Iraqi Geological Journal 53 (2A), 2020: 19-34
Http://igj-iraq.org ISSN 2414 - 6064

INVESTIGATION OF SALT, ALUM CONTENT IN SOFT SOILS AND THEIR EFFECTS ON SOIL PROPERTIES: CASE STUDY IN COASTAL AREAS OF VIETNAM

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Received: 21 April 2020; accepted: 29 May 2020

ABSTRACT

Soft soil is widely distributed in Vietnam's coast area, which normally contains salt, organic matters, and its properties can be affected by the saltwater intrusion. This article presents experimental laboratories to investigate the salt, alum contents in some soft soils distributed in the coastal areas of Vietnam, and their effects on the properties of soft soil. To investigate the effect of salt content and pH values on soil properties, the soil was submerged into different solutions of salt content and pH value for 10 days before testing. The experimental results indicated that the average salt content in natural soils in the studied area changed from 0.31% to 1.58% and had a different level of salt contamination. In some places, the soil had a low pH value (pH<4.5) and high sulfate content. The research also showed that the increase in salt and alum contents caused a decrease in undrained shear strength and an increase in liquid limit and compression index.
Keywords: Salt; Alum; pH; Soft soil; Coast

INTRODUCTION

Vietnam has a long coastline of 3260 km and a density river network, which is one of the five countries that will be seriously affected by the change of climate and rise of sea level (Dasgupta et al, 2009). Soft soil is widely distributed in the coastal areas of Vietnam (Nu and Thinh, 2020, Nu et al, 2020) and should be treated before construction. In Vietnam, soft soil can be improved by mixing with the cement and coal bottom ash from thermal power plants or used for concrete pavement (Nguyen et al, 2019, Nu et al, 2019). When the sea levels rise, seawater percolates into groundwater and resulted in seawater migration towards land (Yukselen-Aksoy et al, 2008) and led to a significant change in water resources (Heedan et al, 2017) and affected on the properties of natural soil or improved soil. Thus, it is necessary to clarify the influence of salt, alum content on the physicomechanical properties of the soil. In the literature, the salt content of heavy metals in soil and its effect on some soil properties were also evaluated (Al – Hamdani et al., 2016) or sewage water of sanitation leads to contamination of groundwater (Shaltami et al., 2020). Soil salinization is a serious problem that restricts agricultural productivity worldwide due to climate change (Li et al., 2014). The soluble salts accumulate in the soil and negatively affect soil properties by crop productivity (Setia et al., 2010). Moreover, soil salinization also affected the crop growth and agricultural productivity in the coastal areas (Xie et al., 2019). Thus, the salt content in soil can impact many fields (Al-Hamdani et al., 2016). (Zhang et al. 2019) established the mapping salt marsh soil properties and indicated imaging spectroscopy could estimate the marsh soil salinity and marsh soil organic.

In the world, the effect of salt content on the properties of different types of soil has been investigated. (Anandhanarayanan and Murugaiyan, 2014) reported that the properties of bentonite soil were significantly affected by seawater and different types of saltwater. It also indicated that an increase in cation valance led to an increase in the maximum dry density and a decrease in optimum water content. (Ören and Kaya, 2003) found that the liquid limit of kaolinitic and mixed clay minerals slightly with increasing salt content. By contrast, the salt content causes a decrease in the liquid limit of montmorillonite clays. It related to the changed in the valence of the cation at any given void ratio. (Di Maio et al., 2004) studied the effect of pure water, NaCl solutions, and cyclohexane on the consolidation properties of the Ponza bentonite, commercial kaolin, the Basaccia clays and the Marino clays and found that the compressibility of soil decreased with the increase in pore solution concentration. This phenomenon was attributed to the decreasing in the diffuse double layer (DDL) thickness. (Yukselen-Aksoy et al., 2008) indicated that there were different effects of seawater on Atterberg limits and compressibility of different clays. Accordingly, the effect of seawater was significant when the liquid limit, plasticity, and shrinkage limit indices were higher than 110%, 70%, and 104% respectively. (Mahmoud and Ahmed, 2017) found that the consistency limits, unconfined compressive strength of soil mixed with 80 or 100% saline water were smaller and the consolidation coefficient of soil and the CBR value were higher than those of soil mixed with pure water. In general, the properties of soil effected by salt concentration were mainly related to the diffuse double layer thickness and clay fabric. Recently, the research result of (Truc et al., 2020) indicated that the modulus and bearing capacity of soft soil in the Hanoi area decreased with the increase of salt content. Therefore, the effect of salt on the physic mechanical properties of soil significantly depends on salt content, cation valence, and the types of soils.

The change in the physicomechanical properties of soil because of pH-induced was also examined by previous studies. Gratchev and Towhata (2011) found that the compression index of two Tokyo's natural soils increased as the pH value increased and the effecting factors were clay mineral, soil structure, and the duration of contamination. Bakhshipour et al. (2016) indicated that the maximum dry density, compressive strength of two different residual soils decreased whereas the permeability, liquid limit, and optimum moisture content increased as the pH decreased. It was related to the reduction in the concentration of elements, and the loose structure for both soils. (Spagnoli et al., 2012) reported that the undrained shear strength from Vane shear test varied with the change in pH value and depended on the change of dissolution of Al^{3+} which acted as a coagulant.

