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Full Length Research Paper

A characteristic of consolidation parameters of marine clay in Busan Area – South Korea

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In this study the city of Busan was selected and investigated for a characteristic of consolidation parameters. Busan is one of representative cities in the southern coast of Korea, where main harbors are located, and many geotechnical investigations were performed due to massive harbor constructions in the past. Consolidation parameters, including pre-consolidation pressure, compression index (C_c), swelling index (C_s), overconsolidation ratio, vertical and horizontal consolidation coefficient (C_v, C_h), vertical and horizontal permeability coefficients (K_v, K_h), were investigated by using the general-purpose statistical analysis software (SPSS) with collected data from laboratory tests and field studies. A correlation between these parameters was evaluated from statistically processed data through regression analysis after removing outliers. As a result, it was shown that the relationship between swelling index and compression index was $C_s = C_c/8$ and correction constant (modified compression index/compression index) $C_c' = 1.1471C_{c(lab)}$. However, there was no relation with outliers. It was also shown that overconsolidation ratio with exponential decay formula, consolidation and permeability coefficients with rational function formula had the highest coefficient of determination.

Key words: Consolidation parameters, correlation, regression analysis, coefficient of determination.

INTRODUCTION

A technology related to soft ground treatments in each field has been widely developed through the massive constructions in Korea, but it is still required to be improved in many fields. Especially, through the recent project (example, for various soft ground improvements) subjected to engineering and economic advantages that a systematic and comprehensive geotechnical investigation tremendously affects to the selection, design, and construction of the reasonable process-improvement. Therefore, there is need for pre-investigation of soft grounds to reasonably and accurately understand the engineering characteristics of the object ground for the economical and efficient process. However, the present condition of distribution and understanding of characteristics to the soft ground are insufficient in Korea due to a lack of information of results obtained through nationwide geotechnical investigation.

Until now, empirical equations, in order to determine compression index, have been suggested by many researchers, including Skempton (1944), Terzaghi and Peck (1976), through a soil laboratory test. Kang (1987) suggested the relationship between liquid limit and compression index in terms of the consolidation characteristic of soft ground, and Kim et al. (1997) reported that the mean of $C_{h(field)}$ / $C_{v(lab)}$ was 1.9 ± 0.31 (90% confidence interval) in the soft ground at Inchon international airport in Korea. Bae and Kim (2009) found that after statistical analyses, it was confirmed that the coefficient of determination increased after the Box-Cox variable transformation thus the explanatory power was being enhanced.

In this study the southern coastal area, where the relatively large geotechnical investigation data was available and major harbors were located, was selected as an object area to investigate characteristically the consolidation

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parameters. Statistical analysis was also considered and performed by using general-purpose software (SPSS, version 10.0) to characterize the parameters, including pre-consolidation pressure, compression index, swelling index, overconsolidation ratio, vertical and horizontal consolidation coefficients, vertical and horizontal permeability coefficients, with laboratory tests and the collection field studies.

In the statistical process descriptive statistics (example, mean and standard deviation) were prepared, and then representative values of geotechnical parameters independent to depth were chosen after removing outliers from the box plot. Correlation analysis was conducted and the correlationship of consolidation parameters was defined, and the most suitable regression equation was proposed through both linear and nonlinear regression analyses in this study.

SOIL CHARACTERISTICS OF SOFT GROUND IN SELECTED REGIONS

Geotechnical investigation data conducted in the areas of Busan port and Busan new port (MMAF, 2004) in Korea were taken into consideration for the new port project. Some cases that had a different tendency from most cases were neglected in this study for normality of the data.

A physical characteristic of the ground was investigated through the basic physical tests (approximately 1,200 tests were performed). For clay in the Busan area, water content was evaluated as being in a range between 18.4 and 129.1%, average equal to 58.05%. Water content was tended to decrease slightly with increasing depth, and it was less than average value at the level of depth below 35 m. Specific gravity and total unit weight were between 2.62 and 2.79, and between 1.323 and 2.116 tf/m^3, respectively. Total unit weight seemed to be dependent with depth but a small correlation was found with a coefficient of determination equal to 0.04. Initial void ratio, has relatively high correlation with consolidation parameters, was defined as between 0.61 and 2.82 (average 1.639) and seemed to decrease with depth ($e = -0.01211D + 1.804$). Liquid limit was in a relatively large range between 24.5 and 118.7% (average 64.06%). Plasticity index was between 3.1 and 77.9% (average 37.3%). Liquidity index with depth below 25 m was generally less than 1.0 and was in plastic state. Moreover, liquidity index tended to decrease with increasing depth with a linear relationship $LI = -0.01169D + 1.041$ (coefficient of determination equal to 0.21). Clay in Busan area was classified by Unified Soil Classification System (USCS) as 82% of CH, 15% of CL and 3% of silty fine-grained soils (ML-CL, ML, and MH). Activity was between 0.43 and 7.6; most specimens were distributed between 0.8 and 1.5 (average 1.09) and mainly composed of Illite with a little of Montmorillonite. Clay was in over consolidation condition between ground and depth equal to 4 m with overconsolidation ratio between 0.5800 and 4.8595 (average 1.8608), depth between 4 and 22 m it was close to normal consolidation condition, and depth below 22 m it was lightly overconsolidation with over-consolidation ratio between 0.3307 and 1.25 (average 0.8296). Oh et al. (2009) suggested that plasticity index was equal to 28.7%, water contents equal to 48.7%, compression index equal to 0.62 and OCR equal to 0.95 in the area of the mouth of Nakdong River.

