INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

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Hanoi soft soils in salt – affected media

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ABSTRACT: In the context of climate change, sea level rise affects plan areas along the coast of Vietnam. The authors simulated the influence of saline intrusion to ground on geotechnical properties of soils by the case study of soft soils in nine places in Hanoi area. Specimens were prepared by making saturation with artificial seawater of four salt concentrations, i.e., 0.0, 9.9, 19.8, and 33.0 ppt. Afterward, they were experimented in the laboratory. The obtained results showed that after affected by artificial seawater, the engineering properties of soils were significantly changed. Namely, coefficient of consolidation decreased; compressibility index, coefficient of volume compressibility, and coefficient of secondary compression increased. This means that, engineering properties of Hanoi soft soils tend to negative change in salt-affected media.

Keywords: Hanoi soft soil, sea level rise, saline intrusion, salt-affected soil, consolidation

1 INTRODUCTION

Global warming is being considered to be main reason of sea level rise phenomenon occurring in the world. At low-lying areas along the coast, sea level rise gradually makes ground to be saturated by saline water. This process is believed to lead to substantially change in engineering properties of soils. Consequently, it will directly influence the construction and infrastructure such as dyke, embankment and traffic road foundation in those areas (Truc & Hung 2007, Truc & Granier 2008).

The study of variation in engineering properties of soil intruded by saline water is considered at first under deformation property aspect. Undisturbed soil samples that originated from shallow sea sediment in Hanoi, Vietnam, were chosen. They are located in the inland area and far from the coast, and soil layers have not been affected by saline water yet. Saline intrusion process executed by artificial seawater in the laboratory was strictly control. To investigate how the relation among deformation, salinity and time-dependent settlement is, one-dimensional consolidation test was applied.

2 SAMPLE PREPARATION

The in-situ works were aimed at collecting undisturbed soil samples and field experiment based on the deep

boreholes. The soil in medium state, i.e. clay or silty clay, which their undrained shear strength, S_u, fluctuates from 25–50 kPa, was studied. Nine research sites are located in and around the inner city of Hanoi, i.e. Hoai Duc 1 (HD1), Hoai Duc 2 (HD2), Hoan Kiem (HK), Bach Mai (BM), Gia Lam 1 (GL1), Gia Lam 2 (GL2), Gia Lam 3 (GL3), Highway No.5 (D5), Yen So (YS). Their distances to the Red River are not over four kilometers (fig. 1). To study effects of salt on the soil properties, saturation for the soil specimens to simulate saline contamination process was carried out in the lab with artificial sea water. Average salinity of the water in the East Sea of Vietnam is reported to be 33.0 ppt; it should be considered corresponding to 100% salinity of seawater. When seawater is not rising, salinity of groundwater in inland area is 0.0 ppt; it is considered corresponding to 0% salinity of seawater. To simulate the saline intrusion progresses, soil specimens were saturated with saline water in the laboratory at four designated salt concentrations, i.e. 0., 9.9, 19.8 and 33.0 ppt corresponding to 0%, 30%, 60% and 100% salinity of seawater, respectively. The saline solution is a mixture of pure water and salt (sodium chloride, NaCl), or can be considered as artificial seawater. Basic chemical component and the content of salt served saturating is NaCl ($\geq$ 92%), SO_4^{2-} ($\leq$2.7%), Mg^{2+} ($\leq$1.3%), Ca^{2+} ($\leq$0.65%). Saturation for soil was carried out in a closed process with two phases, capillary and pressure saturation. Each saturation phase was conducted for 5 days to make

Figure 1. Nine research sites in Hanoi area.

LEGEND		
1	Hoai Duc 1	HD1
2	Hoai Duc 2	HD2
3	Hoan Kiem	HK
4	Bach Mai	BM
5	Gia Lam 1	GL1
6	Gia Lam 2	GL2
7	Gia Lam 3	GL3
8	Highway No.5	D5
9	Yen So	YS

sure the soil specimens to be fully intruded by saline water. Experiment was executed by the consolidation apparatus with automatic data acquisition. Four specimens corresponding to four concentrations of saline water were placed in each separate apparatus. Pressure ranges in the test were 25 kPa, 50 kPa, 100 kPa, 200 kPa, and 400 kPa. Each pressure stage was applied during 24 hour.

