ASEAN Engineering Journal

Full Paper

EVALUATING CONSOLIDATION SETTLEMENT OF SOFT SOILS: A COMPARATIVE ANALYSIS OF EMPIRICAL FORMULAS

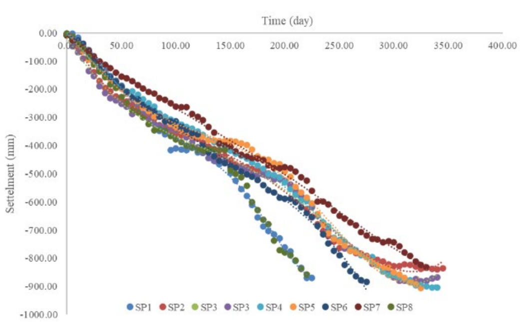
Siti Nurlita Fitri[a,b*], Nila Sutra[c,d], Fitria Wahyuni[e]

[a]Disaster research center, Universitas Sebelas Maret, Surakarta, Indonesia
[b]UNS_Geoscience research group, Engineering Faculty, Universitas Sebelas Maret, Surakarta, Indonesia
[c]Department of Housing and Residential Areas of Magetan Regency, Magetan, Indonesia
[d]Indonesian Railway Polytechnic, Madiun, Indonesia
[e]Civil Infrastructure Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Article history
Received
28 May 2024
Received in revised form
04 August 2024
Accepted
18 September2024
Published online
31 May 2025

*Corresponding author
sitinurlitafitri@staff.uns.ac.id

Graphical abstract



Abstract

The problem of soft upper soil on port construction leads to several serious issues such as cracking, fracturing, landslides, and structural failure due to consolidation settlement. Moreover, reliably estimating the magnitude of settlement is challenging. Therefore, research towards a more reliable method to predict embankment settlement on soft soil is required. An essential factor in predicting soil settlement is the compression index (Cc). Several researchers have introduced the empirical formula to conduct Cc to generate the optimum prediction of settlement consolidation. However, the appropriate results differ with different formulas in various locations. Kijing Port, located in Pontianak Regency, West Borneo, Indonesia, has a soft soil issue. Fourteen boreholes provided Cc from the laboratory, which divides into three zonas, A, B, and C, with 3-8 settlement plate investigations for each Zona. This paper aims to evaluate consolidation settlement based on Cc using several formulas from empirical equations, field instrumentation monitoring, and laboratory results in the Kijing Port Construction Area. Twenty various empirical formulas were analyzed to obtain the magnitude of settlement, which included soil properties such as void ratio, Atterberg limit, specific gravity and water content, divided into two categories, namely Normally consolidated (NC) and over-consolidated (OC) soil. The results show the different result among the source of Cc due to limited data and other factors like calculation mistakes in the lab, the Cc existing data from the laboratory produces varied values when field investigated from SPT soil sampling. This circumstance suggests that comprehensive soil compression and other important data variables are necessary in order to assure development in the field and to acquire correct soil settlement calculation prediction. The general output is also suggested to generate a comprehensive understanding of the soil compression properties of clay in the port project in West Borneo, Indonesia

Keywords: Consolidation settlement, Compression index, Empirical formula, Field test, Kijing Port

1.0 INTRODUCTION

Soft soil is a problematic soil that usually occurs in several projects in Indonesia. This circumstance is because of the high compressibility, void ratio, and also low bearing capacity [1]. This soil has significant issues, namely consolidation settlement which induces the failure of the upper structure. Moreover, structures such as embankments of roads or port reclamation have sensitivity to settlement. Although several methods that usually use to analyze the safety factor of embankments upper the soft soil, cracking, fractures, and probable equipment failures can result from excessive settlement under embankment constructions [2,3]. For example, Yan [4] shows that under consolidated soft clay from recent marine and river delta deposits made up the dredged slope that occur landslide, Australia's coastal areas have a significant impact on the stability of superstructures due to high differential settlement and unbearable lateral deformation [5], and the long consolidation rate during the port project operation[6].

Numerous soil improvement methods are usually conducted to solve soft soil cases. Prefabricated vertical drains (PVD) with a surcharge are often used for such long extended and thick filling development over the soft ground to lower the cost of construction. The PVD can accelerate radial consolidation by decreasing drainage routes and reducing compression time by almost ten times, and this approach is reasonably inexpensive and straightforward to implement [7–10]. However, according to the PVD function, PVD may only accelerate the consolidation of the settlement's final processes; it cannot decrease the settlement's magnitude. As a result, it is crucial to assess the factors that influence the actual soil settlement.

