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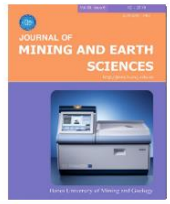

The effects of salt contents on the geotechnical properties of some soft soils in the coastal area of Vietnam

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ABSTRACT

Soft soil is widely distributed in Vietnam, especially along with the coastal areas. Some geotechnical properties of soft soil can be affected by seawater intrusion due to climate change and sea-level rise. However, the research on the effect of seawater on geotechnical properties of soft soil in coastal areas of Vietnam is still limited. In this study, the effects of salt solutions with different seawater proportions on some geotechnical properties of soft soil distributed in some areas from Mong Cai to Thanh Hoa province have been extensively investigated. The undisturbed soil samples were soaked into different salt solutions for ten days before testing. The research results show that the increase in seawater proportions causes an increase in salt content in the soil. Regarding some geotechnical properties, the compression index, and vertical coefficient of consolidation increase while the Atterberg limits and the undrained shear strength of the soil decrease as the salt contents in soil increase.

1. Introduction

Vietnam is one of the countries that will be seriously affected by climate change and sea-level rise (Irish Aid, 2017). The increase in sea level will be from 49 to 95 cm by the last 21st century (MONRE, 2012), and a large area near the coast can be inundated. In addition, the seawater can migrate to land in coastal areas due to the lowering groundwater level below the sea level. Therefore, the effects of saline water on the engineering properties of soil need to be considered (Yukselen-Aksoy at el., 2008).

So far, the effect of saline water, salt contents on the properties of different types of soil have been investigated worldwide (e.g., Yukselen-Aksoy at el., 2008, Studds et al., 1998; Alawaji, 1999; Ören and Kaya, 2003; Mishra et al., 2005, 2006, 2009; Arasan, 2008; Di Maio et al., 2004; Dutta and Mishra, 2016). Ören and Kaya (2003) indicated that the liquid limit of kaolinitic and mixed clay minerals slightly increased with increasing salt content. In addition, the liquid limit, plastic, and shrinkage limits of soil increased as the cation valence increased. Di Maio et al. (2004) reported that the salt solutions significantly affected the properties of bentonite such as liquid limit, compressibility while their effects on the properties of commercial kaolin were negligible. These findings indicated that the

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effect of salt contents on the properties of kaolin clay was insignificant in comparison with those of bentonite since the diffuse double layer (DDL) thickness of kaolin was significantly lower than that of bentonite (Sridharan and Rao, 1975; Di Maio et al., 2004; Dutta and Mishra, 2016). For natural clays, Yukselen-Aksoy at el. (2008) investigated the effect of seawater on consistency limits and compressibility characteristics of ten clayey soils. The research results indicated that the effect of seawater on consistency limit and compressibility behavior of soil with liquid limits up to 110% was negligible. The effect of seawater was most noticed for soils having a high content of montmorillonite mineral. Arasan (2008) examined the effect of inorganic salt solutions on the consistency limits of CL and CH clays. For CL clay, the consistency limit increased as the salt concentration increased up to around 0.2 mmol/l (M). This can be attributed to the dispersion and deflocculation of soil particles. Above 0.2 M, the increase in the plastic limit was insignificant due to the damage of soil fabric. For CH clay, the increase in salt contents up to 0.2 M led to a decrease in the liquid limit. This was due to the flocculation and reduction in the thickness of DDL. The plastic limit decreased at low salt concentrations (0 to 0.001 M), then increased with increasing salt concentration to 0.2 M. The plastic limit was not significantly affected by the salt concentration at above 0.2 M. Recently, Truc et al. (2019) studied the effect of saline intrusion on the properties of cohesive soils in the Red River Delta, Vietnam. The research found that the deformation modulus, bearing capacity decreased with the increase of salt contents. In general, the effect of salt concentration on the properties of soil is mainly related to the DDL thickness and clay fabric. Besides, the effect of salt on the properties of soil depends not only on the salt contents, cation valence but also on the types of soil. However, in most of these investigations, salt solutions (artificial or seawater) with different salt concentrations mixing directly with soil have been utilized. In fact, in the context of sea-level rise, the salt in the seawater can be gradually intruded into the pore fluid system of soil.

