water.

2.4. Results

The analysis of clay mineral composition is done for the soil specimens after saturation with different salt concentrations. Those results indicated that there is almost no change in the mineral composition of the soil before and after saline intrusion. The negligible differences are occasionally met in one soil sample at four concentrations of salt but they are believed to be concern with error due to analysis or machine. The results have good agreement with conclusions of Rashid M.A., et al, (1972) [1], Kirov B., (1989) [2], van Hoorn J.W., & van Alphen J.G. (1994) [3], and Mitchell J.K. & Soga K., (2005) [4]. The diffraction diagrams of analysed results are shown in figure 2. Only two analysed diagrams at 0% and 100% salt concentration of soil samples in Hoai Duc are shown as the representative. Those diagrams manifest two curves almost the same. Besides, the quantitative results are also given as the attachment on the charts.

For Hanoi soft soil, the common and consistent point is the domination of Illite mineral (from 12 to 29%), the subsequence are Kaolinite (from 9 to 22%), and Chlorite (from 4 to 11%). Montmorillonite has a small rate (about 5% in maximum) but some places it is negligible (under 1%). Non-clay mineral quantitatively prevailing is Quartz (from 30 to 62%), Feldspar (from 3 to7 %), Goethite (from 2 to 6%), and some others with low content. Non-clay component is almost not influence on geotechnical properties of saline-intruded soils. Clay minerals of Hanoi soft soils stated above reflect truly the formation condition of sediment related to river, marsh, lake, and/or shallow sea.

Because of no change in clay mineral component between different salinities, table 2 shows the statistic results at 0‰ and 19.8‰ of salinities (0 and 60%) as the representative only.

3. The relationship between clay mineral composition and the geotechnical properties in saline-intruded media

3.1. The researches on saline soil in relation to geotechnical properties

The research of salt influence on geotechnical properties of soil is executed in many areas. Many researches on the chemical treatment of clay have been carried out in the world in which Sweden and Norway are included. Rosenqvist I.Th., (1955) pointed out that the difference between sensitive and non-sensitive clay is primarily due to the salt concentration in the pore water. The formation of the well-known absorbed layer on the mineral surface is obviously to a great extent