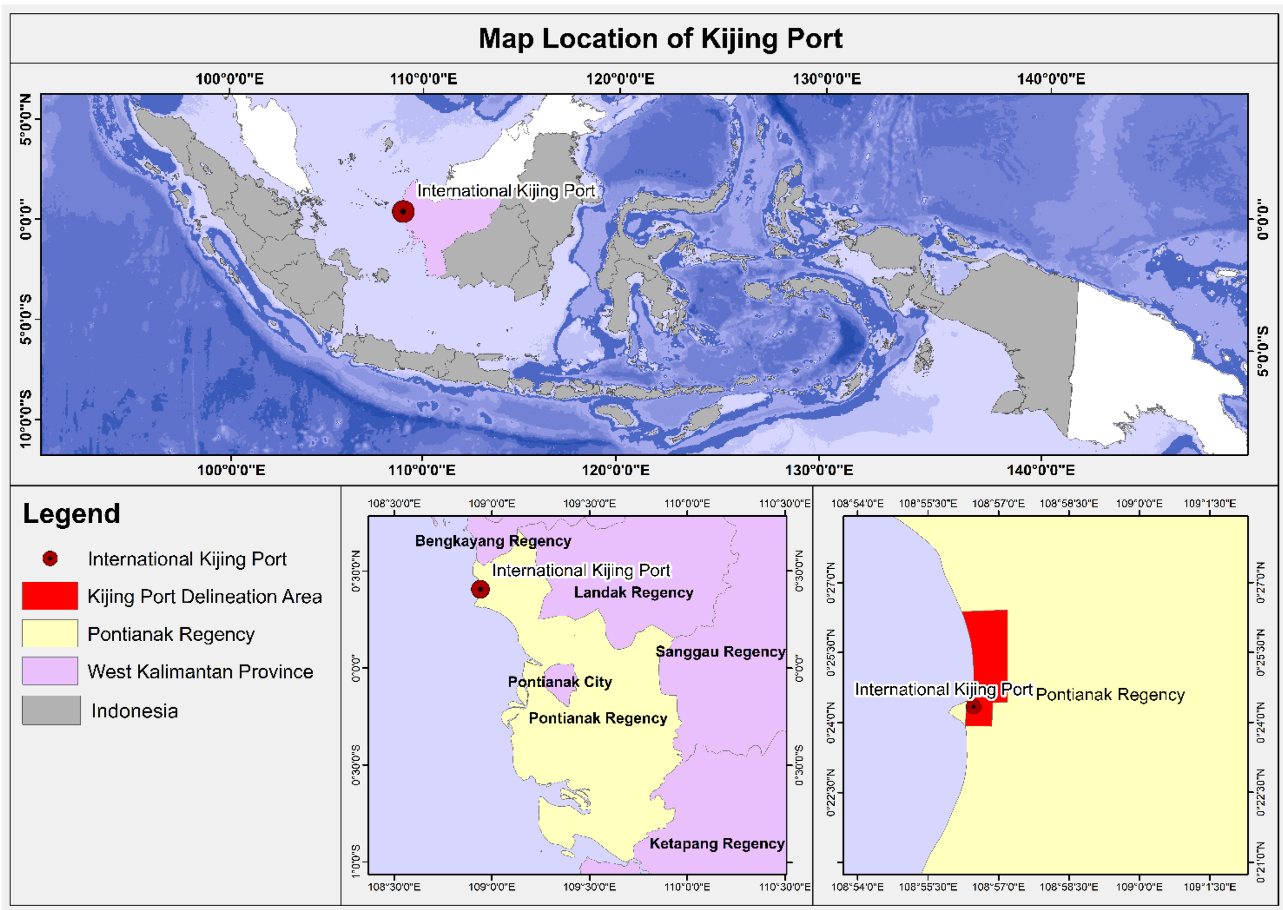


Figure 1 The location of Kijing Port project

A laboratory test, field test based on instrumentation data, and empirical correlation are used to determine the consolidation parameters, which are then used to evaluate predicted settlements. an essential factor in predicting settlement for engineering grounds is the compression index (Cc). Furthermore, Fakharian1 [12] research show that the maximum settlement and consolidation-time relations are both accurately approximated by conventional theoretical solutions if consolidation variables are specified appropriately based on laboratory measurements. The empirical formula to conduct Cc has been introduced by several researchers to generate the optimum prediction of settlement consolidation. However, the appropriate result depicts a different formula in a different location. Therefore, a specific formula is required to analyze continuously to get a similar result for settlement prediction.

The need of constructing a port project in Indonesia leads to the new harbor infrastructure, namely the Kijing Port project- in Indonesia. It is located in the western province of Borneo, Indonesia. Since Port Dwikora development is taken into consideration based on a feasibility assessment published in 2010 by the Ministry of Transportation, Kijing port in Sungai Kunyit District is one of the prospective port options [13]. The detail of this location has presented in Figure 1. This project has a soft soil thickness with PVD and surcharge improvement, divided into several zones. In addition, more than 15 points of settlement plate were located in this site to support the investigation data for soil instrumentation. The soil properties were also conducted by more than fifteen boreholes and laboratory results such as liquid limit, water content, unit weight, specific gravity, void ratio, and plasticity index. However, based on the soil investigation and settlement plate results, there are different settlement magnitude results from laboratory test parameters and instrumentation output. Consequently, the evaluation of the settlement calculation based on the compression index is required to receive the optimum design for soil improvement.

This paper aims to evaluate consolidation settlement based on compression index in several formulas from the empirical equation, instrumentation field monitoring, and the laboratory result. The research is expected to generate the whole picture of soil compression properties in port locations in Borneo-Indonesia. Moreover, a new approach to the appropriate settlement compression index will occur to generate an optimum prediction and lead the project-cost minimization. This study also offers a further comprehensive initial assessment of the soil subgrade related to the soft soil to support sustainable construction projects in Indonesia, which are rarely conducted in a specific location, especially in Borneo.

2.0 METHODOLOGY

2.1 Relevant works

In general, measuring the compression indices of clayey soils (Cc) takes a long time and costs money, especially reconstituted clays with high initial water content. The ability to consistently monitor the consistency limitations of the clay soil and the compression indices might be used to m mitigate these restrictions [14]. The crucial process is determining the Cc based on laboratory tests in huge soil properties and boreholes. Several empirical formulas were established to offer alternatives and solve the problem. For example, based on Chitra [15], the compression Index utilizes index characteristics that are more simply identifiable and require less time to be obtained in the laboratory to calculate the total settlement.

Several variables are usually utilized to examine the coefficient compression (Cc) based on an empirical formula from soil test. Jain used several characteristics such as plasticity index (PI), Liquid Limit (LL), and proctor test properties, including maximum dry density (MDD), optimal moisture content (OMC), also Differential Free Swell (DFS) [16–23]. Furthermore, another study presented research that examined other physical soils' properties, such as void ratio (e0), specific gravity (Gs), and water content (wc) [24]. Lastly, the empirical assessment of Cc, including the shrinkage index parameter, was generated [25].

Numerous research about compression index correlation and the empirical formula have been conducted over several decades. Sudu [26] shows that the compression index declines with increasing porewater salinity and may be explained by a second-order polynomial equation, where the impact of porewater salinity is constrained as it approaches a threshold value. Moreover, the experimental data demonstrated a clear correlation between changes in the liquid limit, moisture content, initial void ratio of the soil samples, and changes in a compression index [27]. Another study described a contradiction between the values of the Cc empirical formula and the outcomes of laboratory testing soil data, according to a comparison of the current empirical formula with the soil sample data [28]. Therefore, the compression index research to find the suitable empirical formula in certain areas has to develop.

Another recent empirical formula for the compression index, Cc = 0.506 e_o -0.11[29], was discovered through the performance of another investigation on the subject. More than 130 undisturbed specimens from various depths that were the product of two years of geotechnical research in Iran's southwest were studied in their study and found a new Cc formula, namely Cc = 0.6787eL- 0.1933 eP [30]. The best correlation for Cc is 0,2608e and Cc = 0,0093 Wc, according to Daoud, Kasama, Saleh, and Negm [31]. In addition, many research have been focused on the prediction of the compressibility behavior of soils using its fundamental physical parameters in order to save the effort of conducting consolidation tests [23,32–34].

This research was conducted with twenty formulas that proposed a significant result to estimate the total settlement from the compression index. The detail has depicted in Table 1. The first equation is Skempton which describes the formula in 1944 while the last formula was Vinod and Bindu in 2020.

Table 1 The empirical formula list to determine compression index

No	Cc Correlation	Formula
1	0.007 (LL-7%)	Skempton (1944)
2	1.15 (e_0-0.35)	Nishida (1956)
3	0.54 (e_0-0.35)	Nishida all clay (1956)
4	0.29 (e_0-0.27)	Hough (1957)
5	0.0115 Wc	Moran (1958)
6	0.43 (e_0-0.25)	Cozzolino (1961)
7	0.009 (LL-10)	Terzaghi and peck (1967)
8	0.75 (Wc-0.5)	Sowers (1970)
9	0.006 (LL-9)	Azzouz et al. (1976)
10	0.037 (e_0-0.003LL-0.34)	Azzouz et al. (1976)
11	0.59 Gs PI/100	Worth and Wood (1978)
12	(LL-13)/109	Mayne (1980)
13	0.01 Wc	Koppula (1981)
14	0.01 (Wc-7.549)	Herrero (1983)
15	0.54 (e_0-0.23)	Moh a kol (1989)
16	(0.156 e_0)+0.0107	Bowles (1989)
17	0.009 (LL-8)	Tsuchida (1991)
18	0.009 (LL-13)	Biarez (1994)
19	0.014 (PI+3.6)	Sridharan & Nagaraj (2000)
20	0.0055 (LL-1.8364)	Vinod and Bindu (2010)

2.1 Settlement Calculation and Field Investigation

In order to provide a reliable estimate, the conventional method of calculating consolidation settling in one-dimensional situations entails soft layering ground [35]. The equation was divided into two categories: normally consolidated clay and over consolidated clay.

