Consolidation Properties of Ho Chi Minh City Soil, Vietnam

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Abstract

This paper presents the experimental results of consolidation properties of soft soil in Ho Chi Minh City of Vietnam. Forty-two samples were collected from different locations and were determined in the laboratory by Oedometer test. The results showed that the coefficient of consolidation of soft soil varies from $0.052 \times 10^{-3}$ to $3.3 \times 10^{-3}$ cm²/s, otherwise the compression index changes from 0.156 to 1.703, soil is in a normally consolidated or over the consolidated state. These properties also change differently with depth. It also indicated that the compressive index of soft soil has a fine linear relationship with the liquid limit, water content, and void ratio. The coefficient of consolidation of soft soil decreases with the increase of compression pressure. These parameters are basic for calculating the settlement of underground structures in Ho Chi Minh City.

Keywords: Consolidation Properties; Compression Index; Coefficient of Consolidation; Soft Soil.

1. Introduction

Being one of the largest cities in Vietnam, Ho Chi Minh is a pioneer in developing urban underground. However, the construction of underground has faced many difficulties because of the soft ground. The thickness of soft ground varies from few meters to more than 20-30m (NAWAPI, 2010). One of the most properties of soft soil that have a great influence on the instability of the construction is the consolidation properties (Radhika et al., 2017). Therefore, the study on consolidation properties of soil should be taken into consideration. In the world, the consolidation properties of soft soil were studied by some researchers. Larsson (1986) determined the consolidation properties of soft soil by laboratory experiments and field observations. The results indicated the main parameters of consolidation properties and confirmed that the consolidation properties of soft soil also consist of primary consolidation and secondary consolidation. Chu et al. (2002) studied consolidation properties and permeability of marine clay in Singapore and indicated that vertical coefficient of consolidation ($C_v$) varied widely and ranged from 0.5 - 2.0 m²/year. O’kelly (2006) investigated the consolidation properties of eleven different types of soft soil in both vertical and horizontal directions. The results showed that the structural characteristics, and the heterogeneity of soil greatly affected the results of the experiment. Bo et al. (2015) showed a large variation of coefficients of consolidation of the upper, middle, and lower parts of the marine clay in Singapore because of different soil structures. Al-Khafaji

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et al. (2015) reviewed and evaluated the relationship between compression index and liquid limit of previous authors. These relationships have a great influence by the mineral composition and there are many relationships with low correlations. Jain et al. (2015) also established a high correlation between the plasticity index (PI) and the compression index of the soil in river valleys in India. Bo et al. (2017) studied consolidation properties of soil by various experimental methods such as oedometer, constant rate of strain (CRS), Rowe cell and isotropic consolidation tests for undisturbed soil. The results showed that compression index varied widely and was affected by experimental methods and constant rate of strain experimental speed. Ahmad et al. (2016) studied the deformation characteristics of marine sediments in Malaysia and showed the change of pre-consolidation pressure, compression index, and swell index.

In Vietnam, soft soil is widely distributed in deltas such as Red River Delta and Mekong Delta and its thickness drastically changes (Nu et al., 2020; Giao and Hien 2007; Nu and Thinh, 2020; Son et al., 2020; Duong et al., 2020). These soft soils are not suitable for construction and must be applied by ground improvement (Nguyen Thi et al., 2019, Nu et al., 2019, Nu et al., 2020). Nu et al. (2019), Nu et al. (2011) and Nu (2014) studied consolidation properties of soft clay soil (anQ^2-3) distributed in coastal provinces of Mekong Delta. The results showed that these consolidation properties depend on location, depth, organic and salt components in soil.

It can be seen that the consolidation properties of soil have been studied by many authors around the world. However, the consolidation properties of soil depend on many factors such as soil type, testing equipment. Therefore, further studies are still needed. In addition, there have not been any in-depth studies on the consolidation properties of soft soil in Ho Chi Minh City of Vietnam, which is the basis for the design of underground construction such as calculating settlement of buildings and predicating the time of consolidation of soft soil during excavation. This paper aims at studying consolidation properties of soil through experiments of soft soil samples distributed in Ho Chi Minh City of Vietnam. This paper also determines the correlation between C_v and some criteria such as liquid limit (LL), water content (W_a) and void ratio (e_0). These results will be applied in designing and constructing underground construction in Ho Chi Minh City of Vietnam.