3 HANOI SOFT SOILS IN SALINE MEDIA

3.1 *Clay mineral composition*

Many previous research works of us indicated that the common point of the soils tested, Hanoi clays, is the domination of Illite mineral (from 12 to 29%). The subsequence ones are Kaolinite (from 9 to 22%), and Chlorite (from 4 to 11%). The swelling clay mineral of Montmorillonite appears in a small rate (about 5% in maximum) but at some places it is negligible (under 1%). Non-clay mineral quantitatively prevailing is Quartz (from 30 to 62%), Feldspar (from 3 to 7%), Goethite (from 2 to 6%), and some other ones with low content. Non-clay component is almost not influence on engineering properties of saline soils. They also showed that there was almost no change in the mineral composition of the soils before and after saline intrusion, as well as almost no change in their content. A negligible differences were occasionally encountered in one soil sample at four salt concentrations but they were believed to be concerning with error due to analysis or machine. These results had good agreement with conclusions of Rashid et al. 1972, Kirov 1989, van Hoorn & van Alphen 1994, Mitchell & Soga 2005.
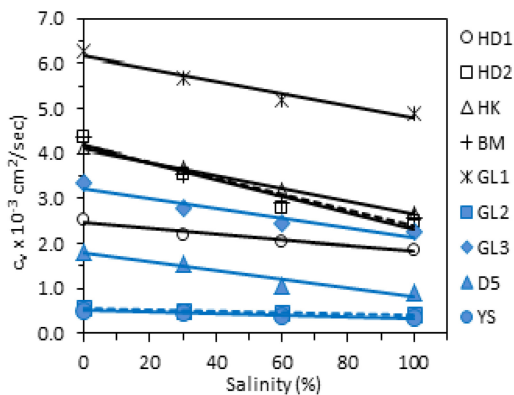

Figure 2. Relation between C_v and the salinity S_a.

3.2 *Consolidation indices*

3.2.1 *Coefficient of consolidation, C_v, of salt-affected soils*

The deformation of soil specimens or the thickness changes recorded during one of the load stages in the one-dimensional consolidation test is used to assess the coefficient of consolidation (C_v). To establish C_v for a pressure stage, the procedure involves plotting the changes of soil specimen height against a function of time and then fitting to this the theoretical T_v versus U_{av} curve.

There are many methods to determine C_v. Herein, application of Square Root of Time method to calculate C_v of Hanoi soft soils saturated with different salt concentrations is suitable. The obtained results of coefficient of consolidation at pressure stage 100–200 kPa of the research soils as well as the graphical statement to perform the relation between C_v and the salinities (S_a) of saturated solution are shown in fig. 2. For each location, there are four values of C_v corresponding to four soil specimens saturated at 0, 30, 60, and 100% salinity of seawater.

From the graph, it is easy to realize that value of C_v decrease when salt concentration increase. That decrease of c_v is quite linear. Of the nine sites, soil specimens at three places, HD2, BM, D5, have a large decrease of C_v between salinities of $S_a = 0\%$ and $S_a = 100\%$. Those changes reach 41 to 50%. The decrease of the remaining soil specimens varies from 22 to 35%. Other changes of C_v compared between three couples $S_a = 30$, 60 and 100 to $S_a = 0$ are given in table 1. Generally, the changing trend of C_v of Hanoi soft soils at different salinities is the decrease. The coefficient of consolidation has a reciprocal relation with salinity of soil tested.

3.2.2 *Compressibility index, C_c, of salt-affected soils*

Compressibility is the natural ability of soil to be deformed. It is stated by means of a coefficient of compressibility or compressibility index, C_c. It can be determined from plot of void ratio and effective pressure. In this paper, compressibility index of the

Table 1. Quantitative change of C_v from baseline ("–" means reduce).

Site	Rate of reduce of C_v (%)		
	$S_a = 30\%$	$S_a = 60\%$	$S_a = 100\%$
HD1	−13.67	−18.86	−26.35
HD2	−19.00	−36.00	−42.80
HK	−10.91	−22.39	−35.30
BM	−19.00	−33.06	−41.33
GL1	−9.87	−17.36	−22.15
GL2	−11.00	−15.83	−23.05
GL3	−16.99	−27.04	−32.76
D5	−12.89	−40.83	−49.75
YS	−13.78	−24.89	−29.20

Table 2. Quantitative change (%) of C_c from baseline.