The detail of the formulas has shown as follow:

Normally consolidated (NC) clay:

$$S_{ci} = \frac{H}{1+e_0}\left[C_c \log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'}\right)\right] \quad (1)$$

Over consolidated (OC) clay:

If (σo' + Δσ) ≤ σc and the equation:

$$S_{ci} = \frac{H}{1+e_0}\left[C_s \log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'}\right)\right] \quad (2)$$

If (σo' + Δσ) > σc, the settlement consolidation has examined with equation follows:

$$S_{ci} = \left[\frac{H}{1+e_0} C_s \, log \frac{\sigma_c'}{\sigma_0'}\right] + \left[\frac{H}{1+e_0} C_c \log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_c'}\right)\right] \quad (3)$$

Where the void ratio is e_0, σ_0 means overburden pressure, H is the thickness of soil layer, Cs presents swelling index, Cc is compression index, Δσ shows distribution of stress and σ_c means pre-consolidation stress.

The established equations were developed as a result of the analysis of inadequate test data consolidation at each depth, especially as it relates to the pre-consolidation stress parameter used to determine the over-consolidated ratio and further calculate the status of the soil as either OC or NC. According to the association between the N-SPT data and the consistency at this level, which is a hard soil layer, to confirm it is not a compressible soil layer, the pre-consolidation stress characteristic was only identified at deep elevation with OC soil conditions. As a result, the compression observed in the field was compared to the NC and OC assumptions.

The soil investigation in the Kijing Port project was held in several boreholes, namely BH 01-18. Each layer has been tested to obtain soil parameters' physical and mechanical properties. The Standard Penetration Test (SPT) was tested to get the consistency of the layer. Based on SPT results, the area was dominated by soft clay in 12-15m depth. Furthermore, according to the site investigation, the settlement plate was conducted in various points related to certain zona, representing the soil condition, namely OC and NC.

The thickness of preloading was applied in the area at various heights, ranging from 4 to 6 meters. Based on the settlement plate observations given in Figures 2 until 4, various compressions were generated at each zona, and the settlement was shown on the soil subgrade under the embankment load at each location. In addition, the embankment was loaded at the highest elevation in accordance with the predictions made by the Asaoka formula, which indicated that the settlement times would range from 250 to 400 days.

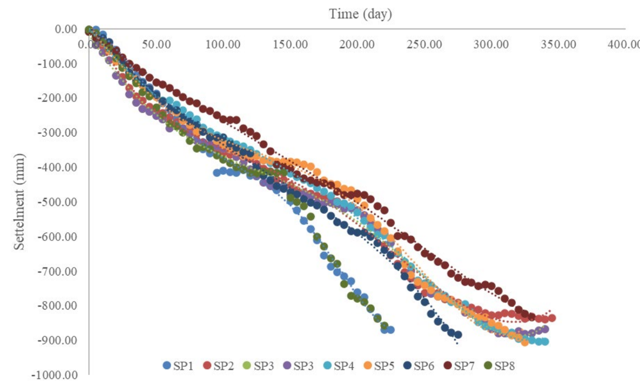


Figure 2 Settlement plate measurements in every research area section Zona A (SP1-SP8)

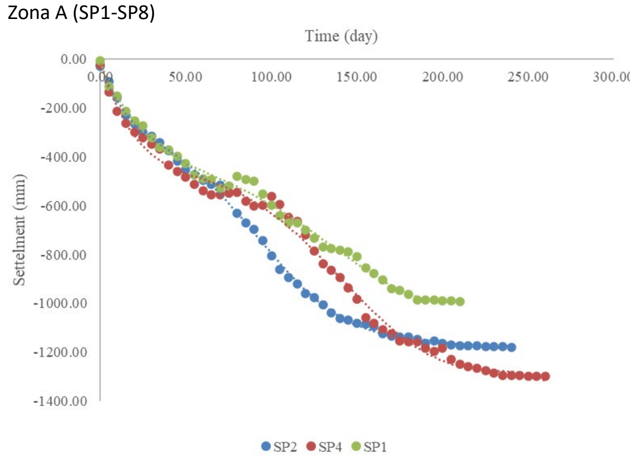


Figure 3 Settlement plate measurements in every research area section Zona B (SP1, SP2, and SP4)

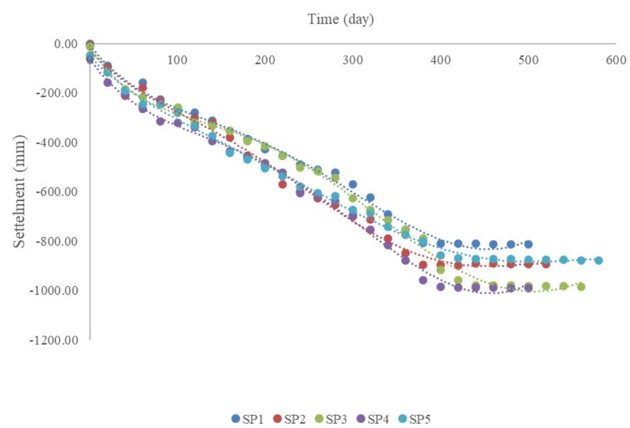


Figure 4 Settlement plate measurements in every research area section Zona C (SP1-SP5)

3.0 RESULTS AND DISCUSSION

3.1 Soil Properties

The correlation between physical properties from laboratory tests and each layer has depicted in Figure 5. The range of value in particular characteristics varied in each item. Moreover, all the data have shown in depth 0-70m. Regarding water content data (Wc), the value varied between 20-80% at a certain depth. Meanwhile, the specific gravity offers a distance between 2.3-2.9. In terms of other properties, the unit weight is described in Figure 5. The rate in the range is 1.5-2.0 t/m^3. Furthermore, the Liquid limit value (LL) is 20-90%, while the void ratio shows a maximum value of 2.1 and the smallest is 0.5. The plasticity index (PI) depicts all depth layers in the 10-60% range.

According to the data in Figure 2, not all the variables will be calculated to determine the total soil settlement. This condition was examined because the soil characteristic used is soft soil consistency, which presents in a maximum 15m depth. Although the soil parameters show until 70m depth, the calculation only utilizes the suitable parameters that exactly soft soil consistency (NSPT value between 0-10) [36,37].

Based on varieties of water content and void ratio, the high value is in BH 3 and BH 11, with the slightest difference among the two parameters being BH 01 in water content and BH11 in void ratio. In addition, regarding another significant value, the liquid limit is the most considerable value in BH 12, and the lowest is BH 18. The differences between the soil parameters are also affected by the depth of the soil sample. The significant pattern of the behavior only sometimes occurs based on the filed data, even though the maximum and minimum ranges of void ratio values and water content are almost similar.

The compressibility of soil and the amount of external load are the main factors determining the overall settlement magnitude.

PVD utilization speeds up water evacuation; they do not affect the soil's inherent characteristics or the load's amount. As a result, the overall settlement volume does not change. Furthermore, the applied force and the soil's fundamental characteristics influence its compressibility. PVD accelerates the process by which the material reaches its final stage, consolidated condition, but does not affect these soil properties.

