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Empirical Correlation Between Soil Plasticity and Consolidation Parameter of Remoulded Clay

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Abstract: *The amount of soil compression due to consolidation is generally predicted by using consolidation parameters determined from Oedometer test. However, the time required to conduct the test is relatively longer than the other laboratory tests. The time required to conduct the test is 7 to 8 days. Therefore, an empirical correlation between soil plasticity (LL and IP) with consolidation parameter value (Cc, Cs and Cv) is needed. In this study, an empirical correlation is developed and the results is compared with the other correlation that has been established by previous researchers. Material used in this study was clay from Surabaya area, kaolinite, and silt; they were mixed to obtain various soil plasticity value (from low plasticity to high plasticity). In order to prepare the soil specimens, the material were mixed in slurry condition and loaded with 1-step loading of 1.45 kg/cm^2 until 100% primary consolidation reached. The soil specimens was then tested with Oedometer test with load increment ratio (LIR) = 1. The results show that the empirical correlation between soil plasticity and consolidation parameter obtained from this study are: Cc= 0.048LL – 0.36 and Cc = 0.00229LL + 0.308e_o + 0.018.*

Keywords: *soil plasticity, consolidation parameter, remolded clay*

1. Introduction

Under external load, the soil consolidation will occurs as a result of expulsion of water from the soil pores. This process will occur continuously until all the excess pore water pressure caused by total stress change is totally dissipate. In construction designing process, it is really important to take account the total consolidation that will occur in the structure and avoid the differential settlement which led to crack in building or structure.

The total and time of soil consolidation can be predicted using consolidation parameter (Cc, Cs and Cv) which is obtained from one-dimensional consolidation test in laboratory (Oedometer test). Oedometer consolidation test which has been developed by Terzaghi since 1925. However, this test is more time consuming compared with other soil test in laboratory. The time required to conduct this test is 7 to 8 days. Therefore, an empirical correlation between soil plasticity (LL and IP) with consolidation parameter value (Cc, Cs and Cv) is needed.

There are several empirical correlation that have been developed by other researchers. Some correlation based from Liquid Limit value has been developed by Skempton (1944), Terzaghi and Peck (1967), Bowles (1979) and Azouz et al (1976) as shown in Table 1. However, those empirical formula is only correlation result of the clay soil in the particular country. Therefore, a new empirical correlation is needed which can more generally applied in all type of clay soil.

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TABLE I: Empirical Correlation of Compression Index (Cc) and Swelling Index (Cs)

Empirical Correlation	Researchers	Description
$Cc = 0.007 (LL – 7)$	Skempton (1967)	Remolded Clay
$Cc = 0.006 (LL – 9)$	Azzouz et al (1976)	All clay, LL < 100
$Cc = 0.0046 (LL – 9)$	Cozzolino (1961)	Brazilian Clay
$Cc = 0.00058LL + 0.411e_o – 0.156$	Herrero (1980)	-
$Cc = 0.37(e_o + 0.003LL – 0.34)$	Azzouz et al.	-
$Cc = 0.006LL + 0.13\ e_o^2 – 0.13$	Kosasih and Mochtar (1997)	Lab. testing

2. Material and Research Method

This research is a laboratory scope that use inorganic clay specimen. The specimen that are used in this research are remoulded clay mixture. The use of remoulded clay in this study is in order to reduce degree of disturbance of the soil specimen and get a homogeneous soil sample for the test.

Material used in this study was clay from Surabaya, kaolinite, and silt; they were mixed to obtain various Liquid Limit and Plasticity Index value. Preliminary physical properties test is conducted for each of the soil mixture. Those physical properties test are: specific gravity (Gs), liquid limit (LL), plastic limit (PL). The plasticity value of soil mixture in this test is chosen based on Casagrande Plasticity chart. In this study, soil mixture has to represent each of the clay plasticity value (low plasticity, medium plasticity, and high plasticity).

Procedure to prepare the soil sample:

1. The clay soil that used is this study was dried soil which is passed #200 sieve and silt was dried soil which is passed #100 sieve. There were mixed in several dry weight variation and the water added to conduct the soil plasticity test to obtain the liquid limit and the plastic limit of the soil mixture. Dry weight variation from that mixture

2. Soil mixture that have been chosen in step 1, then made into slurry condition. Water is added into soil mixture until the water content of the soil is 2 times the value of its liquid limit to make the soil in the slurry condition [2]. Then slurry is poured in to tube which has diameter of 6.35 cm and height of 24 cm and loaded with 1-step loading of 1.45 kg/cm2 until 100% degree of consolidation reached or when there is no water dissipate left from both upper and bottom of the specimen. The tube is modified in order to let the water dissipate from upper and bottom of the soil specimen during loading. Usually the loading process takes 5 – 10 days.