Previous studies indicated that some properties of soil could be affected by the salt content, and the alum content (pH value). However, the effects of salt and alum contents in soil significant depending on the types of soil and contents of salt and alum in soil. In addition, the change of alum content (pH values and SO_4^{-2} content) in acid sulfate soil is rarely concerned. Therefore, this study aims to investigate the properties of salt, alum content, and their influences on the properties of soft soil distributed along Vietnam's coast.

MATERIALS AND METHODS

Materials

In this study, undisturbed soft soil samples were taken from the boreholes in some areas along the coast of Vietnam. The location of soft soil samples and the depths of samples are provided in Table 1. The soft soils at all sites expose on the surface and the thickness change from ten meters to more than twenty meters.

Table 1. Location of the soil samples

No	Sample No.	Locations		Depths of samples, (m)
1	S1	Nghe an province	Vinh city	Up to 10
2	S2	Soc Trang province	Long Phu district	Up to 17
	S3		Soc Trang city	Up to 20
3	S4	Bac Lieu province	Bac Lieu city	Up to 13
	S5		Phuoc Long district	Up to 12
4	S6	Ca Mau province	Ngoc Hien district	Up to 2
	S7		Ca Mau city	Up to 14
	S8		Nam Can district	Up to 7
	S9		Dam Doi district	Up to 4
	S10		Tran Van Thoi district	Up to 4
5	S11	Kien Giang province	An Bien district	Up to 15

Methods

The salt content in soil was determined according to BS 1377: 1990: Part 3. The pH value and sulfate content (SO_3) were determined as similar in a study of Al-Rubaiee and Jajjawi (2018), Al-Kaaby and Albadran (2020). Particle size analysis and Atterberg limits of soil were tested according to the American Society for Testing and Materials (ASTM) standard ASTM D422-63 (ASTM, 2011), ASTM D4318-17e1 (ASTM, 2011a) respectively. The Oedometer tests were performed according to ASTM D2485-18 standard to determine the compression index and vertical coefficient of consolidation. The undrained unconsolidated triaxial compression test (UU) and undrained consolidated triaxial compression test (CU) were used for determining the undrained cohesion force and undrained friction angle in accordance with ASTM D2850-15, ASTM D4767-11(2020) in respective. To examine the influence of salt content (NaCl) on some properties of soft soil such as liquid limit, compression index, and shear strength, two methods were used. First, the relationship between average salt content and these properties of soil at all sites was established. Second, soil samples were collected from site S2 (Long Phu – Soc Trang) were used to investigate the influence of salt content on the properties of soil. In the S2 soil sample, the natural salt content is 0.637%. In this study, the different proportions of salt NaCl of 0.837, 1.037, 1.237, 1.637, 1.937, and 2.237% were dissolved in distilled water. These salt contents are 0.2, 0.4, 0.6, 1.0, 1.3, and 1.6% higher than the natural salt content in the S2 sample. Elmashad and Ata (2016) show that the infiltration and swelling potential of soil significantly changed after soaking soil samples in the salt solution. This indicated the salt in the solution has been moved on to the soil sample. Based on that result, in this study, the S2 soil samples in cutter rings with a height of 2 cm, an inner diameter of 6.2 cm was soaked in different salt solutions for 10 days before testing. After soaking, the salt content in the soil, the liquid limit, the compression index, and the undrained shear strength of soil was determined.

To examine the influence of alum content on some properties of soft soil, undisturbed samples were submerged in solution with different pH values (SO_4^{-2} content). The method to control the pH value was similar to the research of Spagnoli et at. (2012). The soil samples were collected from site S11 (An Bien - Kien Giang) to investigate the impact of pH on some properties of soil. All samples were submerging with different pH values of 2.0, 3.0, 3.5, 4.0, and 5.0 for a period of 10 days. After that, Atterberg limits and mechanical properties of soil samples were determined in accordance with the ASTM standard. The unconsolidated undrained (UU) shear box test was used to determine the undrained shear strength of soil according to ASTM D3080-04. The consolidation test was carried out in accordance with ASTM D2485-18.

RESULTS AND DISCUSSIONS

As shown in Fig. 1, soft soils in the study areas have different levels of salt content. In addition, the level of salt contamination at different depths is also differing. The salt content of soft soil in the site S1 (Vinh city, Nghe An province) has the lowest value (0.15 to 0.50 %) and the average (0.31%). The salt content in soft soil at sites S2-S3 (Soc Trang province) is higher than that in site S1 and varies from 0.21% to 2.08% and tends to decrease with increasing depth. The average value of salt content at sites S2- S3 is 1.20%. The salt content in soft soil at sites S4-S5 (Bac Lieu province) changes from 0.87% to 1.94% with a mean value of 1.32%. In addition, the salt content in soil at sites S4-S5 also tends to decrease as the depth increases. The soft soil in sites S6-S10 (Ca Mau province) has a range of salt content (0.32% to 2.70%) and an average (1.58%). The salt content in soft soils at sites S11 (An Bien district, Kien Giang province) varies from 0.60% to 2.48% and the average is 1.48%. From the results, it can be seen that the highest average value of salt content in soft soil is found at sites S6-S10 and closely followed by soft soil at site S11 (An Bien district, Kien Giang province). The reason for the highest value of salt content in soil at sites S6-S10 can be attributed to the existing conditions and the formation of soft soil. At the sites S4-S11, soft soil formed in the marine – river environment. In these sites, soft soil can be affected by saltwater intrusion and has a high salt content due to the low terrain and the dense hydrographic network with many river mouths flowing into the sea and the complex tidal regime. Moreover, human agriculture and fishery activities also promote saltwater intrusion into the land (Ba and Vinh, 2010). According to the salt content, soft soil can be classified as low – saline soil (0.3~1%) or high – saline soil (1~5%). From the experimental results (Fig. 2), it can be seen that the organic matter in the soft soil changes from 0.64% to 9.80%. The organic content of soft soil at site S1, sites S2- S3, sites S4-S5, sites S6-S10, and sites S11 vary from 2.00-5.00%, 0.64-5.31%, 2.50-7.10%, 1.96-9.00% and 1.91%-9.80% in respective. The highest content of the organic matter is found in soil samples in site S11 (An Bien district, Kien Giang province) while the lowest one is observed in soil sample at site S1 (Vinh city, Nghe An province). The experimental results show that the pH values at sites S1-S6, S7-S10 is higher than pH = 7. By contrast, the soft soil in S8 and S11 has a pH value of 4.0 and 4.5. Soft soils in these sites were classified as acid sulfate soil and acid sulfate soil – saline soil respectively. In these sites, the soft soil has high organic content and SO_4^{2-} content, this is due to the microbial activity and anaerobic conditions, the soil formed the low value and high SO_4^{2-} content and can be affected on the properties of soft soil.