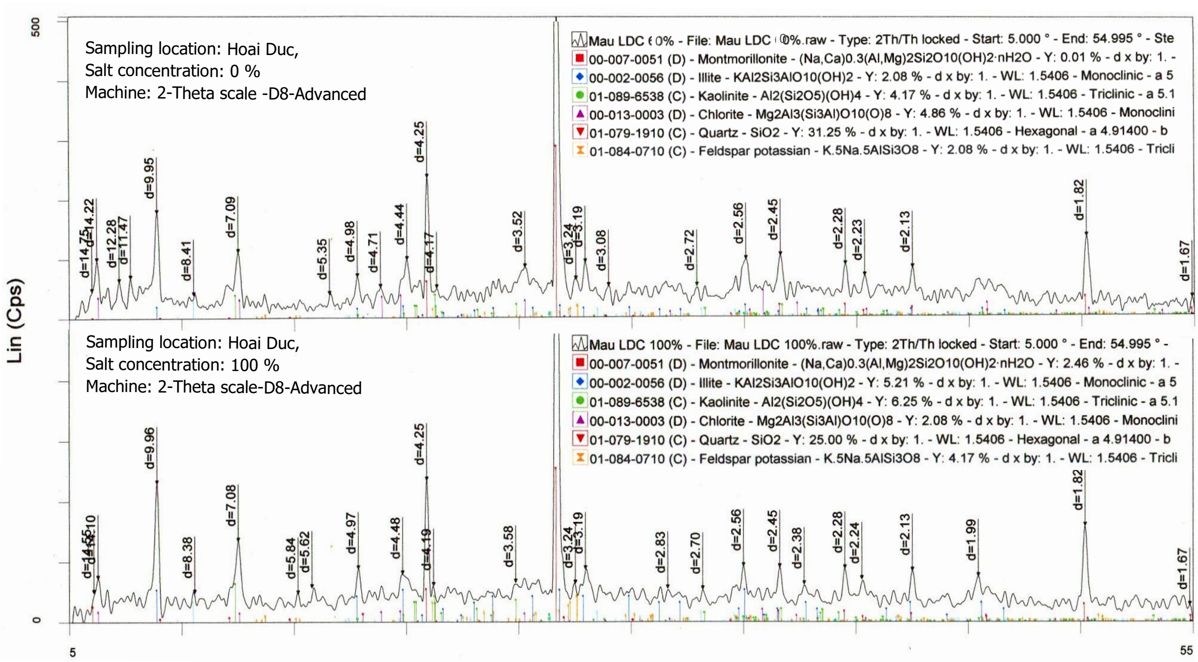

Fig. 2. The diffraction diagrams of clay mineral composition of Hanoi soft soils

Table 2. Statistic result of clay mineral of Hanoi soft soils at 0 and 19.8 thousandths (‰) of salinities

Location	Salinity (‰)	Illite	Kaolinite	Chlorite	Montmo-rillonite	Quartz	Feldspar	Gothite
Hoai Duc	0	19÷21	11÷13	8÷10	< 1	46÷48	4÷6	3÷5
	19.8	19÷21	11÷13	8÷10	< 1	46÷48	4÷6	3÷5
Ha Dong	0	18÷20	14÷16	7÷9	1÷3	47÷49	3÷5	2÷4
	19.8	18÷20	14÷16	7÷9	1÷3	47÷47	3÷5	2÷4
Thanh Xuan	0	20÷22	14÷16	6÷8	2÷4	45÷47	4÷6	2÷4
	19.8	20÷22	14÷16	6÷8	2÷4	45÷47	4÷6	2÷4
Hai Ba Trung	0	26÷28	9÷11	9÷11	2÷4	32÷34	4÷6	2÷4
	19.8	26÷28	9÷11	9÷11	2÷4	32÷34	4÷6	2÷4
Hoan Kiem	0	19÷21	14÷16	6÷8	3÷5	42÷44	4÷6	2÷4
	19.8	19÷21	14÷16	6÷8	3÷5	42÷44	4÷6	2÷4
Hoang Mai	0	25÷27	20÷22	6÷8	3÷5	30÷32	4÷6	2÷4
	19.8	25÷27	20÷22	6÷8	3÷5	30÷32	4÷6	2÷4
Long Bien I	0	14÷16	5÷6	4÷6	< 1	60÷62	4÷6	2÷4
	19.8	14÷16	5÷7	4÷6	< 1	60÷62	4÷6	2÷4
Long Bien II	0	12÷14	15÷17	4÷6	3÷5	49÷51	3÷5	2÷4
	19.8	12÷14	15÷17	4÷6	3÷5	49÷51	3÷5	2÷4
Highway № 5	0	27÷29	15÷17	7÷9	3÷5	30÷32	5÷7	3÷5
	19.8	27÷29	15÷17	7÷9	3÷5	30÷32	5÷7	3÷5
Gia Lam	0	15÷17	11÷13	4÷6	< 1	54÷56	3÷5	4÷6
	19.8	15÷17	11÷13	4÷6	< 1	54÷56	3÷5	4÷6