According to Specific Gravity, the range's largest value is also in different places with 2.8 at BH04, and the minimum value is in BH 09. Moreover, the Plasticity index also has the biggest value at BH 01. The same trend with the Liquid limit parameters, although different with the lowest value in LL condition.

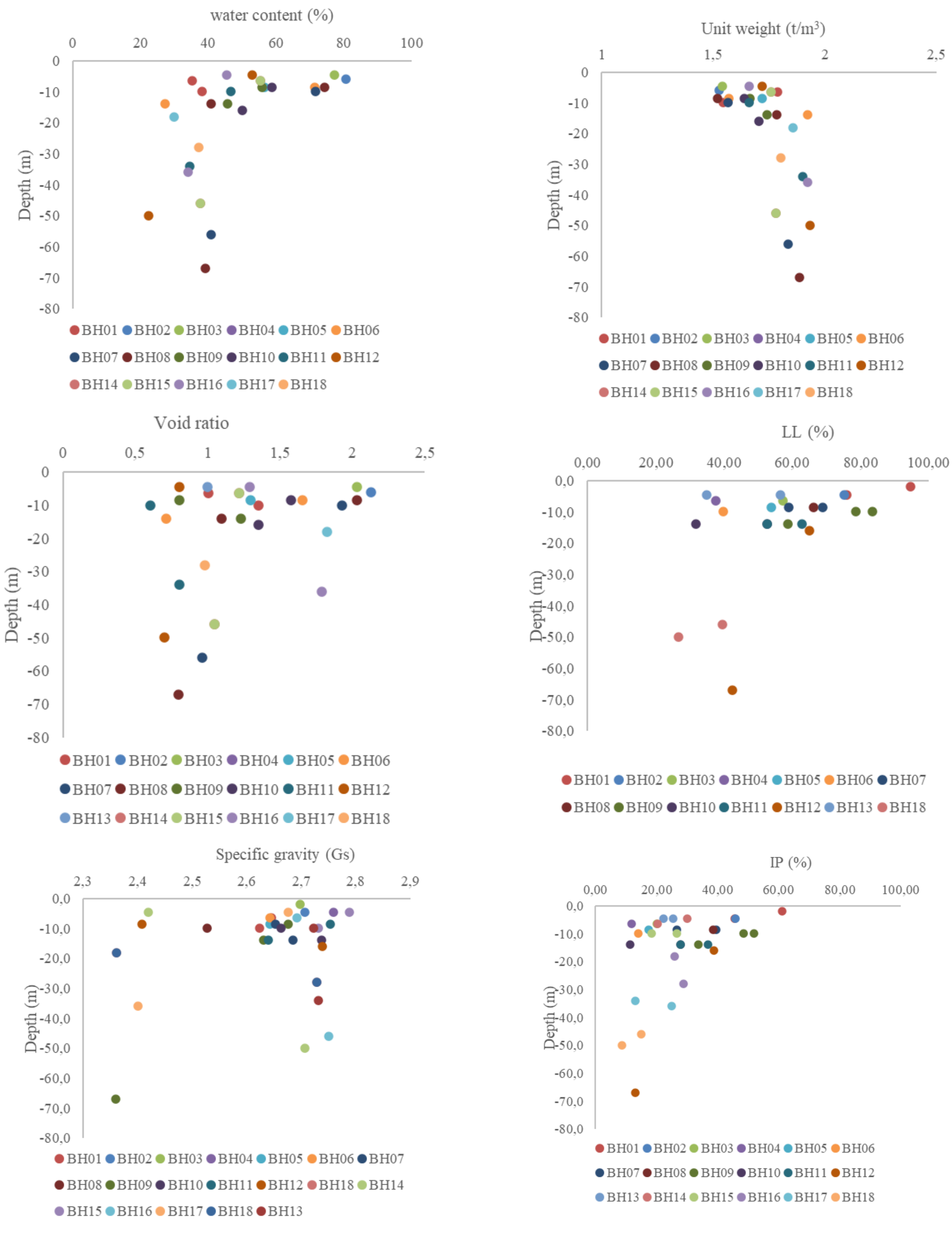


Figure 5 The recapitulation of soil properties in Kijing Port.

3.1 Settlement Analysis

The thickness of each layer was determined at various locations using the results from the field boring test and the N-SPT test, together with the settlement. The soil layers at each site were, and the compression was estimated only at an incompressible soil depth with an N-SPT value of less than ten. The data are summarized into various comparison charts for each cluster area under investigation and presented based on two assumptions which are NC and OC soil, as shown in Figures 6-9.

Figure 6 describes settlement calculation based on various empirical methods based on Table 1, which combines with Cc existing (compression index from laboratory test) and field investigation from settlement plate. The picture depicts the complete analysis of Zona A with the soil condition as Normally consolidated (NC) clay. Based on the figure, The maximum settlement is in Nishida (1956) in number 2, and the lowest is in Azzouz (1976) (variable 10). This trend occurs in all the research Zonas. Moreover, Bowles (1989) (variable 16) has the second small value after Azzouz's (1976), which offers appropriate value with instrumentation results. Meanwhile, the Cc existing produces larger than settlement plate output which presents about 0,65m for this area. Therefore, there were significant differences between the compression estimated using laboratory data and those observed in the field. According to [38] and [39], the application of the one-dimensional consolidation theory under-consolidated clays using laboratory tests to estimate consolidation parameters provided reasonable estimates of the magnitude of consolidation settlement.