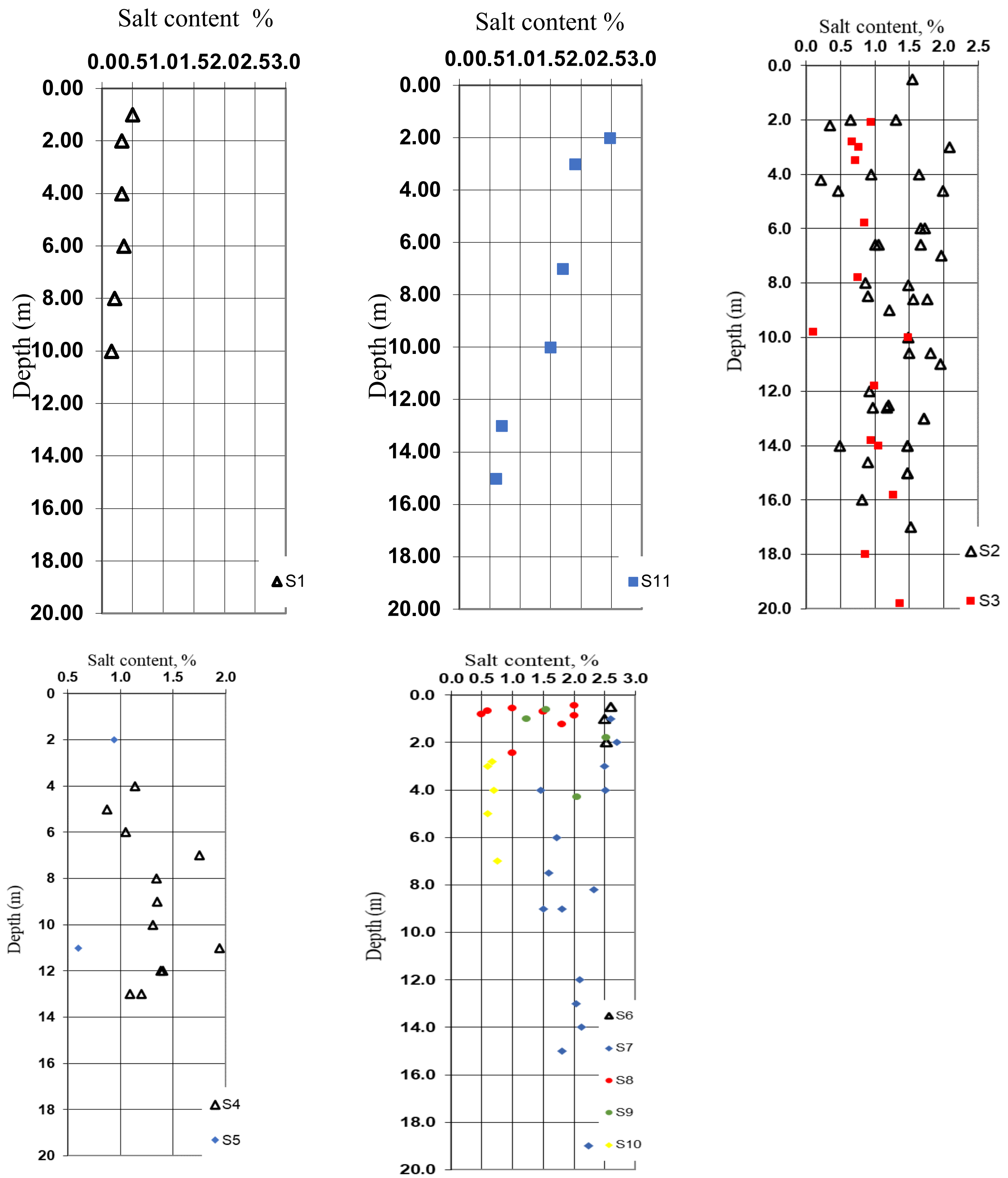

Fig. 1. The salt content of natural soft soil at different sites

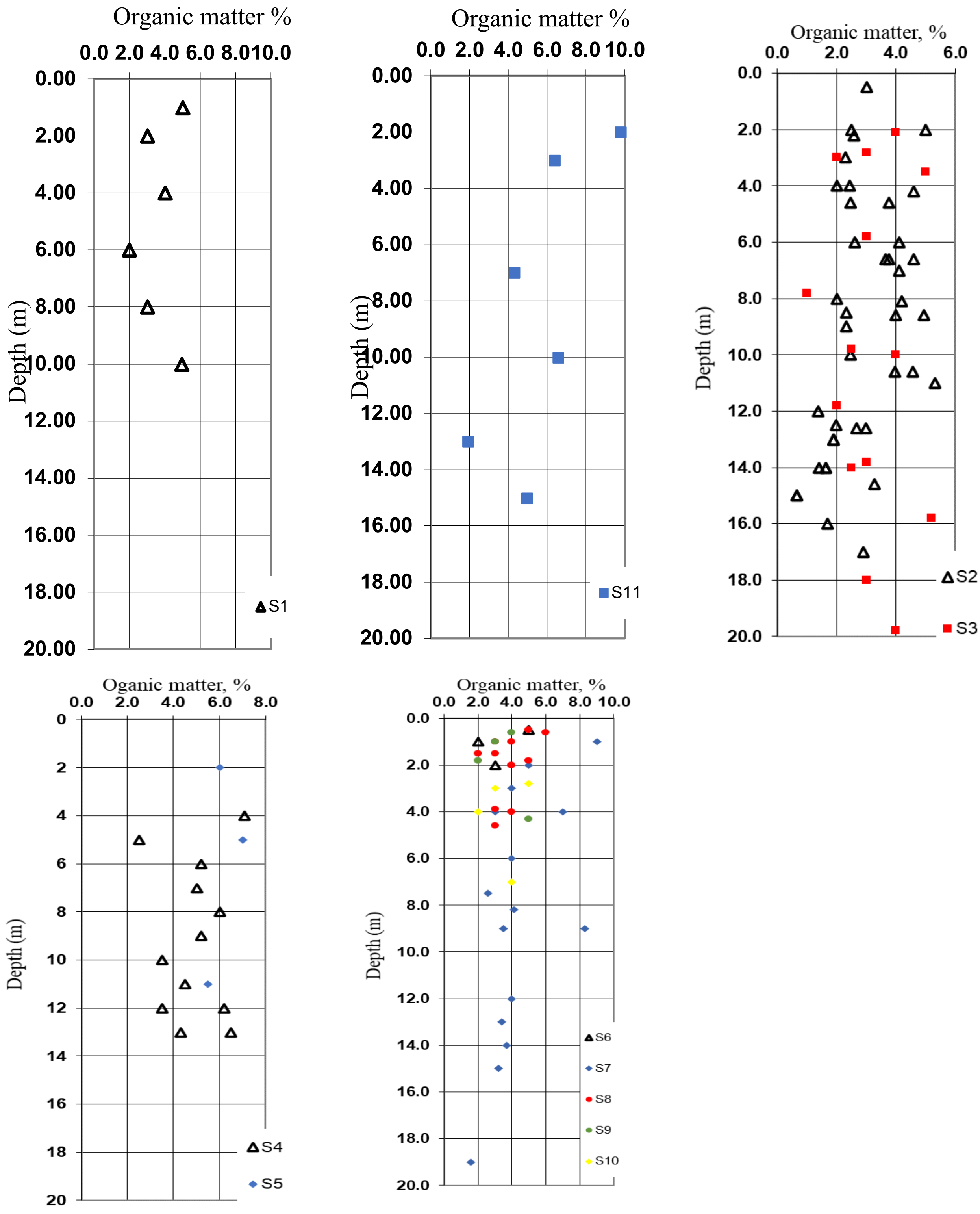

Fig. 2. The organic matter of soft soil at different sites

Table 2. Physico-mechanical properties of natural soils

Physico-mechanical properties			Value				
			Site S1	Sites S2-S3	Sites S4-S5	Sites S6-S10	Site S11
Particle size, %	Sand		33.1	13.6	13.3	12.4	19.4
	Silt		50.7	43.1	39.2	34.2	42.5
	Clay		16.5	43.3	47.1	53.9	37.5
Water content, w, %			35.9	52.3	69.8	74.8	74.2
Unit weight, γ, g/cm^3			1.82	1.68	1.55	1.53	1.54
Dry unit weight, γ_c, g/cm^3			1.34	1.10	0.92	0.88	0.89
Specific gravity, Δ, g/cm^3			2.67	2.69	2.67	2.67	2.67
Void ratio, e			0.996	1.445	1.913	2.046	2.011
Porosity, n, %			49.9	59.1	65.7	67.2	66.8
Saturation, G, %			96.5	97.4	97.2	97.7	98.3
Liquid limit, LL, %			35.3	50.1	64.6	68.1	67.0