Site	Rate of increase of C_c (%)		
	$S_a = 30\%$	$S_a = 60\%$	$S_a = 100\%$
HD1	5.75	11.21	17.15
HD2	7.21	11.90	15.68
HK	3.97	9.15	12.71
BM	7.59	14.38	23.80
GL1	6.28	15.39	25.99
GL2	5.51	11.79	20.20
GL3	4.84	8.54	14.36
D5	1.53	3.67	5.84
YS	2.50	18.39	29.20

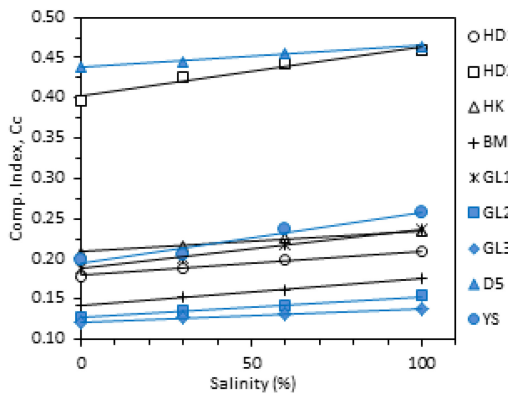Figure 3. Relation between C_c and the salinity S_a.
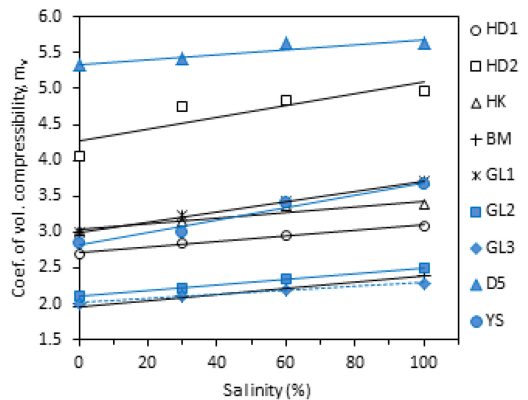
Figure 4. Relation between mv and the salinity S_a.

salt-affected soils is investigated to establish the relation between Cc and the salinities. The obtained results and those relations are graphically displayed in figure 3. One can see a growing up of C_c from salinity 0% to 30, 60, and 100%. The increase seems quite linear. The largest change of C_c is denoted when comparing its value at salinity of 0 and 100 percent. Quantitative change is given in table 2. Soils at four sites, BM, GL1, GL2, and YS, show the largest change of compressibility index (C_c grows up from 20.2 to 29.2%), and soil at D5 gets the smallest change (5.84%) from baseline to the highest salinity. The change of compressibility index of D5 is negligible, whereas that of YS is the most remarkable.

3.2.3 *Coefficient of volume compressibility, m_v, of salt-affected soils*

The compressibility of a clayey soil layer undergoing one-dimensional consolidation is also expressed by the coefficient of volume compressibility, m_v. It is calculated that bases on the change of volume per unit increase in effective stress. The calculation is usually applied with the practiced vertical pressure stages of 100 and 200 kPa.

To display the change of m_v of soils due to saline intrusion, which is served for assessment as well as for

practical purposes, the graphic relation was applied. Accordingly, the relationship of m_v of Hanoi soft soil and the salinities are presented in fig. 4, and the quantitative change assessment is expressed in table 3.

From the visual display one can easily realize an increase in value of m_v from natural state ($S_a = 0\%$) to absolute seawater ($S_a = 100\%$). The coefficient of volume compressibility, m_v, however, does not get an intensive change like C_v, but it is also significant. The change of m_v at saturation solution 30% is smaller than that of 60% and 100%, their values at salinity 100% are the highest. The largest increase of m_v reaches 28.67% from baseline, and the smallest increase is 5.84%. Meanwhile, m_v change from 1.53 to 16.7% at salinity 30%.