2. Materials and Methods

2.1. Materials

To study on soil consolidation properties, soil samples were collected at boreholes from various locations in Ho Chi Minh City of Vietnam. The sampling depth and the locations are shown in Table 1. The underground water varies from 0.5m to 1.5m and was used to calculate the effective stress and is shown in Fig. 4.

| No | Site                        | Locations                                         | Depth (m) |
|----|-----------------------------|---------------------------------------------------|-----------|
| 1  | M1                          | Dien Bien Phu St., Ward 25, Binh Thanh District   | up to 26  |
| 2  | M2                          | Ward 22, Binh Thanh District                      | up to 24.2|
| 3  | M3                          | Ward 22, Binh Thanh District                      | up to 20.2|
| 4  | M4                          | National Route 13, Hiep Binh Phuoc Ward, Thu Duc District | up to 6 |
| 5  | M5                          | Phuoc Kien Ward, Nha Be District                  | up to 12.5|
| 6  | M6                          | Tan Phu Ward, District 7                          | up to 6   |
| 7  | M7                          | Ta Quang Buu St., Ward 6, District 8              | up to 7   |
| 8  | M8                          | Phu Thuan Ward, District 7                        | up to 27.5|
| 9  | M9                          | An Phu Ward, District 2                           | up to 20  |
The soil samples were collected by piston tube and transported to the laboratory. The samples are maintained its original condition from the time of transportation, storage and opening of the test sample. Particle size properties, organic matter content, physical properties of soil, consolidation properties were determined. Particle size properties were performed in accordance with ASTM D422. The liquid limits are determined in accordance with ASTM D4318 – e1.

2.2. Methods

Forty-two samples were determined consolidation properties of soft soil by Oedometer test according to ASTM D 2435 (Fig. 1). The experiment is conducted with many different pressures, the next stress level is twice the previous stress level. The applied compression pressures are 12.5; 25; 50; 100; 200; 400; 800, 1600kPa respectively, depending on sampling depth. Every applied pressure is kept until the degree of primary consolidation level reaches 100% or within 24 hours. During consolidation test, the indices on the strain gauges were investigated at times of 0.1; 0.25; 0.5; 1; 2; 4; 8; 15; 30; 60; 120 minutes; 4; 8; 16; 24 hours or 48 hours. After finishing, at the last compression pressure level, soil sample was unloaded and rebound deformation were recorded. After that, consolidation parameters such as \((C_V)\), compression index \((C_C)\), swell index and \((C_s)\), pre – consolidation pressure \((\sigma_c)\) were determined.

Fig. 1. Consolidation test equipment

3. Results and Discussion

3.1. Composition and physical properties of soft soil

Particle composition and physical properties of soft soil are presented in Figs 2 and 3. The clay content is the largest component, varies from 22.4% to 61.2%, silt content changes from 20% to 40%, and sand content varying from 2.5% to 70.4%. The organic matter content changes from 1.6% to 20.2% (Fig. 2). The natural water content is higher than the liquid limit and soils are in very soft state (Fig. 3).
Natural water content (W) of soft soil ranges from 30.7% to 117.8% with an average of 78.3%. Liquid limit (LL) varies from 29.0% to 92.1% with an average of 67.7%. Plastic limit (WP) varies from 19% to 57.9%, an average of 38.6%. Void ratio of soil is large, ranging from 0.927 to 3.094, an average of 2.109. The unit weight, specific gravity change from 1.39 g/cm$^3$ to 1.81g/cm$^3$ and 2.60 to 2.68g/cm$^3$ respectively. Based on particle contents and Atterberg limits, the soft soils are classified as fat clay (CH) or some Lean clay (CL) in accordance with ASTM 2487. These types of soil are not suitable for construction.