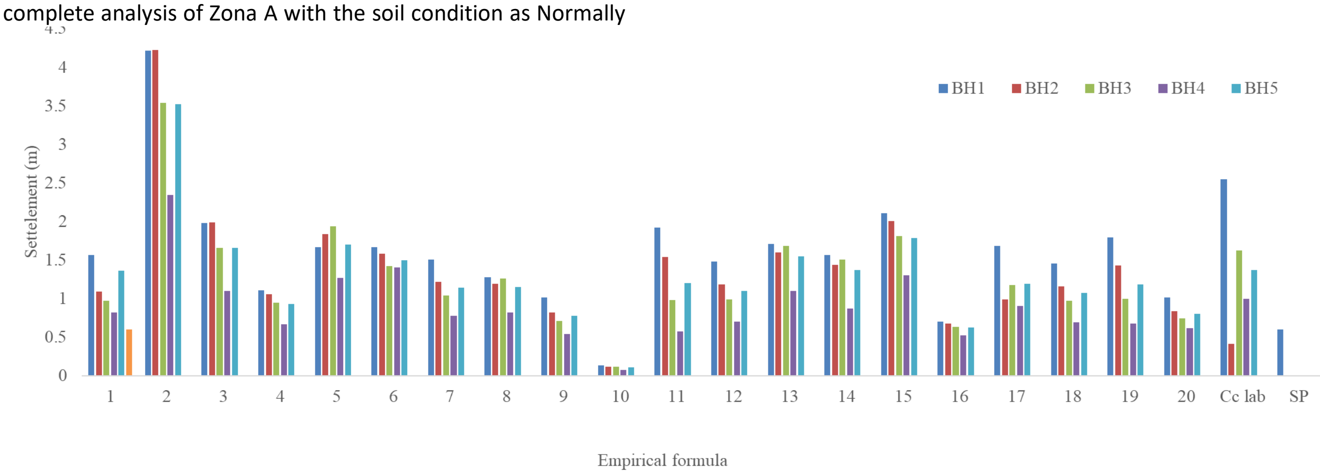


Figure 6 Results of settlement calculations in Zona A with NC condition

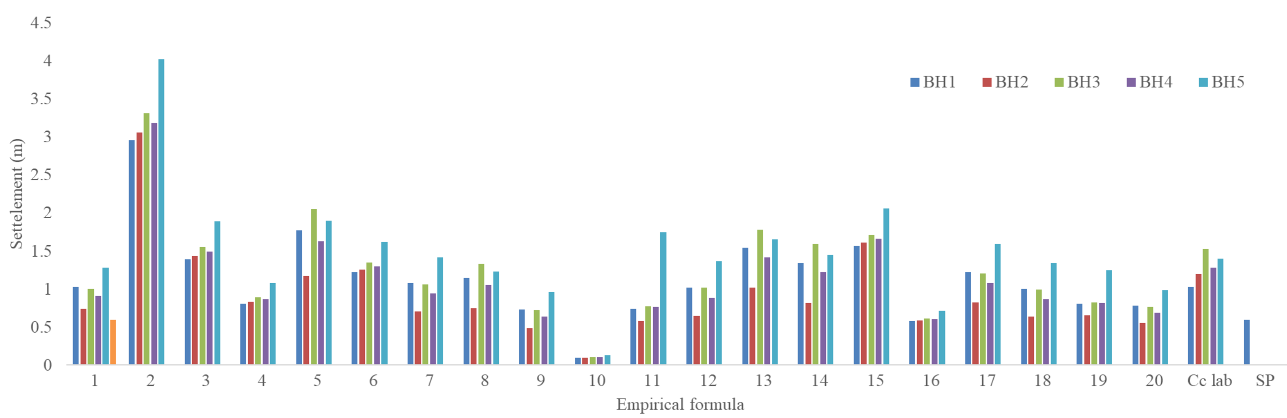


Figure 7 Results of settlement calculations in Zona A with OC condition

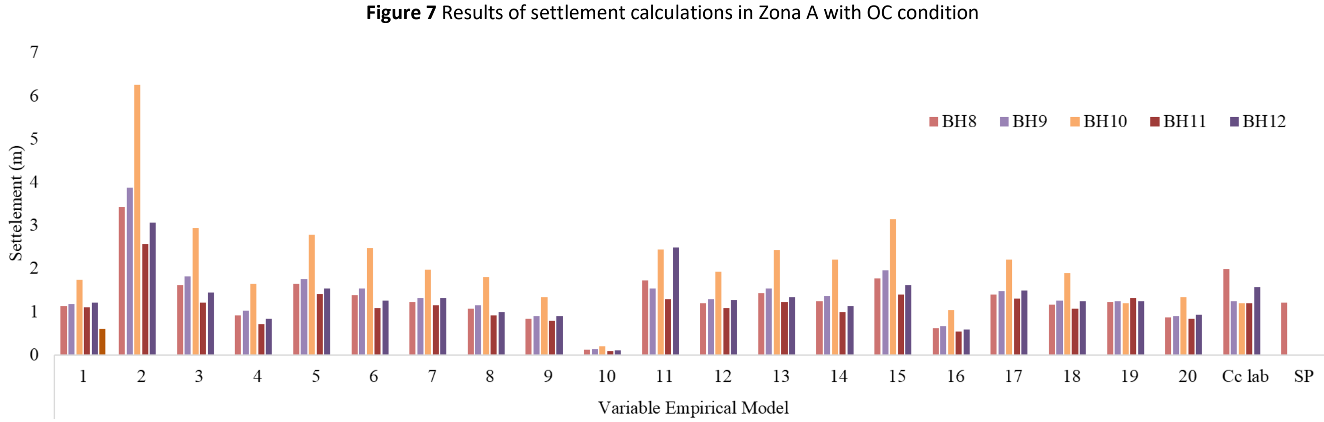


Figure 8 Results of settlement calculations in Zona B with NC condition

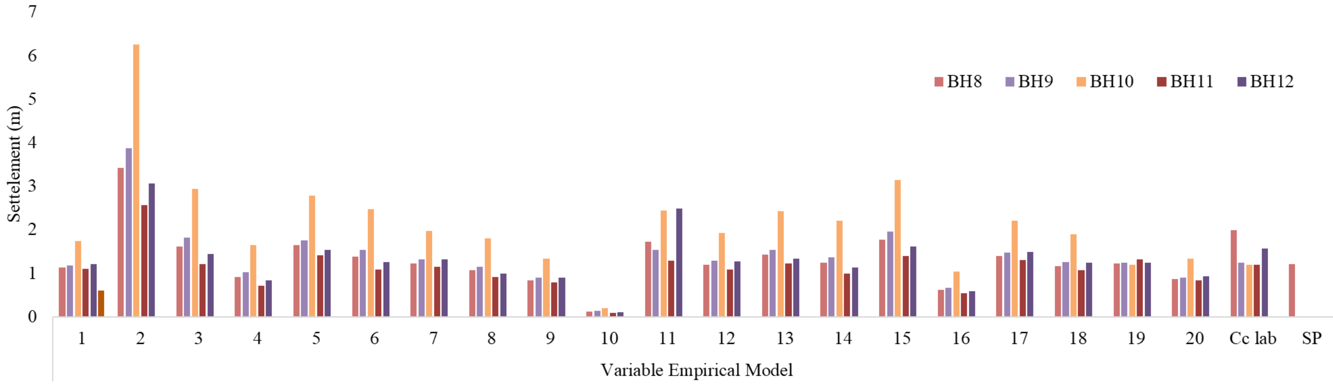


Figure 9 Results of settlement calculations in Zona B with OC condition

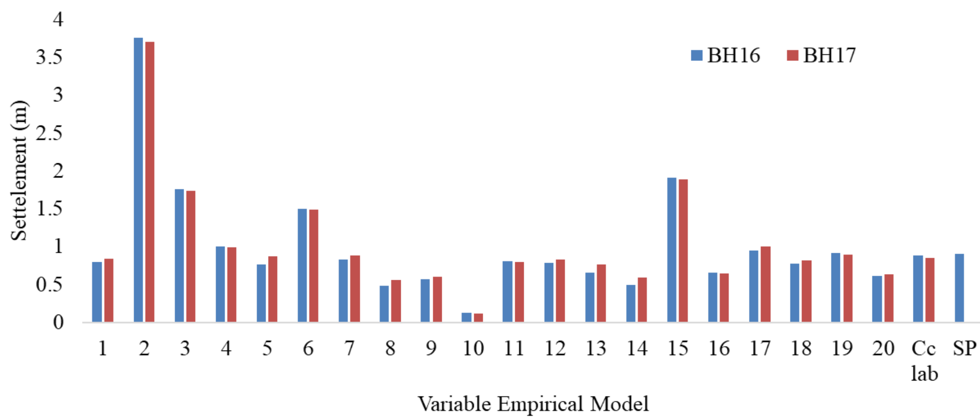


Figure 10 Results of settlement calculations in Zona C with OC condition

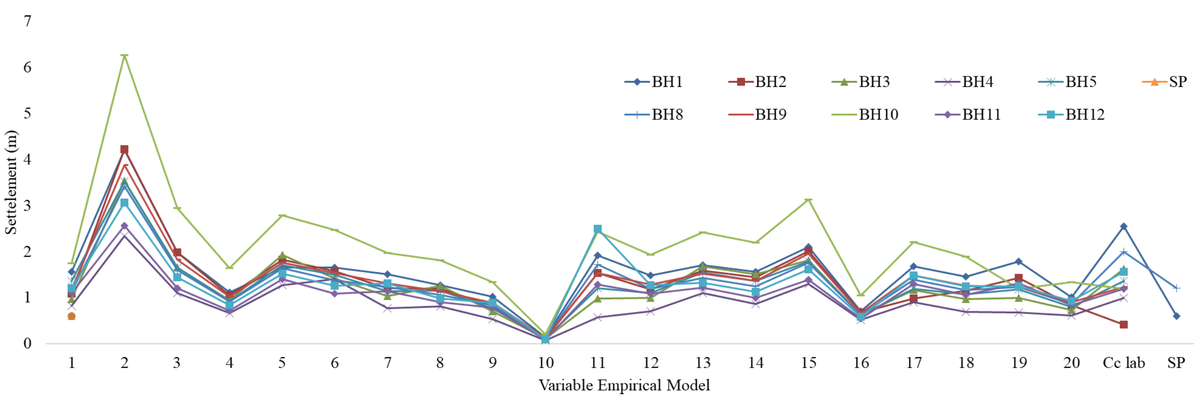


Figure 11 The settlement from field monitoring and settlement estimate ratios obtained by the empirical formulation in all zona (NC condition)

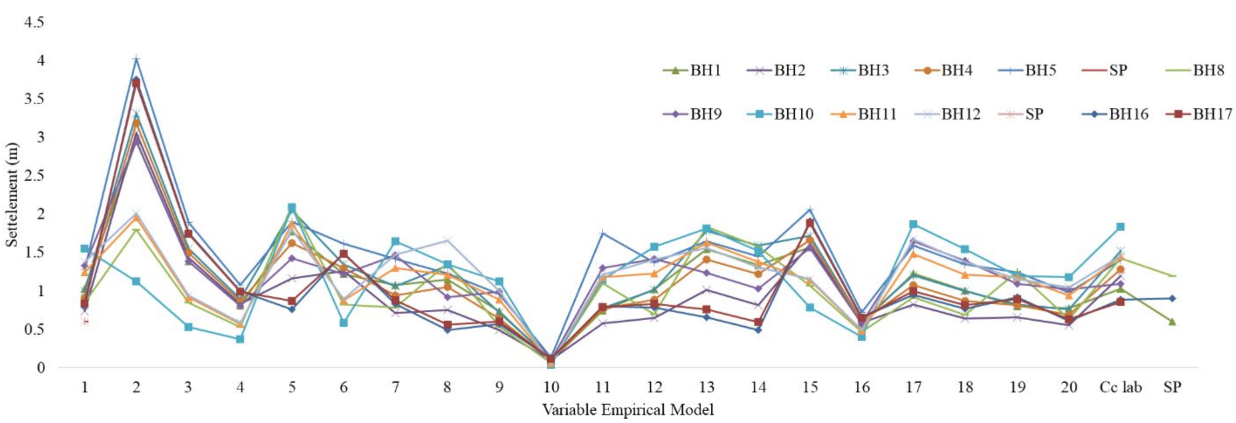


Figure 12 The settlement from field monitoring and settlement estimate ratios obtained by the empirical formulation in all zona (OC condition)

A similar trend has described in Figure 7, which shows that Nishida's (1956) output is unreliable for settlement calculation because of irrational value. Furthermore, Bowles (1989) also has the second level after Azzouz's (1976) in OC soil, the result is suitable for settlement plate value. The OC condition in this figure shows different behavior in Variable 11 and 19, which means Worth and Wood (1978) and Sridharan & Nagaraj (2000). The value describes a big gap between NC and OC conditions. In addition, all these categories utilize the plasticity index in their formula. As moisture content and Atterberg limits are fundamental characteristics of soils, it is possible to determine the soil's compression index using these index parameters. According to recent findings, the Compression Index (Cc) will rise along with the Plasticity Index (PI) value. The association between the Plasticity Index (PI) and the Compression Index (Cc) is developed due to this research [40,41].

In terms of Figure 8, this picture depicts the settlement calculation based on a similar variation of the empirical formula. The location is Zona B which presents the NC soil. The highest point in this area is similar to Zona A, the biggest being Nishida (1956) and the lowest being Azzouz (1976). Furthermore, the top border was Nishida (1956), even though Nishida all clay (1956) (variable 3) gives more analytical results than the other formula. Based on Al-Khofaji et al. [42], the Nishida all clay (1956) formula [Cc = 0.54(e_o - 0.35)] was the best match for the whole range of void ratios and that (Nishida 1956) seems to establish an upper bound estimation for the compression index for void ratios larger than 0.50. Therefore, this indicates that Nishida all clay (1956) was preferred by past investigations over Cc = 1.15(e_o - 0.35), resulting in excessively conservative compression index estimates.