3.2.4 *Coefficient of secondary compression, C_α, of salt-affected soils*

Keverling Buisman (1936), the first professor in soil mechanics at the Delft University, found that the deformations of clay in a consolidation test did not approach a constant final value, but that such deformations continued for a very long time. Clay continues to settle under constant loading at the end of primary consolidation, and this is induced by the continued readjustment of clay particle. One-dimensional consolidation test

Table 3. Quantitative change (%) of m_v from baseline.

Site	Rate of increase of m_v (%)		
	$S_a = 30\%$	$S_a = 60\%$	$S_a = 100\%$
HD1	5.75	9.65	14.96
HD2	16.70	19.15	22.31
HK	3.97	11.27	12.43
BM	7.59	12.46	22.45
GL1	8.45	14.81	24.19
GL2	5.51	11.44	18.79
GL3	5.85	9.60	14.36
D5	1.53	5.51	5.84
YS	4.97	19.37	28.67

Figure 5. Relation between C_α and the salinity S_a.

may conveniently be divided into two phases: the primary and secondary consolidation. The secondary consolidation occurs because the relation of void ratio and effective pressure is time dependent: the longer the clay remains under a constant effective pressure, the denser it becomes. Its magnitude comes at peak for highly plastic soils and especially for organic soils. Magnitude of the secondary compression is always expressed by the slope of secondary period of the e-log(t) curve. It is so-called the coefficient of secondary compression C_α.

For salt-affected soils of Hanoi, C_α is determined by the plot of e-log(t) at different salt concentrations. The obtained results are presented in graphical form of the relationship between secondary compression index, C_α, and the salinities, S_a, (fig. 5).

One can easily affirm an increase of the secondary compression index of soils at salinities 30, 60, and 100% from baseline. This increase appears to be linear, and means that after saturating with saline water C_α of Hanoi soft soil is grown up considerably. The largest change of C_α is manifested when comparing its value at salinity 0% to 100%. The quantitative change is also given in table 4 to offer a better evaluation. Specimens at 2 sites, BM and YS, show the largest change of secondary compression index. Value of C_α in these sites grows up to approximate 60%, meanwhile soils at D5 gets the smallest change (3.11%) from baseline.

Mesri (1973) gave a method to classify the secondary compressibility based on C_α. It is applied to Hanoi soft soils to evaluate their secondary consolidation in salt-affected media. The obtained results are given in fig. 6. Accordingly, Hanoi saline soils are classified into four groups, low, medium, high and very high secondary compressibility corresponding to they occupy 36.1%, 30.6%, 11.1%, and 22.2% sample, respectively. After saturated with saline water, noticeably, state of soils at HK and GL2 moves from *low* to *medium secondary compressibility*.

It is useful to determine the ratio C_α/C_c to establish an overview of the consolidation status of Hanoi soft soils, as well as evaluate their secondary consolidation. The general trend of the ratio C_α/C_c of Salt-affected soils of Hanoi is increasing linearly with
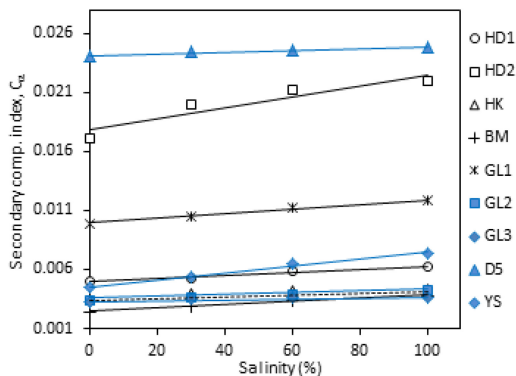
Table 4. Quantitative change (%) of C_α from baseline.