3.2. Consolidation Properties of Soft Soil

As shown in Table 2, it can be seen that soft soil at various locations had different consolidation properties. Compression index of soft soil varied widely. At sites M1, M2, M4, M5, compression index ($C_v$) were higher value than that of other sites, varied from 0.972 to 1.329, 0.893 to 1.317, 0.737 to 1.636 and 0.748 to 1.305 respectively. At sites M3, M6, M7, M8, M9 compression index was lower value than that at other sites, and changed from 0.529 to 0.778, 0.490 to 1.040, 0.615 to 0.819, 0.175 to 1.703 and 0.325 to 1.032 respectively. At site M5, compression index had the largest average value and at site M3, the compression index had the smallest value. This can be related to particle composition, water content, and organic matter content. At site M5, clay content and the natural water content, organic matter content were the highest. Otherwise, at site M3, clay content and natural water content, organic matter content were lowest. At sites M1, M2, M5, M6, M7, swell index (Cs) were higher value than that of other sites,
varied from 0.115 to 0.401, 0.104 to 0.215, 0.132 to 0.26, 0.134 to 0.193 and 0.120 to 0.158 respectively. At sites M3, M4, M8, M9 swell index was lower than that at other sites, and varied from 0.093 to 0.102, 0.056 to 0.106, 0.059 to 0.264 and 0.08 to 0.25 respectively. The ratio of Cv/Cc ranged from 0.06 to 0.34.

The Cv also varied from 0.052.10^{-3} \text{cm}^2/\text{s} to 3.3.10^{-3} \text{cm}^2/\text{s}. At site M1, the Cv was the lowest and varied from 0.102.10^{-3} \text{cm}^2/\text{s} to 0.178.10^{-3} \text{cm}^2/\text{s}. This can be due to the fact that the soil at site M1 contained organic matter content and had high clay content. At site M8, Cv of soft soil had the highest and changed from 0.25.10^{-3} \text{cm}^2/\text{s} to 3.3.10^{-3} \text{cm}^2/\text{s}. The reason is that the soil at site M8 contained alternating layers of sand as well as small clay of 22.4%. Chu et al. (2002) investigated the vertical Cv of marine soft soil in Singapore and indicated that the Cv was very different with depth. The range of (Cv) value of upper layer is from 0.5 to 1.7 \text{m}^2/\text{year}, otherwise the low marine clay has in the range of Cv value of 0.5 to 2.3 \text{m}^2/\text{year}. Bo et al. (2015) determined the Cv of Singapore marine clay at Changi in Singapore and the results show that the upper clay layer had Cv of 0.47 – 0.60 \text{m}^2/\text{year} whereas the lower marine clay had a Cv of 0.8–1.5 \text{m}^2/\text{year}. The reason of difference in Cv of soft soil in upper layer and lower layer was due to the high sensitivity of the marine clay. Fig. 4 shows the variation of compression index (Cc), Cv and preconsolidation pressure (σc) of soft soil with depth. It can be seen that the compression index (Cc) does not change with depth increasing. The Cv of soft soil was almost smaller than 0.7.10^{-3} \text{cm}^2/\text{s} and an increase in Cv of soft soil with increasing depth. The preconsolidation varied from 44.1 to 143.9 \text{kPa} and increases with depth.

Table 2. Results of soil consolidation properties

| No | Properties          | M1       | M2       | M3       | M4       | M5       | M6       | M7       | M8       | M9       |
|----|---------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 1  | Preconsolidation    |          |          |          |          |          |          |          |          |          |
|    | pressure, σc, kPa   | 84.3; 122.2 | 104.8; 120.4 | 60.0; 101.4 | 70.2; 101.4 | 55.4; 119.9 | 46.6; 142.1 | 44.1; 143.9 | 44.1; 143.9 | 53.3; 143.9 |
| 2  | Compression index, Cc| 0.972; 1030; 1.329 | 0.893; 1.036 | 0.529; 0.650 | 0.737; 1.050 | 0.748; 1.076 | 0.960; 1.39 | 0.660; 1.40 | 0.820; 1.40 | 0.870; 1.40 |
| 3  | Swell index, Cs     | 0.220; 0.115; 0.401 | 0.104; 0.132; 0.281 | 0.093; 0.132; 0.281 | 0.056; 0.132; 0.281 | 0.200; 0.132; 0.281 | 0.134; 0.132; 0.281 | 0.120; 0.132; 0.281 | 0.059; 0.132; 0.281 | 0.08; 0.132; 0.281 |
| 4  | Vertical Cv, 10^{-3} \text{cm}^2/\text{s} | 0.140; 0.102 | 0.096; 0.423 | 0.897; 0.236 | 0.270; 0.239 | 0.848; 0.218 | 0.830; 0.281 | 0.219; 0.281 | 0.136; 0.281 | 0.530; 0.281 |
| 5  | Ratio of Cs/Cc      | 0.12; 0.18 | 0.18; 0.27 | 0.08; 0.20 | 0.08; 0.19 | 0.20; 0.09 | 0.18; 0.19 | 0.08; 0.19 | 0.18; 0.19 | 0.20; 0.19 |