CONSOLIDATION CHARACTERISTICS

In this study the normal distribution model for properties of tested data were verified through normality verification by using Q-Q plot and Kolmogorov-Smirnov method. Statistical analysis was performed by applying with significance level equal to 0.05 (5%), which was widely used for general purposes.

Compression index (C_c) and swelling index (C_s)

Consolidation characteristics were investigated based on the results of approximately 820 oedometer tests and 60 CRS, Rowe cell tests. A variation of compression index (C_c) with respect to the depth obtained from the oedometer test results is presented in Figure 1a. A distribution of compression index obtained from CRS, Rowe cell test is also shown in Figure 1b. The results (seen Figure 1) seemed to be under a big pre-consolidation load because it was quite constant with the depth with a small variability.

As a result of the oedometer test, compression index was in a range between 0.129 and 2.05, average compression index was equal to 0.691. The results through CRS test were also in the same range 0.131 to 0.983 (average 0.55). The results through Rowe cell test were found to be similar. Song (1988) and Yoon and Kim (2003) suggested compression index as being 0.13 to 1.24, and Kim et al. (2008) suggested it as being 0.3 to 1.2.

Figure 1c shows the relation between swelling index and depth obtained through oedometer test, this tends to decrease with depth and especially it was lower than average with depth below 30 m. Swelling index was evaluated as between 0.012 and 0.203 (average 0.086), and it was 1/8 of compression index ($C_s = C_c/8$). Das (2006) claimed that swelling index was less that compression index and most of cases were between $1/5C_c$ and $1/10C_c$ and also suggested that swelling index and compression index are 0.12 to 0.35 and 0.05 to 0.07, respectively. This showed that the results could be different with a type of clays and a formation background.

Pre-consolidation pressure and OCR

Figures 2a and b show that pre-consolidation pressure (P_c) tends to increase with an increasing depth; the results