In Vietnam, soft soils are widely distributed, especially along the coast from Red river delta to Mekong river delta (e.g., Giao and Hien, 2007; Truc et al., 2019; Phuc and Giao, 2020; Quang and Giao, 2014, Nu et al., 2020). Therefore, in the context of climate change and sea-level rise, the effect of salt intrusion on some geotechnical properties of these soft soils needs to be investigated. In this study, the effects of salt contents on some geotechnical properties (Atterberg limits, compressibility, and undrained shear strength) of some natural soft soils distributed along the coast from Mong Cai to Thanh Hoa province have been examined. Furthermore, the intrusion of salt from the environment into the pore fluid system of soil also has been evaluated. The salt solutions with different salt contents were created by mixing distilled water with different proportions of seawater. The undisturbed soil samples were submerged in the salt solutions for 10 days before testing.

2. Materials and methods

2.1. Soil samples

The soil samples distributed in some locations along the coastline of Vietnam from Mong Cai to Thanh Hoa were collected for this investigation. Undisturbed soil samples were taken in Mong Cai – Quang Ninh (M1- mbQ_2^3), Hai Phong (M2- $mQ_2^{1-2}hh_2$; M3 - $mbQ_2^{1-2}hh_1$), Cua Ba Lat - Nam Dinh (M4 - $amQ_2^3tb_3$), and Thanh Hoa (M5- mbQ_2^3). Some properties of soft soil samples are shown in Table 1. It can be seen that the salt contents in these soil samples slightly range from 0.24 to 0.36 %. These soil samples are classified as less salt contaminated soil, except for M3 in Hai Phong classified as no salt contaminated soil. This can be due to the distribution depth of this soil sample. As shown in Table 1, this sample was taken from the deeper layer than other samples. The clay contents in these soils vary from 19.5 to 53.4%. The highest content of clay fraction was found in soil samples in Hai Phong (M3), while the lowest one was observed in the soil sample (M1) in Quang Ninh.

Table 1. Some properties of soft soil samples.

Samples	Formation	Location	Depth of samples	Particle size, %			Organic content, %	Salt content, %	pH value
				Sand (2-0.05 mm)	Silt (0.5-0.005 mm)	Clay (<0.005 mm)			
M1	mbQ_2^3	Mong Cai, Quang Ninh	2.2-3.0	52.8	26.5	19.5	2.35	0.35	6.65
M2	$mQ_2^{1-2}hh_2$	Hai Phong	4.0-4.5	35.9	30.8	33.3	2.79	0.36	7.08
M3	$mbQ_2^{1-2}hh_1$	Hai Phong	8.0-9.5	27.0	19.6	53.4	4.30	0.24	7.22
M4	$amQ_2^3tb_3$	Ba Lat, Nam Dinh	0.0-1.0	50.3	24.7	25.0	2.79	0.31	6.11
M5	mbQ_2^3	Bim Son, Thanh Hoa	0.0-1.0	39.9	25.8	34.3	6.71	0.33	7.17

Table 2. Chemical composition of seawater.

Cation	Na + K	Ca^{2+}	Mg^{2+}	NH_4^+	Fe^{2+}	Fe^{3+}
mg/l	2280.0	50.1	164.2	4.42	0.1	0.2

2.2. Seawater

The seawater samples were taken from the sea in Mong Cai of Quang Ninh province. The salinity of seawater is 14g/l and the pH value of 7.8. The chemical composition of seawater is provided in Table 2.