dependent both on the salt concentration and on the type of cations. Moum J., et al., (1968) believed that potassium chloride (KCl) seem to be the most suitable chemical when taking into account the ability of increasing the shear strength and the rate of diffusion, as well as the cost and other practical aspects. The list of cations positively affected shear strength of soil behind KCl are Fe^{3+}, Ca^{2+}, Mg^{2+}, and Fe^{2+} respectively; Na^{+} do not perform its role obviously. Subsequently, the research on the role of KCl to undrained shear strength of sensitive clay by Eggestad A., and Sem H., (1976) [5] was obtained a good agreement with previous ones. From 1985 to 1989, Germanov T., and Kirov B., [2, 6] conducted researches on influence of wastewater that include sodium chloride (NaCl), detergent and crude oil on deformation and consolidation of clay paste and loess soil. They concluded that deformation of the saturated loess decreases under action of saline water and increases under action of water containing detergent. The presence of carbonates in the mineral composition of the soils tested is believed the main cause of the change. This has a good agreement with research of Moum J., et al. (1968). Gbenga M.A., et al. (2009) [7] also thought that, Ca^{2+} results in formation of strong bond among clay minerals responsible for the increments of cohesion and friction angle of soil. In some researches with Japanese soils by Komine H., (2007) [8,9] the conclusion was that the soils dominated by smectite-clay mineral are easily degraded by brine water. Therefore water retention and liquid limit of these soils are reduced, and hydraulic conductivity is increased; whereas soils dominated by allophane-clay mineral (it has composition similar to kaolinite) have higher value of liquid limit and water retention, lower value of hydraulic conductivity in seawater. However, Aksoy Y.Y., et al., (2008) believed that the effect of seawater on soil becomes significantly when liquid limit, plasticity and shrinkage indices are more than 110%, 70%, and 104%, respectively [10]; and the permeability is reduced to 70% when freshwater displaces seawater during remediation of an aquifer affected by seawater intrusion (Markus F., et al., [11]).

The important researches on the RRD soft soils in saline-saturated condition were conducted by Truc N.N., Toan D.T, et al. [12-14]. They realized that saline intrusion makes clayey soils in the RRD decrease the general module, shear strength, specific gravity and increased the permeability. For weathering soils in mountainous areas, the changes are nearly vice versa. Kirov B., and Truc N.N., (2010) made an important comparison the variation of geotechnical properties of clayey soils in the RRD and Bulgarian soils in some kinds of saturation mediums [15]. The results are recognized to be different among these soils. The saturated solution and soil mineral composition are the main causes of the change in geotechnical properties of those soils. Although the presence salt does not ordinarily affect the structure of the clay particles themselves, important change in physical and mechanical properties of soil may result [3, 4]. Under mineral aspect, Mondol N.H., et al., (2007) thought that pure smectite is less compressible than pure kaolinite in both dry and brine-saturated states. It is likely that the mechanical compaction found for chlorite and illite will be intermediate between those found for kaolinite and smectite (Chilingar and Knight, 1960; Meade, 1963; Meade, 1966; Rieke and Chilingarian, 1974) [16].

3.2. Change of geotechnical properties of Hanoi soft soils due to saline intrusion

Beside the tests as mentioned above, physical properties of soils, i.e. natural water content, unit weight, and specific gravity of soils are also executed. The variation in physical parameters before and after the saturation of soils with saline water is surveyed, but it is not yet realized the obvious change in law except saturated water content. However, mechanical properties of soils are the focus of this study. In the paper, the authors just give the experimental results of freshwater-saturated soils and soils saturated by 19.8‰ solution of sodium chloride (NaCl). That salty concentration presented is considered as a moderate value of salinity range from 0 to 33‰. The result of laboratory experiments with two cases, saline and fresh water, for soft soils in Hanoi and three areas along the coast of the RRD manifest a remarkable change of mechanical characteristics. The specifications that are being taken into consideration include the coefficient of compression *a*, general module *E*, compression index *Cc*, shear strength parameters *c*, *φ*, and hydraulic conductivity *k*. The representative compression curves of soils are given in fig. 3a, and fig. 3b for the shear strength. The completely precise result is also shown in table 3. The green line (-o-) is illustrated soil saturated by salty water and the red one (-◆-) is for soil in fresh water condition. In the whole cases, the green lines lie under the red ones. This means soils in salty condition are more compressible than that of fresh condition.

In saline-saturated condition, compression index, *Cc*, of Hanoi soft soils is decreased by 10.83% in average when it is compared to that of freshwater-saturated case. Coefficient of compression, a, is also reduced but with a smaller rate, i.e. 2.86 to 4.44 %. General module of soils, *E*, is decreased from 4.65 to 10.06%. The reduction of *Cc*, *a*, and *E* of the rest research areas is performed in the table 3.