However, the appropriate result in NC soil in Zona B is Sridharan & Nagaraj (2000), Biarez (1994), and Skempton (1944) gives logical result compared to instrumentation data, despite Sridharan & Nagaraj (2000) having the smallest gap among the three formulas. Meanwhile, the Cc data from laboratory also has different output to settlement plate. Songyu et al. [43] observations that the CPTU procedure can forecast the settlement amount better than the laboratory-calculated estimates using parameters obtained from the consolidation tests supported by their results. Meanwhile, it was thought that the lack of consolidated data drove the significant difference in these results.

Figure 9 shows the settlement in the OC condition of Zona B. The matching behavior is in the nearest result of settlement prediction from field instrumentation which shows in Sridharan & Nagaraj (2000). Moreover, the biggest range between OC and NC soil is in Nishida (1956), Nishida all clay (1956), and Moh a kol (1989). All these variables utilize the void ratio as the dominant factor to predict the compression index. According to Khafaji [42], although the void ratio significantly estimates the settlement value, the Liquid limit also has an important role in determining the compression index formula. The results of the other research show that there is the almost complete agreement between the ratings for compressibility based on plasticity index results and the ratings for compressibility based on liquid limits values, which range from low to high compressibility [44].

Another location is Zona C which has the OC condition in Figure 10. The borehole shows two different parameters, BH 16 and 17. The trend followed the Zona B that indicates Sridharan & Nagaraj (2000) is the best formula for prediction compression index, which has suitable results with settlement plate investigation. In addition, the highest and lowest border is similar to all the areas, namely Nishida (1956) (variable 2) and Azzouz (1976) (variable 10). In this area, the cc existing from the laboratory provides almost the same value with field investigation as all the research locations.

The result shows a similar trend in the highest and lowest prediction in all Zone, namely Nishida (1956) at 1.15 (e_o-0.35) and Azzouz (1976) at 0.037 (e_o-0.003LL-0.34). However, the relevant results among locations are different. The Bowles (1989) describes (0.156e_o) +0.0107 as suitable for Zona A in NC and OC conditions, but in other locations, Sridharan & Nagaraj (2000) means 0.014 (PI+3.6) has the most relevant result. The result is because of the big gap between the value at BH 01 in liquid limit and index plasticity parameters, which makes the output of the correlation bigger than others. this condition makes the settlement consolidation calculation more relevant in the zone.