2.3. Methods

To investigate the effect of different salt contents on properties of soil, the different salt solutions were created by mixing distilled water with seawater at different proportions. Distilled water was mixed with 0% seawater (salt concentration is 0 g/l); 30% seawater (salt concentration is 4.2 g/l); 50% seawater (salt concentration 7.0 g/l); 70% seawater (salt concentration of 9.8 g/l). The undisturbed soil sample in the cutter ring with a height of 2 cm, an inner diameter of 6.2 cm, was soaked in different salt solutions for 10 days before testing. The soil samples were soaked in the salt solutions to the depth of about 10 cm, equal to a pressure of 10 kPa. The time of soaking the samples in the salt solution is roughly calculated based on Fick's law of diffusion because of the difference in salt concentration between in and out of soil samples. For each type of soil, three soil samples in cutter rings were prepared and soaked in each salt solution. One sample was used for physical property tests (salt contents and Atterberg limits), one sample for consolidation test, and the last one for the shear strength test. The salt contents in soil and Atterberg limits were conducted according to TCVN 8727:2012 and TCVN 4197:2012, respectively. The oedometer tests were conducted in accordance with ASTM D 2485 to determine the compression index and vertical coefficient of consolidation. The unconsolidated undrained (UU) shear box test was used for determining the undrained shear strength of soil following TCVN 4199:1995.

3. Result and discussions

3.1. The salt content in the soil after soaking in the salt solution

The results of salt contents in soil samples after soaking in different salt solutions for 10 days are listed in Table 2, and their variations are plotted in Figure 1. In general, the salt content in all soil samples increases as the salt content in submerged solutions increases. After 10 days of soaking in different salt solutions, the salt concentration in the soil samples of M1, M2, M3, M4, and M5 increased 60-200%, 28-153%, 54-221%, 42-161%, and 18-194% in respective. The highest increase in the salt content in soil is found in the soil sample M3, while the lowest increase in salt content is observed in the soil sample M2. This can be attributed to the salt content in the original soil sample. For soil sample M3, the salt

Table 3. The salt content in soils before and after submerging in different salt solutions.

Samples	Formation	The salt content in soil, %				
		Original soil	Solution with 30% seawater (4.2g/l)	Solution with 50% seawater (7.0g/l)	Solution with 70% seawater (9.8g/l)	Solution with 100% seawater (14g/l)
M1	mbQ_2^3	0.35	0.56	0.71	0.87	1.05
M2	$mQ_2^{1\text{-}2}hh_2$	0.36	0.46	0.60	0.68	0.91
M3	$mbQ_2^{1\text{-}2}hh_1$	0.24	0.37	0.52	0.75	0.77
M4	$amQ_2^3tb_3$	0.31	0.44	0.55	0.71	0.81
M5	mbQ_2^3	0.33	0.39	0.72	0.93	0.97

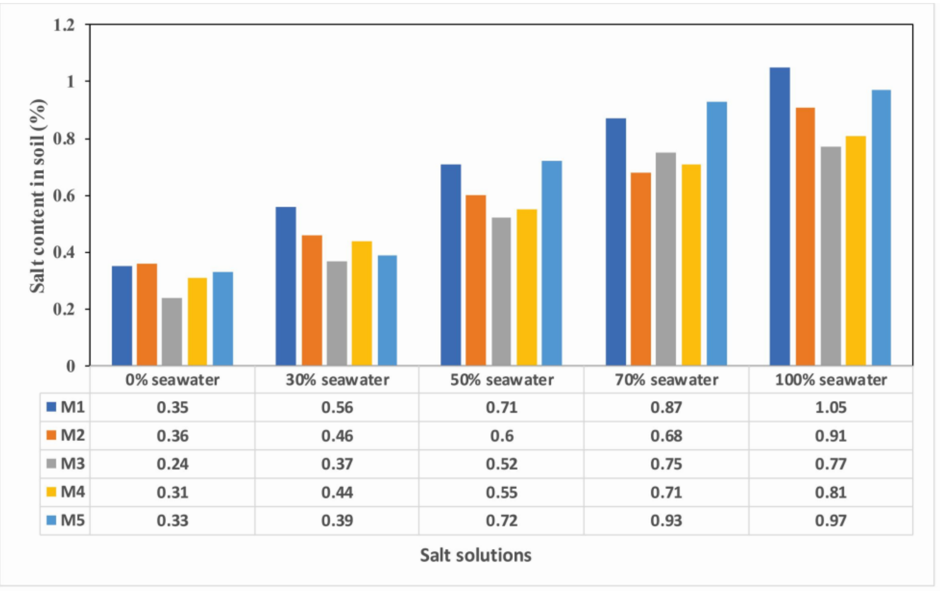

Figure 1. Variation of salt content (%) in the soil after submerging in different salt solutions.