Plastic limit, PL, %			22.1	24.7	31.3	28.2	32.8
Plasticity index, IP, %			13.2	25.4	33.3	39.9	34.3
Liquidity index, I_S, %			1.05	1.09	1.15	1.17	1.21
Undrained shear strength	*UU*	Cu, kPa	17.4	12.3	12.1	10.4	11.5
		φ_u, degree	1°28′	°56′	1°17′	°52′	°11′
	Q_u	Q_u, kPa	40.2	27.0	23.1	18.4	22.0
		C_u, kPa	20.2	13.5	11.6	9.2	11.2
	VST	S_u, kPa	22.5	17.8	12.7	18.4	16.7
Total shear strength	Ccu, kPa		11.3	13.2	13.5	11.6	11.9
	φc_u, degree		13°26′	13°29′	13°21′	13°38′	13°16′
Effective shear strength	$C'cu$, kPa		8.2	11.4	12.4	10.7	9.2
	$\varphi'cu$, degree		28°19′	22°41′	19°26′	23°33′	22°43′
Pre-consolidated pressure, Pc, kG/cm^2			0.71	0.79	0.53	0.58	0.49
Compression index, Cc			0.207	0.478	0.722	0.807	0.749
Recompression index, Cr			0.033	0.090	0.126	0.177	0.160
Coefficient of consolidation, $Cv.10^{-3}$ cm^2/s			1.03	0.52	0.21	0.25	0.46