Note: 84.3; 69.4; 119.9- Average, Min and Max value respectively

The variations in Cv with compression pressure are provided in Fig. 5. The Cv decreased with increasing of compression pressure. If the compression pressure is lower than 50 kPa, the Cv decreased rapidly. After that, the compression pressure was higher than 50 kPa (in normal consolidated state), the Cv decreased slowly. In case of void ratio decreased and the compression pressure increased, the permeability coefficient of soft soil decreased and resulted in a decrease in Cv. Moreover, the compression pressure increased, the soil particles tend to be more tightly arranged, resist the effects of external forces, and the total settlement and the amount of soft soil compressibility increased and resulted in decrease in the Cv.
In order to clarify the effect of physical properties, organic content of soft soil on the compression index, the relationship between them was established. First, the relationship between compression index and the natural water content was determined and provided in Figs. 6 and 7. An increase in natural water content from 29% to 94.4% resulted in an increased in compression index from 0.175 to 1.329. It can be seen that the increase in the natural water content resulted in an increase in compression index. In these soils, the mineral composition includes illite, kaolinite, and montmorillonite, and chlorite in which the common clay mineral was illite or kaolinite, and the amount of montmorillonite was low (Nu at al., 2020). Moreover, the permeability of soft soil is low (Nu, 2014). It was interesting to see that in these soils, organic matter content changed from 1.6% to 20.2% and an increase in organic matter content resulted in compression index. It was also depending on the clay content, in these soils. All these factors could be affected on the natural water content and compression index. Second, the relationship between compression index and the liquid limit (LL) was established and presented in Fig. 8. It can be shown that the increase in the liquid limit resulted in an increase in compression index. It is consistent of the result of Nu (2014) and the reason for this is the high of organic matter content, the clay content, the presence of illite, and montmorillonite in these soils. This is also believed that the increase in liquid limit made a high compressibility of soil and resulted in an increase in compression index.
Fig. 6. Correlation between compression index and organic matter content

Fig. 7. Correlation between compression index and natural water content

Fig. 8. Correlation between compression index and liquid limit (LL)

The relationship between compression index and void ratio are showed in Fig. 9. It can be shown that the increase in the void ratio resulted in an increase in compression index. It is consistent of the result of Nu (2014). This is also believed that the increase in void ratio due to the high of organic matter content, the clay content, the presence of illite, montmorilonite in these soils made a high compressibility of soil. Thus, the compression index increases. The linear regression relationship between compression index and natural water content, liquid limit, void ratio is presented in Table 3. The relationship is different with the research of Al-Khafaji at el. (2015), Jain at el. (2015), Nu (2014) as shown in Table 4. Jain et al. (2015) indicated the high correlation between compression index and plasticity index of soft soil in various river valley projects in India. This is believed that the increase in liquid limit resulted in increase of compression index. The linear regression analysis of the compression index and the
plasticity index are shown as follows $C_c=0.0082\text{PI}+0.0475$ with coefficient of determination $R^2$ is 0.898 (Figs. 6, 7, 8, 9 and 10).