3. Soil sample after consolidation process in step 2 is taken out from the tube (Fig. 2a) and then conduct a physical properties test such as: water content (Wc), unit weight, specific gravity (Gs).

4. Soil sample from step 3 also tested with oedometer test with Load Increment Ratio = 1 to obtain the consolidation parameter (Cc and Cs)

Consolidation parameter value from each soil sample which have various plasticity (step 4) then analyse to make an empirical correlation between consolidation parameter and plasticity of the soil. The developed correlation from this study will be compared with some correlation that has been developed by another researchers in table 1.

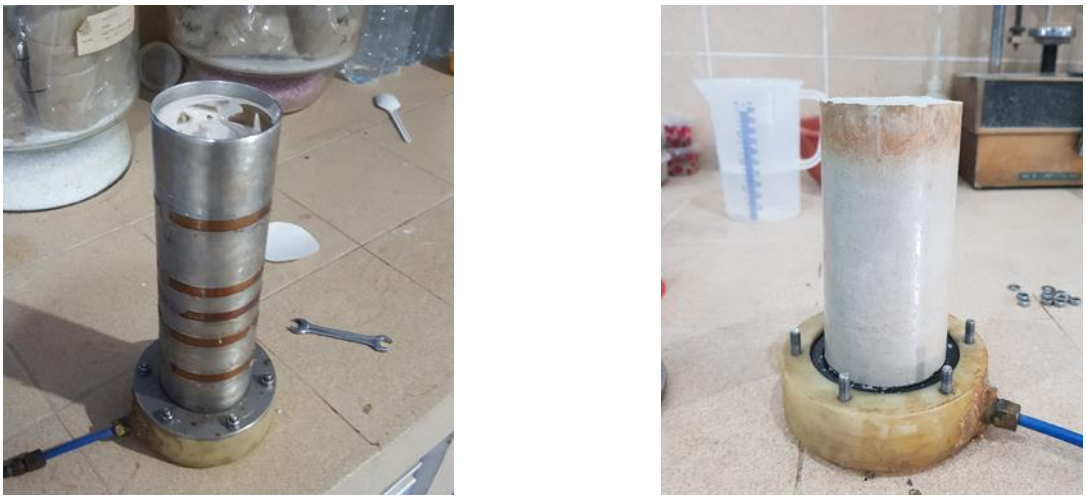

Fig. 1 a. Soil sample in Slurry condition the consolidation tube, b. Soil Specimen after Remoulded Process

3. Result and Discussion

Consolidation Parameter Obtained From Remolded Clay

The plasticity value of soil mixture in this test is chosen based on Casagrande Plasticity chart. In this study, soil mixture has to represent each of the clay plasticity value (low plasticity, medium plasticity, and high plasticity). After a series of Atterberg limit test, in this study is chosen four soil mixture with liquid limit and plasticity index value showed in Table 2.

TABLE II: Liquid Limit and Plasticity Index Value of the Soil Mixture

Soil Mixture	Liquid Limit	Plasticity Index	Gs
Kaolinite 92.5% + Silt 7.5%	34	11	2.559
Kaolinite 75% + Surabaya Clay 25%	62	30	2.610
Kaolinite 100%	71	24	2.867
Surabaya Clay 100%	116	61	2.713

Each of soil mixture is then tested with oedometer consolidation test twice to obtain more reliable result. The test result is showed in Table 3.

TABLE III: Liquid Limit and Plasticity Index Value of the Soil Mixture

Soil Mixture	Liquid Limit	Plasticity Index	Gs	e_o	Wc	Cc	Cs
Kaolinite 92.5% + Silt 7.5%	34	11	2.559	1.384	52.16	0.50	0.108
Kaolinite 92.5% + Silt 7.5%	34	11	2.559	1.348	52.16	0.52	0.127
Kaolinite 75% + Surabaya Clay 25%	62	30	2.610	1.513	56.25	0.61	0.191
Kaolinite 75% + Surabaya Clay 25%	62	30	2.610	1.493	56.25	0.66	0.183
Kaolinite 100%	71	24	2.867	1.897	59.47	0.72	0.193
Kaolinite 100%	71	24	2.867	1.887	59.47	0.82	0.138
Surabaya Clay 100%	116	61	2.713	1.993	71.28	0.88	0.204
Surabaya Clay 100%	116	61	2.713	2.055	71.28	0.92	0.219

3.1. Statistical Analysis

The empirical correlation between soil plasticity of remolded clay was calculated in terms of both linier value and logarithmic value. Table 4 describes empirical correlation of liquid limit vs compression index. As showed in the table 4, the compression index has statically good correlations with liquid limit value both linier and logarithmic value with R value 0.897 and 0.908 respectively. This R value shows that there is a strong relationship between liquid limit value and compression index value.