From the experimental results in Table 2, it can be found that soil is in very soft state, the liquid limit is higher than 1.0. The average water content varies from 35.9% at sites S1 (Vinh city, Nghe An province) to 74.8% at sites S6- S11 (Ca Mau province). The average porosity of soil is high and changes from 0.999 at sites S1 to 2.046 at sites S6-S11.

The compression index *Cc* changes from 0.207 at site S1 to 0.807 at site S6-S11. It shows that soft soil has high compressibility. The average undrained cohesion (Cu) obtained from UU test ranges from 10.4 kPa at site S6-S11 to 17.4kPa at site S1. The vertical coefficient of consolidation of soft soil varies from $0.21\times10^{-3}cm^2/s$ to $1.03\times10^{-3}cm^2/s$. Thus, it can be found that the soft soil in sites S6-S11 has the highest water content, void ratio, compression index, and the lowest undrained shear strength. In general, all soils listed in Table 2 are also unfavorable for construction activities.

Effects of the Salt Content

First, the relationship between salt content and some properties of natural soils were established and provided in Figs. 3, 4 and 5. The increasing of the salt content causes an increasing in the undrained shear strength (UU) and a decreasing in the liquid limit, and compression index (C_c).

At site S1, salt content in soil is the lowest and the undrained shear strength of the soil is the highest, the compression index and the liquid limit of the soil are the lowest. By contrast, salt content in soil at site S6-S10 is the highest and the undrained shear strength of the soil is the lowest, the compression index and the liquid limit of the soil are the highest.

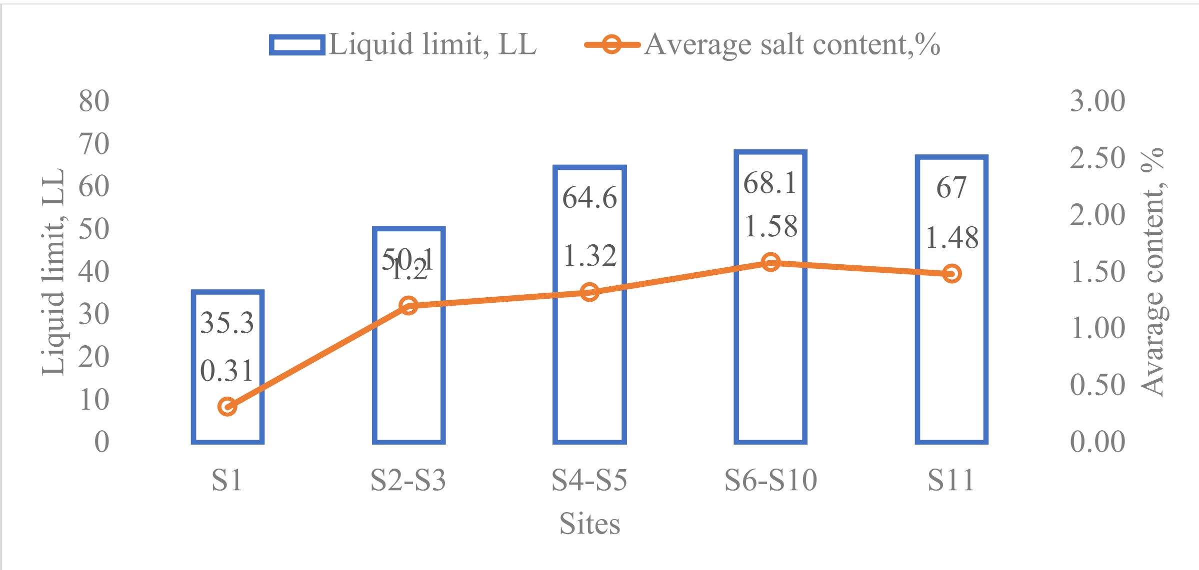

Fig. 3. The relationship between the salt content and the liquid limit of the soft soil

Fig. 4. The relationship between salt content and undrained shear strength obtained from UU test of soft soil