The different results between the Cc factor and one or more other factors, including the 1) invalidated laboratory test results due to changes in soil situations from undisturbed to disturbed affected by the condition of the test sample, laboratory assistant operating the test, and condition of the equipment, are believed to be the causes of the difference between the theoretical settlement calculations and field observations. 2) Incorrect input of data such as Cc, void ratio, compressible layer thickness, overburden pressure, and applied stress above ground level; 3) Misclassification of the soil profile as homogeneous or in layers when it is heterogeneous; 4) Error-causing interruptions in the field; and 5) the condition of saturated or unsaturated in soil conditions [2]. Furthermore, the other proposed approach is using another method. Several criteria based on the MEP (multi-expression programming) model were used to validate the model to calculate settlement. The outcomes show that the suggested model settlement offers accurate Cc calculations. The resulting model performs noticeably better than the current conventional models [24].

Figures 11 and 12 present the result of all the settlement estimations in two conditions, NC and OC. In the NC soil case, Borehole 3 has the maximum estimates to predict settlement which is the lowest, dominated by Borehole 11. In addition, this soil parameter is located in a different area, Zona A and Zona B. Regarding OC soil, the maximum and minimum point fluctuates more than NC soil. However, all the soil parameters have been analyzed to obtain a confident level of data that reaches 90% reliability. This condition means that the varied soil parameters usually generated different NC and OC soil results to predict settlement consolidation. Consequently, empirical equations with high correlation coefficient values predict the soil compression index of the current research area with great accuracy since there is a strong correlation between the soil characteristics proposed in the study and the compression index.

4.0 CONCLUSION

In general, the two conditions of soil, namely NC and OC soil and all zona, have similar trends regarding the maximum and minimum border of settlement prediction. The highest border is the Nishida (1956) at 1.15 (e_o -0.35), and the lowest is the Azzouz (1976) at 0.037 (e_o-0.003LL-0.34). However, the appropriate calculation between the empirical formula and settlement instrumentation differs between Zona A and Zona B, although Zona B and Zona C have the same result. Consequently, the Bowles (1989) describes (0.156 e_o)+0.0107 as suitable for Zona A in NC and OC conditions, but in other locations, Sridharan & Nagaraj (2000) means 0.014 (PI+3.6) has the most relevant result. The Cc existing data from the laboratory obtained produces different values with field investigation because of the lack of data and other factors such as errors of calculation procedure and laboratory. This condition implies that in order to obtain accurate calculation results and ensure development in the field, it is required to have thorough soil compression and other key data factors. Therefore, further research in other areas and data must still be collected.

Acknowledgement

and assistance in providing access to field data for this research. Their cooperation and contribution have significantly enriched the quality and reliability of the study.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Nguyen, T.N., T.D. Nguyen, T.S. Bui. 2021. Geotechnical Properties of Soft Marine Soil at Chan May Port, Vietnam. *Inzynieria Mineralna*, 1. DOI: https://doi.org/10.29227/IM-2021-02-18.

[2] Wahyudi, H., Y. Lastiasih, T.R. Satrya, M. Arif, P.T.K. Sari. 2021. The Comparison Of The Soft Clay Settlement Under An Embankment Load Using Field Instrumentation And Empirical Formulation. *International Journal Of GEOMATE,* 21: 93-102. DOI: https://doi.org/10.21660/2021.84.j2151.

[3] Fitri, S.N., F. Wahyuni. 2022. Safety Factors Investigation Based on FEM and LEM Approach in Toll Road Embankment Slope. *Civil Engineering and Architecture,* 10: 1948–1966. https://doi.org/10.13189/cea.2022.100518.

[4] [4] Li, S., Z.Q. Yue, L.G. Tham, C.F. Lee, S.W. Yan. 2005. Slope failure in underconsolidated soft soils during the development of a port in Tianjin, China. Part 1: Field investigation. *Canadian Geotechnical Journal*, 42: 147-165. https://doi.org/10.1139/t04-089.

[5] Indraratna, B., C. Rujikiatkamjorn, P. Baral, J. Ameratunga. 2019. Performance of marine clay stabilised with vacuum pressure: Based on Queensland experience. *Journal of Rock Mechanics and Geotechnical Engineering*, 11. DOI: https://doi.org/10.1016/j.jrmge.2018.11.002.

[6] Ha, T. 2020. Lach Huyen port infrastructure project and soil improvement works. *Geotechnical Engineering,* 51: 12–19. DOI: https://doi.org/10.14456/seagj.2020.60

[7] Indraratna, B., Baral, P., Rujikiatkamjorn, C., Nguyen, T.T. 2019. Soft Ground Improvement—Theoretical, Experimental, Numerical and Field Studies. In: Latha G., M. (eds) Frontiers in Geotechnical Engineering. Developments in Geotechnical Engineering. Springer, Singapore DOI: https://doi.org/10.1007/978-981-13-5871-5_10

[8] Nazir, R., H. Moayedi, P. Subramaniam, S.S. Gue. 2017. Field performance of transition rigid piled embankment with surcharged vertical drain over soft ground. *International Journal of Geomate,* 13: 151-155. DOI: https://doi.org/10.21660/2017.35.60892.

[9] Nazir, R., H. Moayedi, P. Subramaniam, S.S. Gue. 2018. Application and Design of Transition Piled Embankment with Surcharged Prefabricated Vertical Drain Intersection over Soft Ground. *Arabian Journal for Science and Engineering*, 43: 1573-1582. DOI: https://doi.org/10.1007/s13369-017-2628-6.

[10] Siti Nurlita Fitri. 2022. Desain Perbaikan Tanah Dasar, Pangkal Jembatan, Oprit dan Pondasi pada Jembatan Sungai Babakan pada Proyek Jalan Tol Pejangan-Pemalang, Media Sains Indonesia

[11] PH, T. 2017. Research on Correlation between Compression index (Cc) and Other Properties of Soil for Geotechnical Design in Coastal Regions of Viet Nam and Cambodia. *MOJ Civil Engineering,* 2: 97-101. DOI: https://doi.org/10.15406/mojce.2017.02.00034.

[12] Fakharian, K., A. Mehdizadeh. 2015. Investigation of field instrumentation in a preloading project. Proceedings of the Institution of Civil Engineers: *Geotechnical Engineering,* 168: 87-98. DOI: https://doi.org/10.1680/geng.13.00018.

[13] Wahono, D. 2015. Terminal Petikemas pada Pelabuhan Internasional Pantai Kijing di Kecamatan Sungai Kunyit Kabupaten Pontianak. *Jurnal Online Mahasiswa Arsitektur Universitas Tanjungpura*, 3. 37-55. DOI: https://doi.org/10.26418/jmars.v3i1.9798

[14] Habibbeygi, F., H. Nikraz, F. Verheyde. 2017. Determination of the compression index of reconstituted clays using intrinsic concept and normalized void ratio. *International Journal of Geomate*, 13: 54-60. DOI: https://doi.org/10.21660/2017.39.98271.

[15] Jain, V.K., M. Dixit, R. Chitra. 2015. Correlation of Plasticity Index and Compression Index of Soil. *International Journal of Innovations in Engineering and Technology,* 5: 263-270

[16] Sridharan, A., H.B. Nagaraj. 2004. Coefficient of consolidation and its correlation with index properties of remolded soils. *Geotechnical Testing Journal*, 27: 469-474 DOI: https://doi.org/10.1520/gtj10784.