TABLE IV: Correlation between Liquid Limit and Consolidation Parameter on Remolded Clay

Correlation	R	Regression
Cc = 0.0048LL + 0.3617	0.897	Linier
Cc = 0.328 ln (LL) – 0.662	0.908	Logarithmic
Cs = 0.0011LL + 0.1006	0.755	Linier
Cs = 0.0763 ln(LL) – 0.143	0.876	Logarithmic

However, single soil-parameter model appear to be least reliable in predicting the compression index. The use of multiple soil parameter model for prediction of the consolidation parameter is recommended [4]. The multiple soil parameter is reasonable because the liquid limit is a soil property that is depend on soil type, particle size and particle surface characteristic. Consequently, in this study, an addition soil parameter such as void ratio should be included to account to predict the consolidation behavior or parameter. The empirical correlation result based on multiple soil parameters are showed in Table 5.

TABLE V: Prediction of Consolidation Parameter based on Multiple Soil Parameter on Remolded Clay

Correlation	R	Regression
Cc = 0.00229LL + 0.3083eo + 0.0188	0.957	Multi Variable
Cs = 0.00103LL + 0.0023eo + 0.097	0.868	Multi Variable

Correlations that use multiple soil parameter (liquid limit and initial void ratio) give a better R value of the empirical correlation. The empirical that obtained are Cc = 0.00229LL+ 0.3083eo + 0.0188 with R value of 0.97 and Cs = 0.00103LL + 0.0023eo + 0.097 with R value of 0.868. This is obviously has a more reliable result than the correlation with just use liquid limit value only.

Compression Index Comparison between Measured Data and Empirical Correlation

As described in Table 6, compression index correlation based on only liquid limit value of soil give a wide range of deviation compared with actual result in the laboratory. Deviation value ranged from 43 % to 62% which mean the empirical correlation cannot predict accurately the value of compression index. The empirical correlation that obtained from this study has a deviation of 5%.

In other hand, empirical correlation that derived from multiple soil parameter (liquid Limit and initial void ratio) give a better deviation. According to Table 7, deviation value ranged from 17% – 19%. The empirical correlation that obtained from this study has a deviation of 2%. This value means the correlation with multiple soil parameter can predict the compression index value quite precisely. This data confirmed statement that explained earlier that not only liquid limit that influenced soil characteristic but also soil type, particle size and particle surface.

TABLE VI: Comparison of Compression Index Prediction Using LL only

Liquid Limit (LL)	Cc Hasil Lab.	Developed Correlation		Azzouz		Skempton		Cozzolino	
		Cc	Deviation	Cc	Deviation	Cc	Deviation	Cc	Deviation
34	0.51	0.524	3%	0.150	71%	0.168	67%	0.115	77%
62	0.63	0.659	5%	0.318	50%	0.364	42%	0.243	61%
71	0.77	0.702	9%	0.372	52%	0.427	45%	0.285	63%
116	0.90	0.918	2%	0.642	29%	0.742	18%	0.492	45%
				Mean R=	50%	Mean R=	43%	Mean R=	62%

TABLE VII: Comparison of Compression Index Prediction Using Multiple Soil Parameter

Liquid Limit (LL)	Initial Void Ratio (e_o)	Cc Hasil Lab	Developed Correlation		Azzouz		Herrero		Kosasih & Mochtar	
			Cc	Deviation	Cc	Deviation	Cc	Deviation	Cc	Deviation
34	1.366	0.51	0.517	2%	0.417	18%	0.425	17%	0.316	38%
62	1.503	0.63	0.624	1%	0.499	21%	0.497	21%	0.535	15%
71	1.892	0.77	0.764	1%	0.653	15%	0.662	14%	0.761	1%
116	2.024	0.90	0.904	1%	0.751	16%	0.743	17%	1.098	22%
					Mean R=	18%	Mean R=	17%	Mean R=	19%