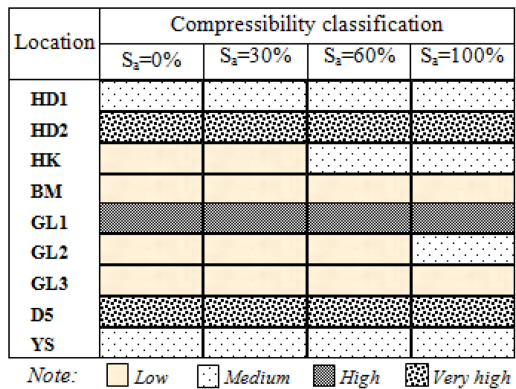| Site	Rate of increase of C_α (%)		
	$S_a = 30\%$	$S_a = 60\%$	$S_a = 100\%$
HD1	7.03	19.21	25.34
HD2	16.82	24.01	27.97
HK	14.03	21.53	24.19
BM	20.83	41.67	58.33
GL1	5.62	13.54	19.07
GL2	6.07	11.46	22.66
GL3	8.23	11.19	12.28
D5	1.24	2.26	3.11
YS	18.89	44.44	64.44

Figure 6. Classification of secondary compressibility for salt-affected soils of Hanoi after Mesri's method.

salinity, but the values are also quite low compared to the values given by Mesri and Godlewski in 1977. The ratio increases from 0.032 to 0.034 in average corresponding to salinity goes up from 0 to 100%.

The relationship between C_α and C_c is also shown in fig. 7. In average, C_α/C_c value of those soils is 0.0332 with coefficient of correlation is $R^2 = 0.915$ (very good relationship).
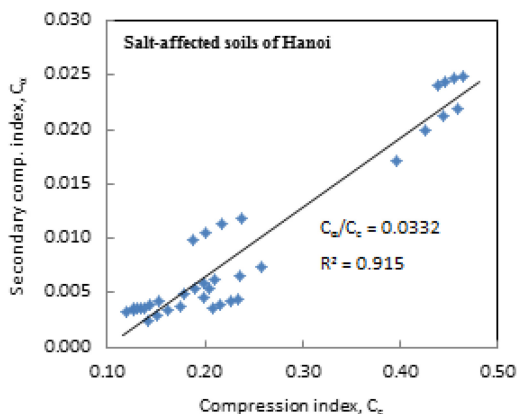
Figure 7. Relation between C_α and C_c.

4 DISCUSSION

In salt-affected media, geotechnical properties of soft soils depend on type of clay minerals present in the soil. When soil rich in clay minerals such as Allophane, Kaolinite, or soil contains carbonates (Ca^{2+}, Mg^{2+}), its geotechnical properties are positively improved. Inversely, soil rich in Montmorillonite, Illite, and Chlorite is then mostly degraded in saline water (Germanov & Kirov 1985, Kirov 1989, Hideo 2007, Yeliz 2008, Gbenga et al. 2009).

The common point of Hanoi soft soils is the predomination of Illite mineral; the subsequent ones are Kaolinite, and Chlorite. Montmorillonite appears with smaller rate, even in several places it is negligible. Chlorite and Illite mineral have some structural feature similar to each other. These clay minerals are intermediate but generally close to Montmorillonite rather than Kaolinite. Besides, the mix clay minerals of expandable and intermediate clay in the soils are considerable. Under normal conditions, Kaolinite minerals are not expandable. This means the presence of swelling minerals in the soil enhance its expandable capacity. The swelling clay minerals have chemical bond not strong enough, big cation exchange capacity, and big specific surface area. In salt-affected media, the interaction of negative-charge layer around clay particle and positive charge in saline water results in neutralizing the charge and afterward degrading the soils. Consequently, soils are increased compressibility and secondary consolidation in saline media.

5 CONCLUSIONS

The ground that is intruded by saline water related to climate change-induced sea level rise is being warned for the coastal lowland areas of Vietnam. In fully saturated soil condition with solution of different salt concentrations, geotechnical properties of the soils are changed. Although there is no change in clay mineral composition of the soils due to the effects of salt, but their consolidation indices are varied. Namely,

coefficient of consolidation, C_v, decreased; compressibility index, C_c, coefficient of volume compressibility, m_v, and coefficient of secondary compression, C_α, increased from baseline. This means that, engineering properties of soil tend to negative change in saline media. The ratio C_α/C_c of Hanoi saline-saturated soils is fairly low when compared with the assessment of Mesri and Godlewski. The negative change in geotechnical properties of salt-affected soils of Hanoi is believed to be because they contain a remarkable amount of mix-expandable and intermediate clay minerals. They are easily neutralized the charge, and leads to degradation of soils in salt-affected media.

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