![Fig. 10. Correlation between compression index and void ratio](image)

**Table 3. Correlation between compression index and some physical properties**

| Properties               | Regression model | Coefficient of determination $R^2$ |
|--------------------------|------------------|-----------------------------------|
| Natural water content    | $C_c = 1.6359W_n - 0.1919$ | 0.812                             |
| Liquid limit             | $C_c = 1.6728LL - 0.1888$  | 0.8064                            |
| Void ratio               | $C_c = 0.5756e^{-0.2585}$  | 0.8409                            |
| Organic matter content   | $C_c=0.0753\text{OMC}+0.388$ | 0.5852                            |

**Table 4. Correlation between compression index and some physical properties**

| Equation                                                                 | Applicability                               | References                                      |
|--------------------------------------------------------------------------|----------------------------------------------|-------------------------------------------------|
| $C_c = 0.007(LL - 7)$                                                    | Remolded clays                              | Skempton, 1944                                  |
| $C_c = 0.0186(LL - 30)$                                                  | Motley clays form Sao Paulo city            | Cozzolino, 1961                                |
| $C_c = 0.006(LL - 9)$                                                    |                                              | Azzouz et al., 1976                             |
| $C_c = 0.014(LL - 0.168)$                                                |                                              | Park and Lee, 2011                              |
| $C_c = 0.046(LL - 9)$                                                    |                                              | Bowles, 1989                                   |
| $C_c = 0.007(LL - 10)$                                                   | Remolded clays                              | Skempton, 1944                                  |
| $C_c = 0.009(LL - 8)$                                                    | Osaka Bay clay                              | Tsuchida, 1991                                 |
| $C_c = 0.009(LL - 10)$                                                   | Normally consolidated clays                 | Terzaghi and Peck, 1967                        |
| $C_c = 0.006(LL - 9)$                                                   | All clays with LL V 100%                   | Azzouz et al., 1976                             |
| $C_c = 0.009(LL - 8)$                                                   | Osaka Bay clay                              | Tsuchida, 1991                                 |
| $C_c =0.54 (e-0.35)$                                                    | Undisturbed clays                           | Nishida, 1956                                  |
| $C_c = 0.4 (e - 0.25)$                                                  |                                              | Azzouz, 1976                                   |
| $C_c = 0.3 (e - 0.27)$                                                  | America’s clay                              | Rendón- Herrero, 1980                          |
| $C_c = 0.0102 (W_n - 9.15)$                                             | Alluvial clay and silt in Bangladesh        | Serajjudin, 1987                               |
| $C_c = 1.325$                                                           | Remoulding clays                            | Wroth et al., 1978                             |
| $C_c =0.014(\text{PI}+3.6)$                                             |                                              | Similarly, Sridharan and Nu, 2000               |

\[
C_c = (W_n)^{0.851}(\gamma_c)^{0.715}(M)^{0.023}(HC)^{-0.001} 
\]

Soft sandy clay (amQ$_2^{2.3}$) in the coastal province of Mekong Deltal of Vietnam

Note: $C_c$= Compression index, $W_n$ = Natural water content, $LL$ = Liquid limit, $E$= Natural void ratio, $PI$=Plasticity index, $\gamma_c$ = Dry unit weight, $M$ = Salt content in soft soil, $HC$= Organic matter content
4. Conclusions

Based on the results of the soft soil in Ho Chi Minh City, the following conclusions are drawn:

- Soft soil is distributed widely in the study area, exposed on the surface and the thickness of soft soil changes up to 30 – 40 m. The soil belongs to fat clay to lean clay in a very soft state. Soft soil has high natural water content, liquid limit and void ratio.
- Soft soil has high compressibility, the compression index varies from 0.156 to 1.703 with an average of 0.830.
- The coefficient of consolidation of soft soil is small and varies from 0.052.10^{-3} to 3.3.10^{-3} cm²/s with an average of 0.61.10^{-3} cm²/s.
- The Cv decreases with increasing compression pressure.
- The compression index has a high correlation with liquid limit, moisture content and void ratio. The increase in water content, void ratio, liquid limit resulted in increase in compression index.