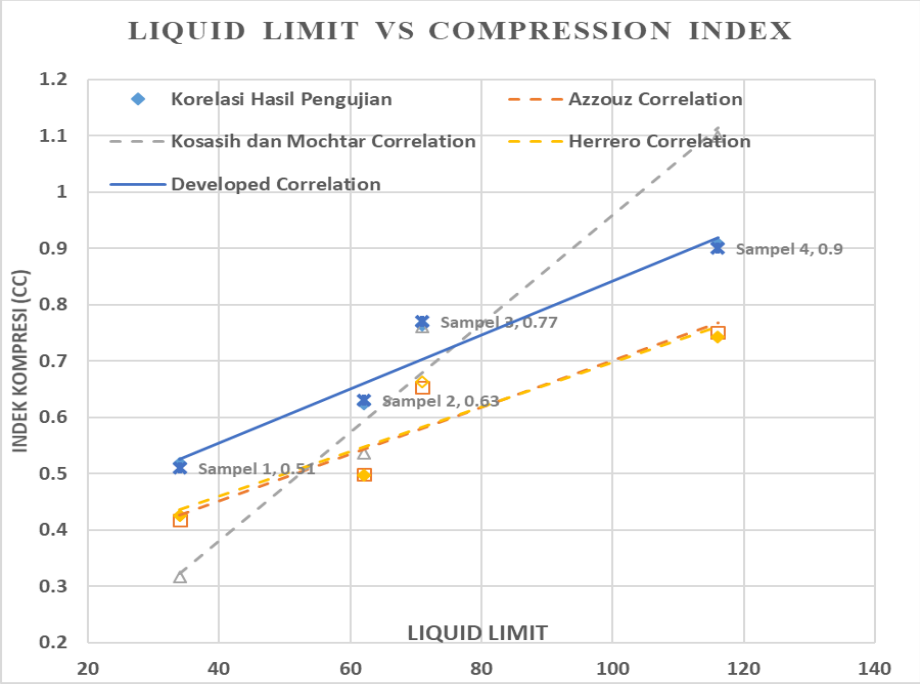

Fig 3: Comparison of Correlation

4. Conclusion

Remoulded clay use in this study is to reduce degree of disturbance of the soil sample and to obtain homogeneous soil samples. The result of the soil samples is relatively homogeneous which is indicated from no wide data distribution in each of the soil test. Regression between soil plasticity and compression index value show that there is a strong relationship between those two parameter. That is indicated by the R value of linier regression is 0.897 and for logarithmic correlation have R value of 0.904.

However, to increase the accuracy of the prediction of the compression index, the multiple soil parameter have taken into account in the correlation. In this study, liquid limit and initial void ratio correlation have a slightly better result in predicting compression index value. The empirical correlation that obtain from this study is Cc = 0.00229LL + 0.3083eo + 0.0188 with R value 0.957 and Cs = 0.00103LL + 0.0023eo + 0.097 with R value 0.856. Another multiple soil parameter empirical correlation that have been established by previous researcher also give a good result with deviation value range from 17% to 19%. With high value of R, then this empirical correlation can predict accurately the value of consolidation parameter using plasticity and initial void ratio value of the soil.

5. Acknowledgments

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6. References

[1] K. M. Putu Tantri, and K. F. Yerry, “The Empirical Correlation Using Linear Regression of Compression Index for Surabaya Soft Soil,” in Proc. ASEM13 Conf., 2013, pp. 308- 319.

[2] W.A Made Dodiek, “Correlation of Undrained Shear Strength Value Obtained from Unconfined Compression Test and Laboratory Vane Shear Test,” Proc. Jurnal Ilmiah Teknik Sipil Vol. 12, 2008.

[3] A. Kosasih, “Pengaruh Kadar Air, Angka Pori, dan Batas Cair Tanah Lempung Terhadap Indeks Pemampatan Konsolidasi Cc dan Indeks Pengembangan Cs,” M.S. thesis, Dept. Civil Eng., Sepuluh Nopember Institute of Technology, Surabaya, Indonesia, 1997.

[4] A.S. Azzouz, R.J. Krizek and R.B. Corotis, “Regression Analysis of Soil Compressibility” in Soils and Foundation, 1976, pp. 19-29.

[5] A. W. N. Al Khafaji and O.B. Andersland, “Equations for Compression Index Approximation”, Journal of Geotechnical Engineering ASCE, 118, 1992, pp. 148 – 155.

https://doi.org/10.1061/(ASCE)0733-9410(1992)118:1(148)

[6] M.D. Braja, Principles of Geotechnical Engineering, 5th edition, California, U.S.A.: Thomson, 2006, ch.10, pp. 259-300.

[7] G. L. Yoon, B.T. Kim and S.S. Jeon, “Empirical Correlation of Compression Index for Marine Clay from Regression Analysis,” in Journal, 2004, pp 1213 – 1221.