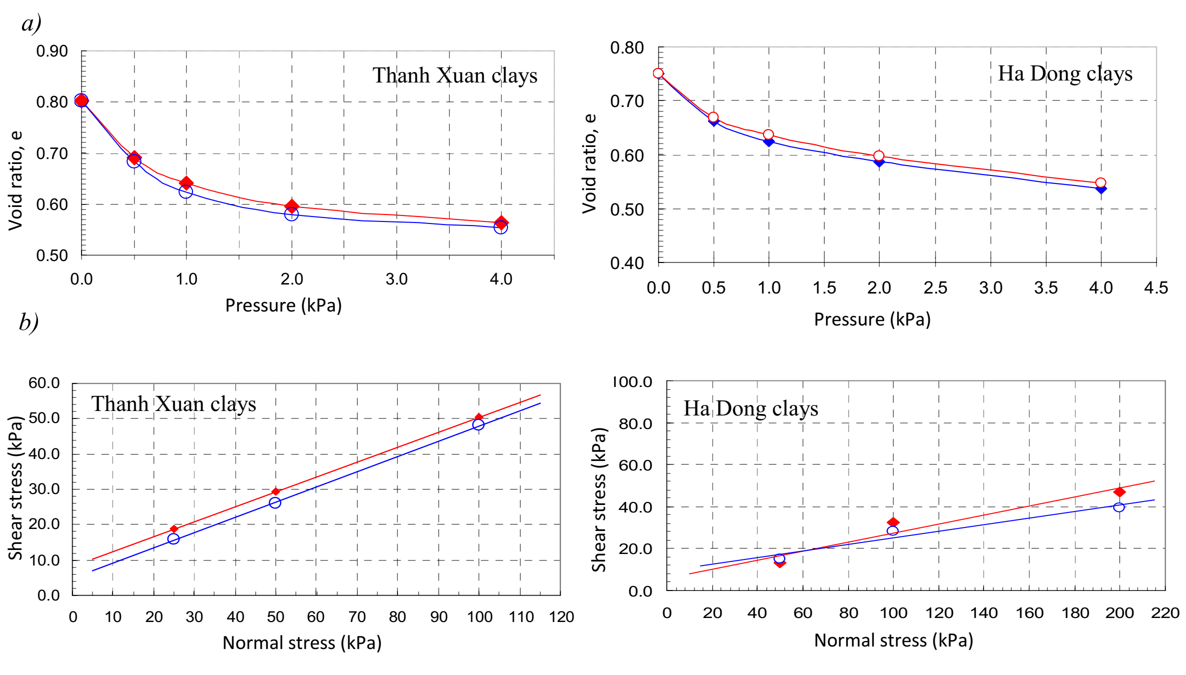

Fig. 3. The average compression curves (a) and shear strength (b) of soils at 2 representative areas (-o- saturated by artificial seawater, -◆- saturated by fresh water)

Table 3. Change rate of geotechnical parameters of soils, comparing before and after saline intrusion

Region	Coef. of compression a (%)	Compression index, Cc, (%)	General module E, (%)	Friction angle, φ, (%)	Cohesion, c, (%)	Hydraulic conductivity, k, (%)
Thanh Xuan*	- 4.44	- 13.17	- 10.06	- 13.04	- 14.96	+ 4.26
Ha Dong*	- 2.86	- 8.50	- 4.65	- 12.81	- 15.14	+ 6.00
Hai Phong**	- 5.00	- 2.88	- 1.61	- 8.32	- 3.50	+ 7.73
Nam Dinh**	- 7.14	- 3.053	- 1.16	- 8.18	- 15.46	+ 3.70
Thai Binh**	- 12.07	- 4.667	- 1.94	- 12.19	- 13.64	+ 2.48

** Research areas in Hanoi, ** Three provinces along the coast of the RRD*

This means once the soils tested are saturated by saline water the compressibility increases.

Similarly, shear strength of soils are also attenuated. In Thai Binh, Nam Dinh, and Hai Phong the decrease in internal friction angle φ of soils reaches 12.19% in maximum, whereas it reaches 13.04% for one of Hanoi area. Cohesion of soils reduces approximately from 13 to 15%. However, shear strength of Hai Phong soils attenuate slighter, this may be due to soil layers in Hai Phong have been affected by seawater naturally.