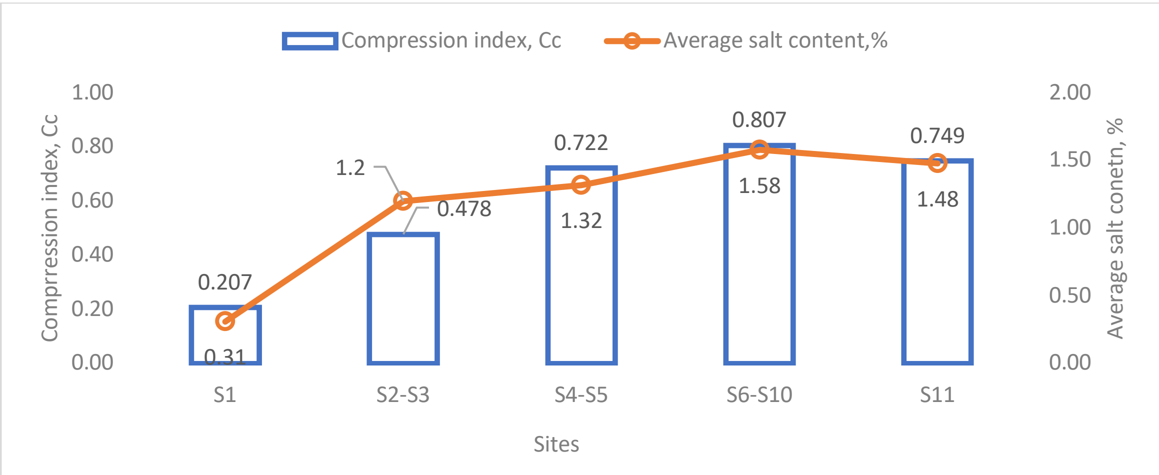

Fig. 5. The relationship between salt content and compression index (Cc)

Second, the influence of salt content on some properties of soil at site *S2* (Long Phu district, Soc Trang province) is investigated. Figs. 6 and 7 show the effect of salt content on the compression index (Cc) and liquid limit (LL) of soft soil in site S2 (Long Phu, Soc Trang province). It indicates both liquid limit and compression index increase as the salt content increase from 0.458 to 1.299%. Accordingly, the compression index and liquid limit increase from 0.458 to 0.721 and 60.5 -77.2% respectively. The reason for increasing index and liquid limit with increasing salt content can be assigned to the fabric of clay particles (Sridharan and Rao, 1975; Sridharan et al., 1988; Sridharan et al, 2000). (Nu and Ngoc, 2020) explained the reason is that the lower salt concentration made an increase in the diffuse double layer thickness and fabric changes. By increasing the salt content from 1.299 to 2.077%, the liquid limit, and the compression index decrease from 0.721 to 0.409, and 77.2 to 57.3% in respective. It was believed that the diffuse double layer thickness decreases because of the flocculation of clay particles when the salt content increase (Nu and Ngoc, 2020). (Anwar et al., 2018) indicated that the salt content increases with the increase of liquid limit because of the decreasing of the interparticle distances.

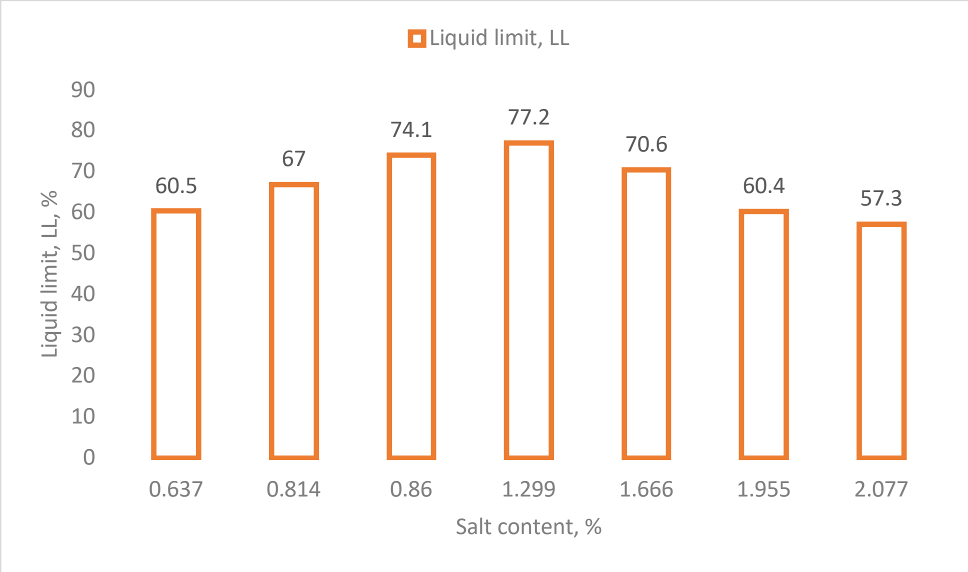

Fig. 6. The relationship between compression index Cc and salt content at site S2 (Long Phu, Soc Trang province)

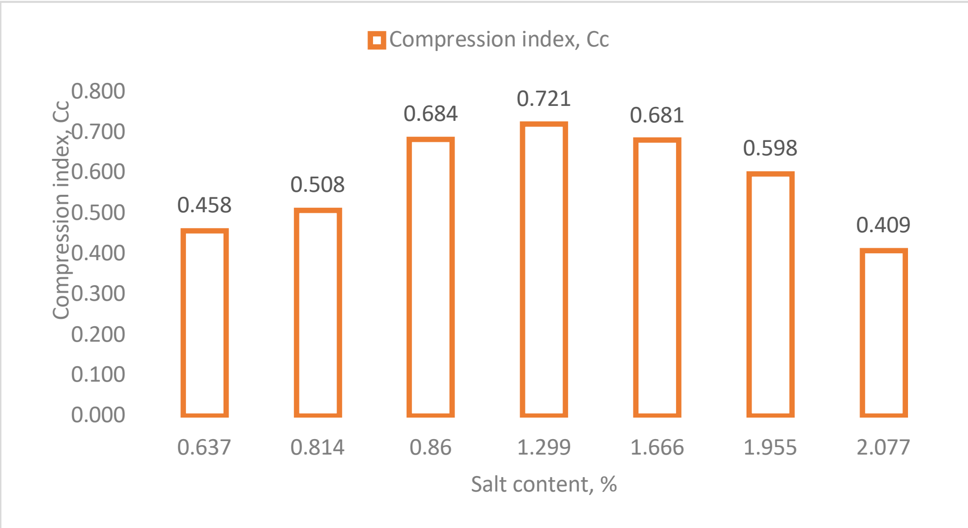

Fig. 7. The relationship between the liquid limit *LL* and salt content at site *S2* (Long Phu, Soc Trang province)