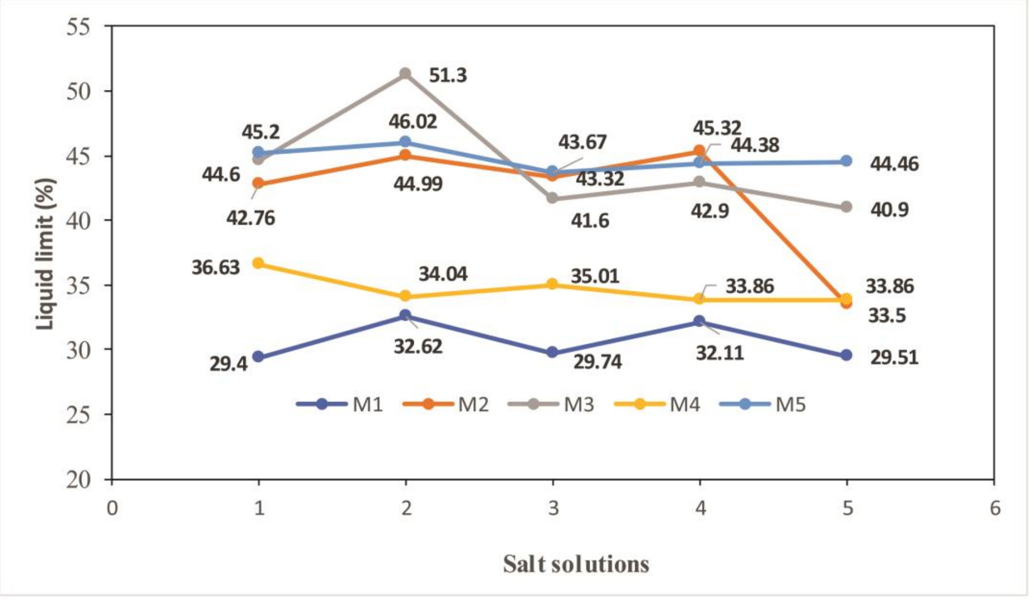

Figure 2. The variation of the liquid limit in different salt solutions.

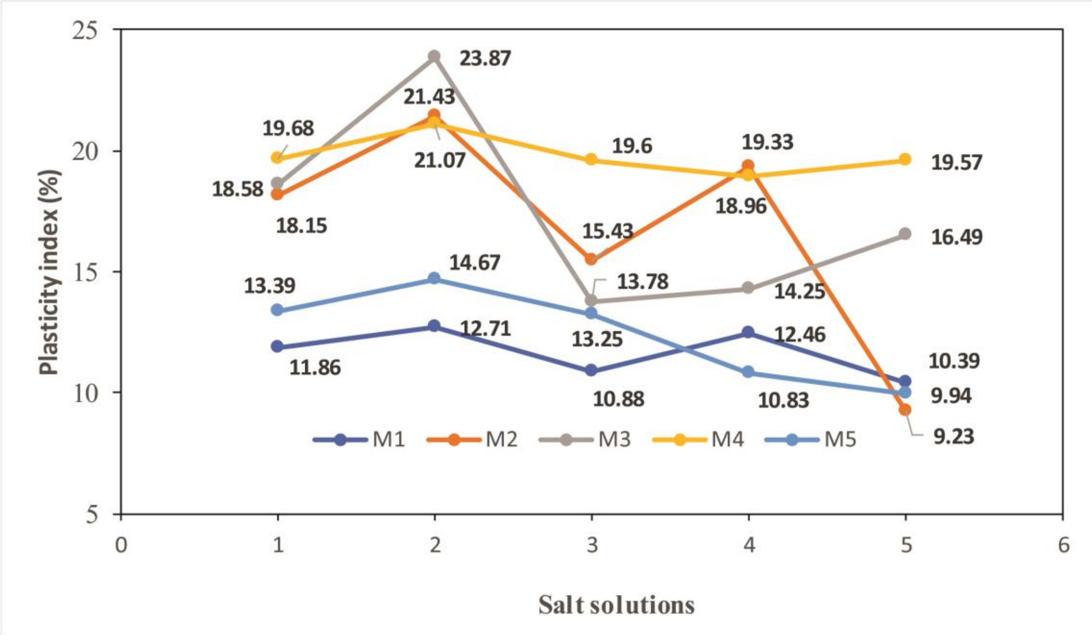

Figure 3. Variation of the plastic limit of soil in different seawater solutions.