For the hydraulic conductivity, k, it is increased in saline media. From table 3, one can easily realize that the permeability coefficient is moved up at average value of 4.8 %. For Hanoi soft soils, it is 5.1% in average. Increase in permeability of soil in saline media implies the possibility of increased underground erosion and reduction in load bearing capacities due to washing away of materials.

3.3. Discussion

In the saline-affected media, geotechnical properties depend on type of clay minerals present in the soil. When soil rich in clay minerals such as allophane, or minerals originated from weathering of bed rock, such as kaolinite, or soils contains carbonates (Ca^{2+}, Mg^{2+}), geotechnical properties of saline soils are positively improved. Inversely, soil rich in montmorillonite, illite, and chlorite is then mostly degraded in saline water [2,7,8,9,10,14].

Soft soils in Hanoi are mainly originated from lacustrine and shallow-sea sediment. Clay mineral composition of the soils is predominated by illite. Kaolinite, chlorite, and montmorillonite, respectively are present in the soils with a smaller content. Chlorite and illite mineral have some similar aspects to each other. Their cation exchange capacity (CEC) is from 10 to 40 meq/100g and specific surface area is approximate to each other (10÷55 and 10÷100 m^2/g) (see table 4). These clay minerals are generally close to montmorillonite rather than kaolinite. In addition, the ability of montmorillonite clay to expand increases the surface area and CEC strongly. Under normal conditions, kaolinite minerals are not expandable [17]. This means they are able to swell up and the swellable capacity is stronger than that of kaolinite. The presence of montmorillonite in the soil enhances its expandable capacity. Additionally, in saline-affected media, the interaction of negative-charge layer around clay particle and positive charge in saline water results in degrading of soil. The swellable clay mineral has chemical bond not strong enough, big cation exchange capacity, and big specific surface area.

In Hanoi soft soils, the amount of swellable minerals are predominated, therefore the soils are easily degraded by water rich in positive charge like seawater. Consequently shear strength of soil reduces, compressibility and hydraulic conductivity increases when soil is affected by saline water.

4. Conclusion

Hanoi soft soil is mainly originated from lacustrine and shallow-sea sediment. Mineral composition of the soils determined by X-ray diffraction analysis showed that Illite fluctuated from 12 to 29 percent is predominated clay mineral. Kaolinite, Chlorite, and Montmorillonite, respectively, are

Table 4. Characterization of four mainly clay minerals (after Mitchell, 1976)

Clay mineral	Chemical designation	Bonds between layers	Ion exchange	Capacity of cation exchange (meq/100g)*
Illite	$(K,H_2O)_2Si_8(Al,Mg,-Fe)_{4,6}O_{20}(OH)_4$	K-ions, strong	Some Si always exchanged with Al. K provides balance between the layers	10 – 40
Kaolinite	$Al_4\ Si_4O_{10}(OH)_8$	O-OH, strong	Small	3 – 15
Chlorite	$(SiAl)_8(Mg,Fe)_6-O_{20}(OH)_4$ (2:1 layer)	$(MgAl)_6(OH)_{12}$	Al against Si in 2:1 layer Al against Mg in intermediary layer	10 – 40
Montmo-rillonite	$Si_8(Al_{3.34}Mg_{0.66})-O_{20}(OH)_4$	O-O, very weak, swellable	Mg exchanged with Al	80 – 150

** meq = milliequivalents, i.e. the amount of the substance that in the chemical process, corresponds to 1 mol of the other substance.*

minerals present with smaller content.

In the saline-saturated media, there is no change in mineral composition recorded, but in that media, Hanoi soft soils are degraded. Shear strength of soil reduces, compressibility and hydraulic conductivity increases. That degradation is caused by the interaction of negative charge layer around clay particle and positive charge in saline water. The presence of the montmorillonite, illite, and chlorite makes that interaction easier and the soils more swellable.

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