[17] Danial Mohammadzadeh, S., S.F. Kazemi, A. Mosavi, E. Nasseralshariati, J.H.M. Tah. 2019. Prediction of compression index of fine-grained soils using a gene expression programming model. *Infrastructure*s, 4: 1-12. DOI: https://doi.org/10.3390/infrastructures4020026.

[18] Park, H. Il, S.R. Lee. 2011. Evaluation of the compression index of soils using an artificial neural network. *Computers and Geotechnics,* 38 472-481. DOI: https://doi.org/10.1016/j.compgeo.2011.02.011.

[19] Mayne, P.W. 1980. Cam-clay predictions of undrained strength. *Journal of the Geotechnical Engineering Division,* ASCE, 106: 1219-1242. DOI: https://doi.org/10.1061/ajgeb6.0001060.

[20] Wroth, C.P., D.M. Wood. 1978. Correlation Of Index Properties With Some Basic Engineering Properties Of Soils. Canadian Geotechnical Journal, 15: 137-145. DOI: https://doi.org/10.1139/t78-014.

[21] Azzouz, A.S., R.J. Krizek, R.B. Corotis. 1976. Regression Analysis Of Soil Compressibility. *Soils and Foundations,* 16: 19-29 DOI: https://doi.org/10.3208/sandf1972.16.2_19.

[22] SOWERS, G.B., G.F. SOWERS. (1951). Introductory Soil Mechanics and Foundations. *Soil Science,* 72: 405 DOI: https://doi.org/10.1097/00010694-195111000-00014.

[23] Trask, P.D. 1949. Soil Mechanics in Engineering Practice. Karl Terzaghi, Ralph B. Peck. *The Journal of Geology,* 57: 622. DOI: https://doi.org/10.1086/625679.

[24] Mohammadzadeh S., D., J. Bolouri Bazaz, A.H. Alavi 2014. An evolutionary computational approach for formulation of compression index of fine-grained soils. *Engineering Applications of Artificial Intelligence*, 33: 58-68. DOI: https://doi.org/10.1016/j.engappai.2014.03.012.

[25] Shimobe, S., G. Spagnoli. 2022. A General Overview on the Correlation of Compression Index of Clays with Some Geotechnical Index Properties. Geotechnical and Geological Engineering, 40: 311-324 DOI: https://doi.org/10.1007/s10706-021-01888-8.

[26] Fan, R., J. Liu, S. Liu, Y. Du, M. Liu, S. You. 2021. Predicting the Compression Index of Saturated Reconstituted Contaminated Clays Using Index Properties. *KSCE Journal of Civil Engineering,* 25: 3289-3297DOI: https://doi.org/10.1007/s12205-021-1577-5.

[27] Alam, M.K., N. Islam, M.Z. Abedin, M.S. Islam, R. Dey, A.J. Valsangkar. (2022). Prediction of compressibility and shear strength behaviour of in-situ cohesive soil from reconstituted clay. *International Journal of Geotechnical Engineering*, 16: 655-669. DOI: https://doi.org/10.1080/19386362.2022.2049048.

[28] Sari, P.T.K., Y.K. Firmansyah. 2013. The Empirical Correlation Using Linear Regression of Compression Index for Surabaya Soft Soil. The *2013 World Congress on Advances in Structural Engineering and Mechanics (ASEM13)*

[29] Mohsen Farzi. 2017. Suggesting a Formula to Calculate the Compression Index in Ahvaz. *Indian Journal of Science and Technology.* 10: 1-8. DOI: 10.17485/ijst/2017/v10i32/106232

[30] Habibbeygi, F., H. Nikraz. 2018. Characterisation of the undrained shear strength of expansive clays at high initial water content using intrinsic concept. *International Journal of GEOMATE*, 14: 176-182 DOI: https://doi.org/10.21660/2018.44.41572.

[31] Daoud, W.A., K. Kasama, N.M. Saleh, A.M. Negm. 2016. Statistical Evaluation Of Geotechnical Correlations. *International Journal of GEOMATE,* 10 1929-1935. DOI:https://doi.org/10.21660/2016.21.5398.

[32] Skempton, A.W. 1946. Notes on the compressibility of clays. Quarterly *Journal of the Geological Society of London,* 102: 205-209. DOI: https://doi.org/10.1144/GSL.JGS.1946.102.01-04.10.

[33] Nishida, Y. 1956. A Brief Note on Compression Index of Soil*. Journal of the Soil Mechanics and Foundations Division,* 82: 3. DOI: https://doi.org/10.1061/jsfeaq.0000015.

[34] Cozzolino, V.M. 1961. Statistical forecasting of compression index, in: The *Fifth International Conference on Soil Mechanics and Foundation Engineering, Paris*, 51–53.

[35] Yune, C.-Y., G. Olgun. 2016. Effect of Layering on Total Consolidation Settlement of Normally Consolidated Clay in 1D Conditions. *Journal of Geotechnical and Geoenvironmental Engineering*, 142: 2 DOI: https://doi.org/10.1061/(asce)gt.1943-5606.0001415.

[36] *Bowles, J.E. 1981.* Physical and geotechnical properties of soils. Physical and Geotechnical Properties of Soils. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts.* 18(6): 109. DOI: https://doi.org/10.1016/0148-9062(81)90529-5.

[37] Salem, M., R. El-Sherbiny. 2014. Comparison of measured and calculated consolidation settlements of thick underconsolidated clay. *Alexandria Engineering Journal,* 53: 107-117 DOI: https://doi.org/10.1016/j.aej.2013.11.002.

[38] Nazir, R., N. Sukor, H. Niroumand, K.A. Kassim. 2013. Performance of soil instrumentation on settlement prediction. *Soil Mechanics and Foundation Engineering,* 50: 61-64. DOI: https://doi.org/10.1007/s11204-013-9211-2.

[39] Ibrahim, N.M., N.L. Rahim, R.C. Amat, S. Salehuddin, N.A. Ariffin. 2012. Determination of Plasticity Index and Compression Index of Soil at Perlis. *APCBEE Procedia,* 4: 94-98. DOI: https://doi.org/10.1016/j.apcbee.2012.11.016.

[40] Jain, V.K., M. Dixit, R. Chitra. 2015. Correlation of Plasticity Index and Compression Index of Soil. *International Journal of Innovations in Engineering and Technology*, 5: 263-270

[41] Al-Khafaji, A.W.N., O.B. Andersland. 1992. Equations for compression index approximation. *Journal of Geotechnical Engineering*, 118: 148. DOI: https://doi.org/10.1061/(ASCE)0733-9410(1992)118:1(148).

[42] Liu, S., G. Cai, A.J. Puppala, Q. Tu. 2011. Prediction of embankment settlements over marine clay using piezocone penetration tests. *Bulletin of Engineering Geology and the Environment,* 70: 401-409. DOI: https://doi.org/10.1007/s10064-010-0329-4.

[43] Webster, R. 2007. Interpreting Soil Test Results: What do all the Numbers mean? - by P. Hazelton & B.Murphy. *European Journal of Soil Science,* 58: 1219-1220. DOI: https://doi.org/10.1111/j.1365-2389.2007.00943_8.x.