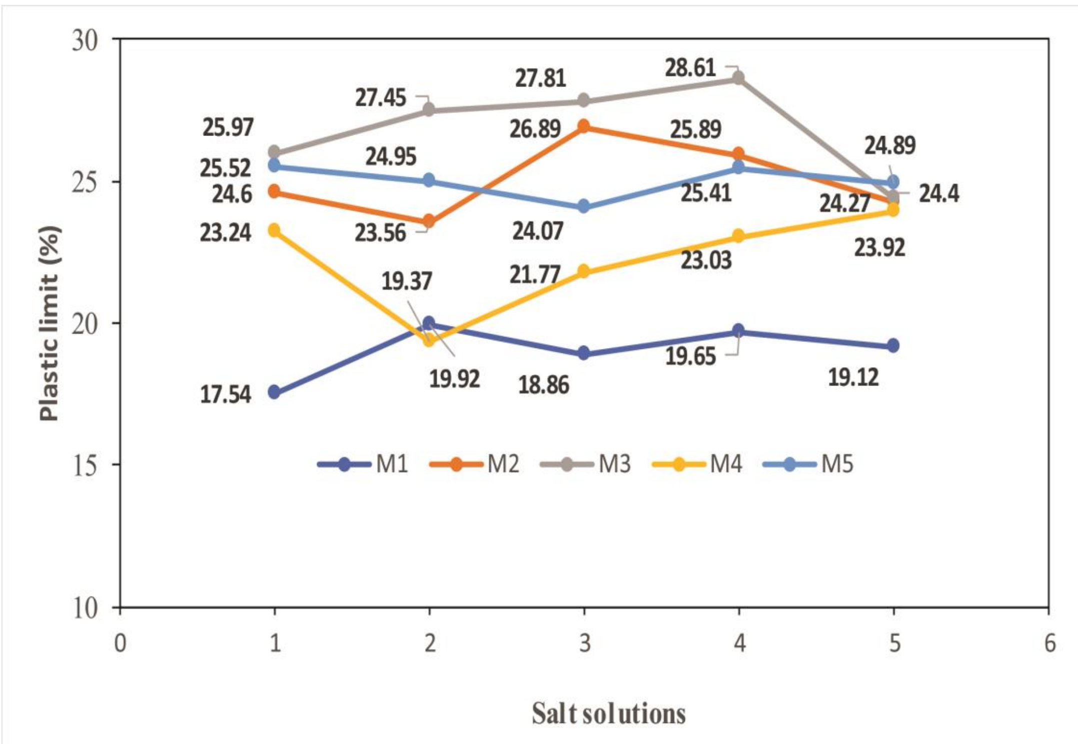

Figure 4. Variation of the plasticity index of soil in different seawater solutions.