Fig. 8 shows that the increasing of salt content causes a decreasing in the undrained shear strength obtained from UU test. The undrained shear strength decreases from 17.8kPa to 7.1kPa when the salt content increases from 0.637% to 2.077%. It is consistent with the results of Truc et al. (2020) that the deformation modulus and bearing capacity decrease with the increasing of salinities.

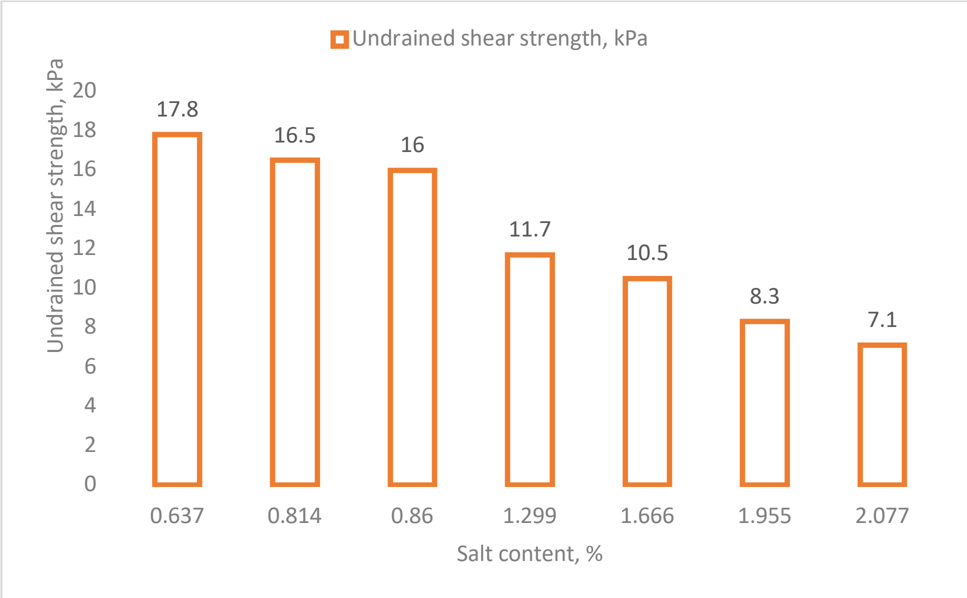

Fig. 8. The relationship between salt content and undrained shear strength of soft soil at site *S2* (Long Phu, Soc Trang province)

Effect of the Alum Content (pH Values)

Fig. 9 shows the effect of different pH values on the Atterberg limits of soft soil. It can be found that the consistency limits increased with decreasing in pH value. It is similar to the experimental results of Bakhshipour et al. (2016). It may be due to the fact that the attractive force between the increased with increasing surface tension led to an increase in the liquid limit (Matsumoto et al., 2018).

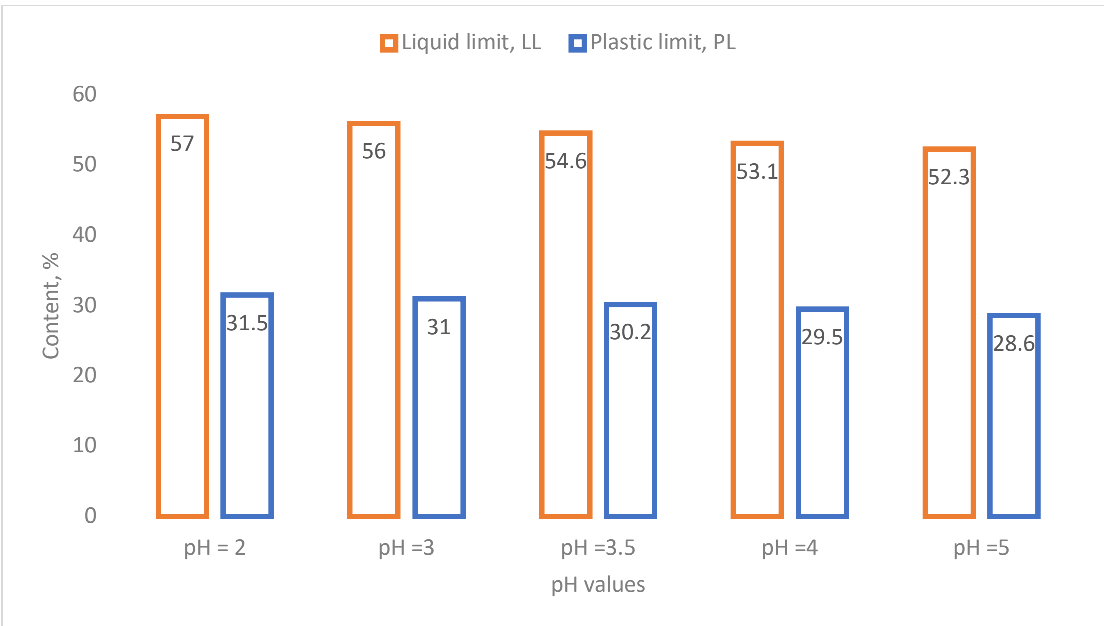

Fig. 9. The relationship between pH-induced and Atterberg limits of soft soil at site S11 (An Bien, Kien Giang province)