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References

Ahmad, N. R., Harahap, I. S. H., 2016. The compression behaviour of marine clays in Malaysia. Proceedings of the 35th International Conference on Ocean, Offshore and Arctic Engineering.1-6.
Al-Khafaji, A.W., Maillacheruvu, K.Y., Sainz, M., Neuman, R., 2015. Analysis of empirical compression index equations using the liquid limit. Implementing Innovative Ideas in Structural Engineering and Project Management.
Bo, W. M., Arulrajah, A., Sukmak, A. P., Horpibulsuk, S. 2015. Mineralogy and geotechnical properties of Singapore marine clay at Changi. Soils and Foundations. 55(3), 600 – 613.
Bo, M. W, Choa, V., Chu, J., Arulrajah, A., and Horpibulsuk, S. 2017. Laboratory investigation on the compressibility of singapore marine clays. Marine Georesources and Geotechnology, 35(6).
Chu, J., Bo, M. W., Chang, M. F., and Choa, V., 2002. Consolidation and permeability properties of Singapore marine clay. Journal of Geotechnical and Geoenvironmental Engineering. 128(9), 724 -732.
Duong, N. T, Nu, N. T. Effect of different types of rice husk ash on some geotechnical properties of cement-admixed soil, Iraqi Geological Journal. 53(2C), 2020, 1-12.
Giao, P. H., Hien, D. H. 2007. Geotechnical characterization of soft clay along a highway in the Red River Delta. Lowland Technology International 9(1):18-27.
Jain, V.K., Dixit, M., Chitra, Dr. R., 2015. Correlation of plasticity index and compression index of soil. International Journal of Innovations in Engineering and Technology. 5(3), 263- 270.
Larsson, R. (1986). Consolidation of soft soil, Swedish Geotechnical Institute, Linkiioping. Report No.29.
NAWAPI - Southern Water Resources Planning and Investigation Federation, 2010. Engineering geological maps and hydrogeological maps, map scale 1:50.000.
Nguyen Thi, N., Thinph, P. H., Son, B. T., 2019. Utilizing coal bottom ash from thermal power plants in Vietnam as partial replacement of aggregates in concrete pavement. Journal of Engineering.
Nu, N. T, Toan, D. M., D. M, Tinh, N. V., 2011. Determining the parameters of consolidation of amQ_{-3} soft to very soft clay (CL, CH) distributed in Soc Trang area for calculating settlement of soil and ground improvement by vertical drains method. Journal of Mining and Earth Sciences, 32 - 39.
Nu, N. T., 2014. Researching of engineering geological properties of soft clayey soil amQ_{-3} distribution in the coastal provinces of Mekong delta for ground improvement for road construction, Ph. D. thesis (In Vietnamese).
Nu, N. T, Duong, N. T., Phong, N.V., 2019. The effects of salt contents on the geotechnical properties of some soft soils in the coastal area of Vietnam. Journal of Mining and Earth Sciences. 60 (6), 51-60.
Nu, N. T., Son, B. T, Ngoc, D. M., 2019. Experimental study of reusing coal ash for base course of road pavement. Electronic Journal of Geotechnical Engineering. 945-960.
Nu, N. T and Thinh, P.T. Soft soils in the Me Kong Delta of Vietnam. Actual Science. 4(1), 24- 31.
Nu, N. T., Toan, D. M., Thinh, P. H, Son, B. T., 2020. Determination of particles and minerals content in soft clay soil of the mekong delta coastal provinces, southern Vietnam for inorganic adhesives stabilization. Iraqi Journal of Science. 61(4), 791- 804.
Nu, N. T, Duong, N.T, Son, B.T, Thinh, P.H., 2020. Investigation of salt, alum content in soft soils and their effects on soil properties:Case study in coastal areas of Vietnam. Iraqi geological Journal. 53(2A), 2020, 19-34.
Nu, N.T., Son, B. T, Dung, T. L., 2020. The potential of using fine rock for replacing soft soil in construction of a breakwater at Chan May port. Journal of Mining and Earth Sciences, 61(4), 75-85.
O’kelly, B. C., 2006. Compression and consolidation anisotropy of some soft soils. Geotechnical and Geological Engineering. 24, 1715-1728.
Radhika, B. P. A., Krishnamoorthy, Rao, A. U., 2017. A review on consolidation theories and its application. International Journal of Geotechnical engineering. 14 (1): 9-15.
Son, B. T, Nu, N. T, Duong, N. T, Ngoc, D. A., 2020. Application the point foundation (PF) method for soft soil improvement: a case study from Vietnam, Iraqi Geological Journal. 53 (2D),1-18.