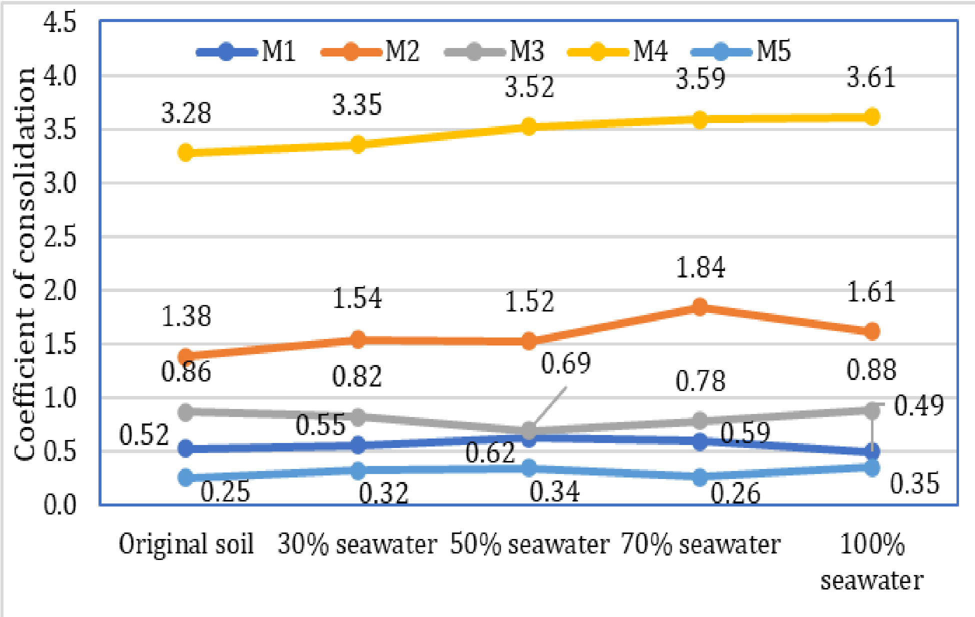

Figure 5. Variation of compression index of soil after soaking in different salt solutions.

content in the original sample was very low. Thus, after soaking, the salt content in this sample may increase higher than that in other samples. By contrast, the salt content in the original sample M2 was rather high. This may lead to a low increase in the salt content of this sample after soaking in the salt solution. In addition, the permeability of these soil samples may also affect the salt content in the soil after soaking.

3.2. Physico – mechanical properties of soil

3.2.1. Atterberg limits

The liquid limit, plastic limit, and plasticity index of soil samples after soaking in different salt solutions for 10 days are presented in Figures 2-4.

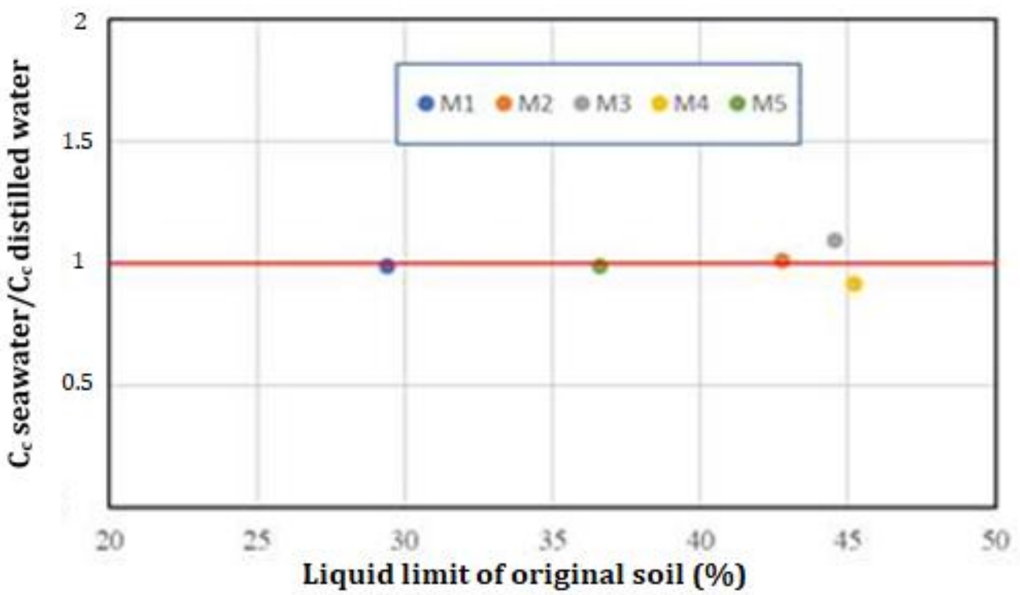

Figure 6. Relationship between the ratio of C_c seawater/C_c distilled water and the liquid limit of the original soil.