Figs. 10 and 11 show the effect of pH value on the compressibility and undrained shear strength of soft soil. From the research results, it indicates that the decrease of pH value causes decrease of undrained shear strength otherwise compressibility of soil increases. Bakhshipour et al. (2016) found that the low value of pH caused a decrease in the compressive strength of soil. This reason explained that the infiltration by artificial acid most of the minerals was leached out from the soil, destroy the bonds between clay particles/aggregates, and thus a significant change in the mineral structure. It was also similar to the results of Momeni et al. (2020) that the more acidity (lower pH value), the more would increase the consistency limits and unconfined compressive strength (UCS) values decrease. (Gratchev and Towhata, 2016) indicated that in acidic pH, the compressibility of kaolinite soils increases at low pH. The reason for increasing compressibility can be attributed to the destruction of the carbonate bonds between clay particles form a loos structure with larger voids (Gratchev and Towhata, 2016).

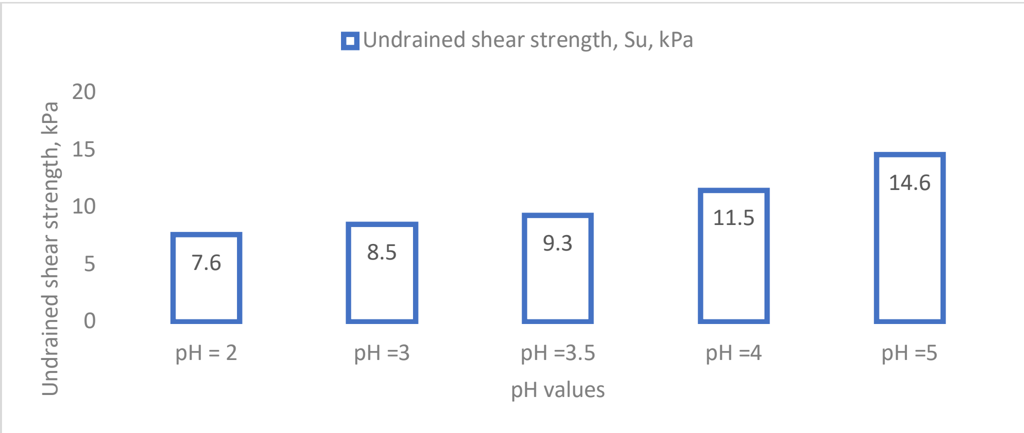

Fig. 10. The relationship between pH-induced and undrained shear strength of soft soil at site S11(An Bien, Kien Giang province)

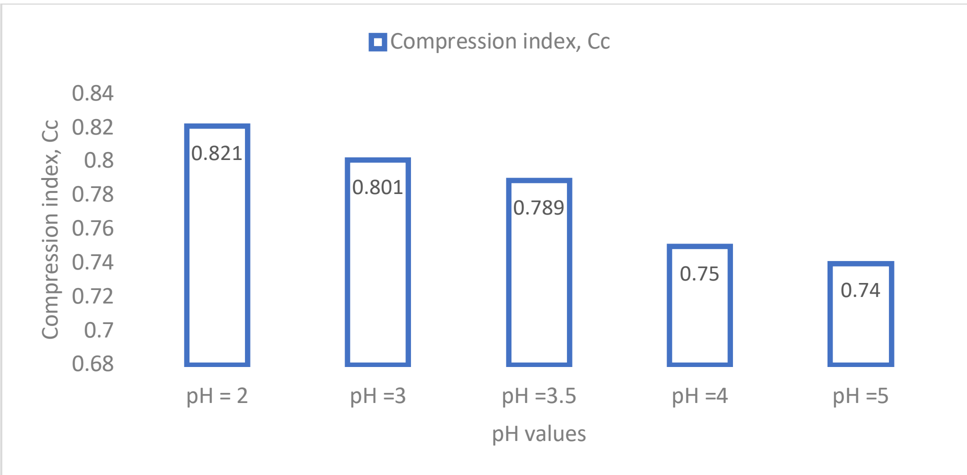

Fig. 11. The relationship between pH-induced and compression index of soft soil at site S11(An Bien, Kien Giang province)

CONCLUSIONS

From research results, some conclusions can be drawn as follows:

1. The soft soils distributed at study locations exposed on the surface with high compressibility, low coefficient of consolidation, and low undrained shear strength. These soils are classified as low – saline soils or high – saline soils. In some areas, soil belongs to acid sulfate soils.
2. The increase in salt content in soft soil causes a decrease in undrained shear strength and an increase in compression index, liquid limit of soft soil.
3. The increase of pH value in soft soil leads to a decrease in Atterberg limits, compression index and an increase in undrained shear strength.

ACKNOWLEDGMENTS

We would like to thank the support of Ha Noi University of Mining and Geology, Ministry of Education and Training to complete this study. We are very grateful to the reviewers for their appropriate and thoughtful suggestions to improve the paper. The authors are very grateful to the editor in chief Prof. Dr. Salih M. Awadh, the secretary of Journal Mr. Samir R. Hijab. and head of the technical editors Dr. Heba S. Al-Mimar for their great efforts and valuable comments.

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