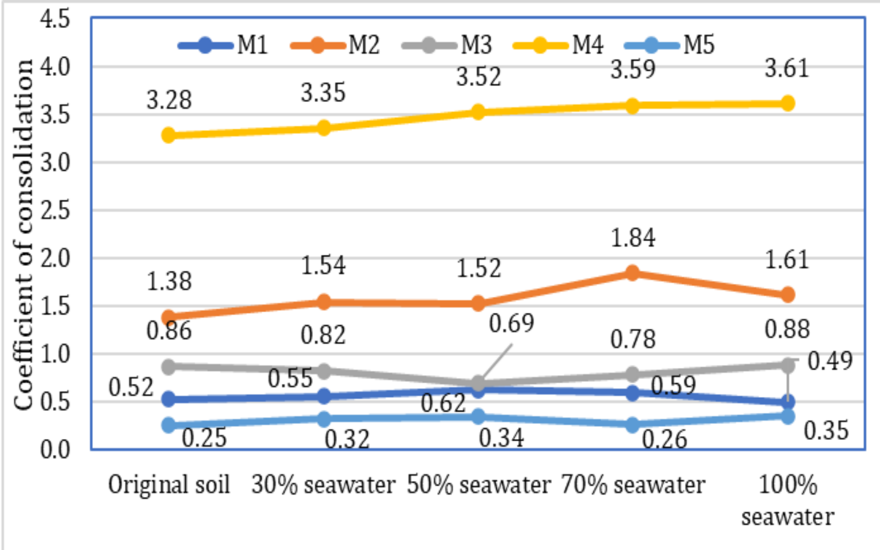

Figure 7. Variation of the vertical coefficient of consolidation (Cv) after soaking in different seawater solutions.

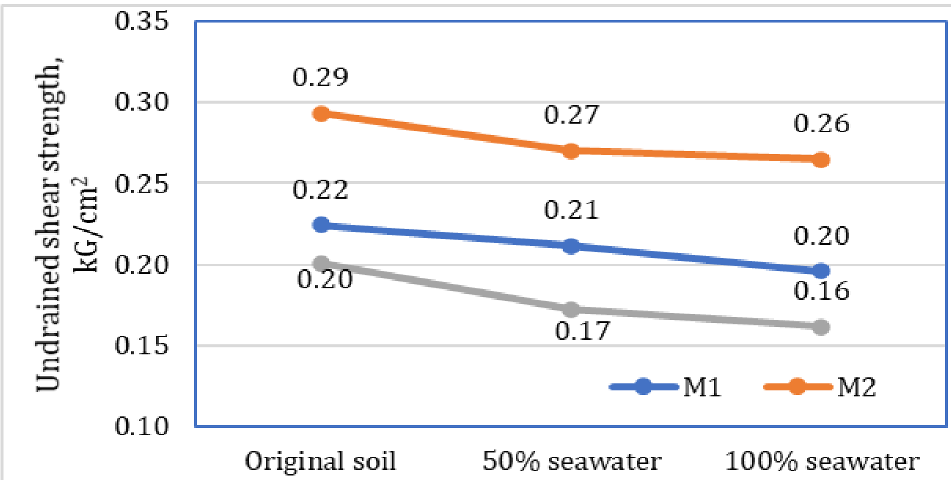

Figure 8. Variation of undrained shear strength of soil after soaking in different salt solutions.

In general, it is found that the submerging of soil in 30% seawater solution resulted in an increase in the liquid limit, except sample M4, and the ranges of increase values are from 1.81% to 15.02%. This phenomenon was also found in kaolin and Bangkok clay (Horpibulsuk et al., 2011). The research results of Horpibulsuk et al. (2011) showed that the liquid limits of kaolin clay and Bangkok clay increased with increasing the salt concentration from 0.001 to 0.01 M and from 0.01 to 0.1M respectively. The reason for increasing the liquid limit with increasing salt concentration can be attributed to the fabric of clay particles (Sridharan and Rao, 1975; Sridharan et al., 1988; Sridharan et al., 2000). The liquid limit of soil tends to decrease with increasing the seawater proportions above 30%, and the ranges of decrease values after soaking in 100% seawater are from 1.64% to 21.66%, except for soil sample M1 in Mong Cai. After submerging in 100% seawater, the liquid limit of the M1 sample in Mong Cai increases by 2.93%. The change in the plastic limit is complex. However, the decrease or increase in the plastic limit of soil after sooking is insignificant. When soil samples were submerged in 100% seawater solution, the decrease in plastic limit was from 1.34% to 6.05%, except for soil sample M1 in Mong Cai. For this sample, after soaking in 100% seawater solution, the plastic limit is increased by about

9%. The plasticity index increases as the seawater increase from 0 to 30%. When the seawater increases above 30%, there is a decrease in the plasticity index with the level of decrease from 0.56% to 49.15%. The highest decrease in the plasticity index is found in the M4 sample in Nam Dinh province. The change in the plasticity index is seen to be different in different locations. This can be attributed to the differences in the characteristics of each soil sample, such as clay content, clay mineral. The results of Atterberg' limits in the present study are consistent with those in the research of Yukselen-Aksoy at el. (2008). This also indicates that soaking soil in seawater solutions can also lead to a significant decrease in the plasticity index.

3.2.2. Compressibility characteristics

The compressibility characteristics of soil samples after soaking in different seawater solutions are shown in Figures 5, 6. As shown in Figure 5, the compression index varies complexly with different concentration of seawater. The relationship between the ratio of the compression index of soil in seawater to that of original soil (C_C seawater/C_C distilled water) and the liquid limit of the original soil is shown in Figure 6. It can be seen that under the condition of 100% seawater, the highest decrease in the compression index is found in soil sample M4 in Nam Dinh while the highest increase in Cc is found in soil sample M3. In general, the effect of salt intrusion on the compression index of soil samples after ten days of soaking is insignificant, especially for samples M1 and M2. This finding is consistent with the research result of Yukselen-Aksoy at el. (2008). Yukselen-Aksoy at el. (2008) found that the effect of seawater on the compression index of soil was noticeable when the liquid limit of soil was higher than 100%. Accordingly, the compression index of soil mixed with seawater was significantly lower than that of soil mixed with distilled water.

The variation of the vertical coefficient of consolidation of samples after 10 days of submerging in different seawater solutions is shown in Figure 7. The vertical coefficient of consolidation almost tends to increase as the seawater concentration increases, except for sample M1 in Mong Cai. It was also seen that this tendency was more or less the same as that of the compression index when the clayey soils were tested with seawater (Ören et al., 2004).

3.2.3. Undrained shear strength

The results of the undrained shear strength obtained from the UU direct shear test are shown in Figure 8. As shown in this figure, the increase in salt concentration results in a decrease in the undrained shear strength. The increase in salt concentration will lead to a decrease in DDL thickness and results in a decrease in attractive force among soil particles. The decrease in the attractive force with increasing salt concentration can lead to a decrease in the shear strength of soil (Naeini and Jahanfar, 2011). Naeni and Jahanfar (2011) reported that the undrained shear strength of soil tended to decrease as the NaCl concentration in soil increased above 2%. According to the above results, it can be seen that the submerging of samples in different salt concentrations in seawater will lead to different saline intrusions in the soil, which depends on the degree of salt adsorption into the diffuse double layer of clay particles. It can be used for forecasting the change of properties of soft soil due to the sea level rise. The rise of sea level will make the soil saline due to the inundation of seawater and capillaries in the soil. Therefore, it will change the physical and mechanical properties of the soil. From the sea to the land, saline intrusion will change with different levels and depends on different salty environments. The land which is near the sea or will be flooded in the future due to sea-level rise will be changed in terms of its physico – mechanic mechanical properties that, in turn, greatly affect the construction activities.

4. Conclusions

Based on the results obtained from this study, some conclusions can be drawn as follows:

- The liquid limit, plasticity limit, and plasticity index of soil vary greatly depending on the soil types and the salt content. These indices tend to decrease when samples are submerged in 100% seawater, especially for the plasticity index. This may be due to the type of salt and the salt concentration affecting the diffuse double layer thickness and then resulting in a change in the physical properties of the soil.

- The effects of salt content on the compression index and vertical consolidation coefficient of studied soils are not clear. For some studied soils, these effects are insignificant.

- The increase in salt concentration leads to a decrease in the undrained shear strength of the soil.

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