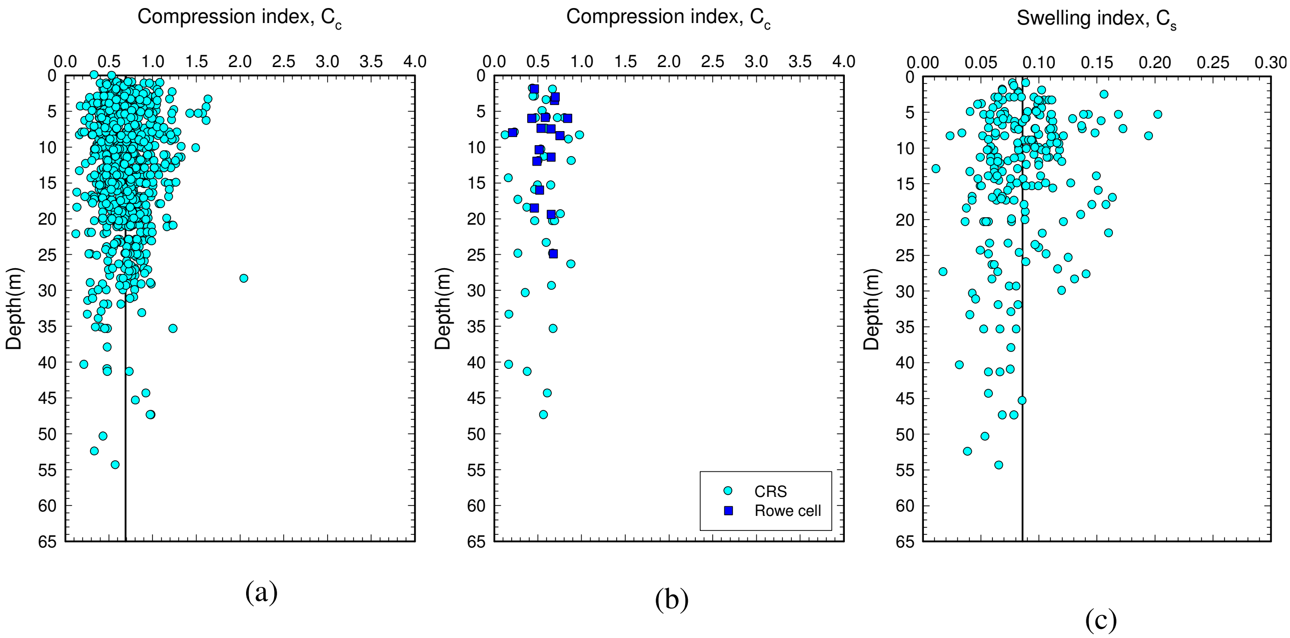


Figure 1. (a) Depth - C_c (odometer test), (b) depth - C_c (CRS, Rowe cell) and (c) depth - C_s.

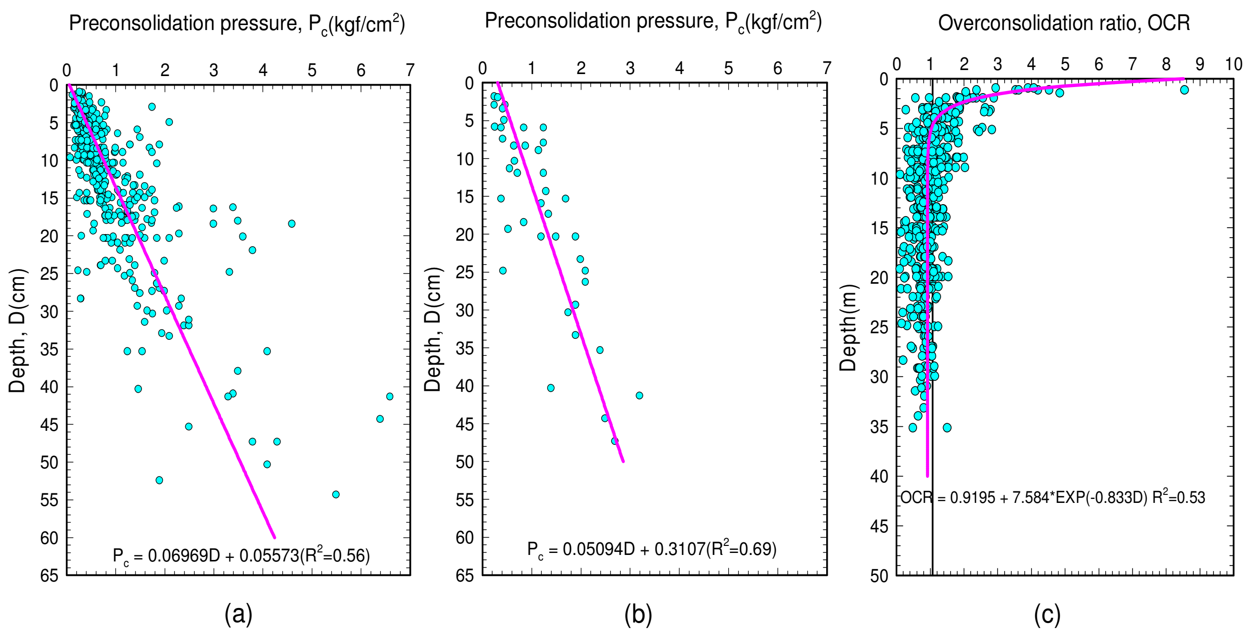


Figure 2. (a) Depth-P_c (odometer test), (b) depth-P_c (CRS, Rowe cell) and (c) depth-OCR.

were obtained through CRS, Rowe cell tests. The result from the oedometer test for pre-consolidation pressure was 0.08 to 6.6 kgf/cm^2 in relation as P_c = 0.06969D + 0.05573 (R^2 = 0.56). The result from CRS, Rowe cell tests was in a similar range.

In Figure 2c, it was over consolidation condition that OCR was distributed between 0.5800 to 4.8595 with average equal to 1.8608 within depth 4 m. It was also shown that normal consolidation condition with depth between 4 and 22 m was 0.25 to 2.01 (average 0.9524), this was almost in a consolidation condition when depth was below 22 m. The correlation between OCR and depth was defined as OCR = 0.9195 + 7.584e$^{-0.833D}$ (R^2 = 0.53) and evaluated that coefficient of determination was

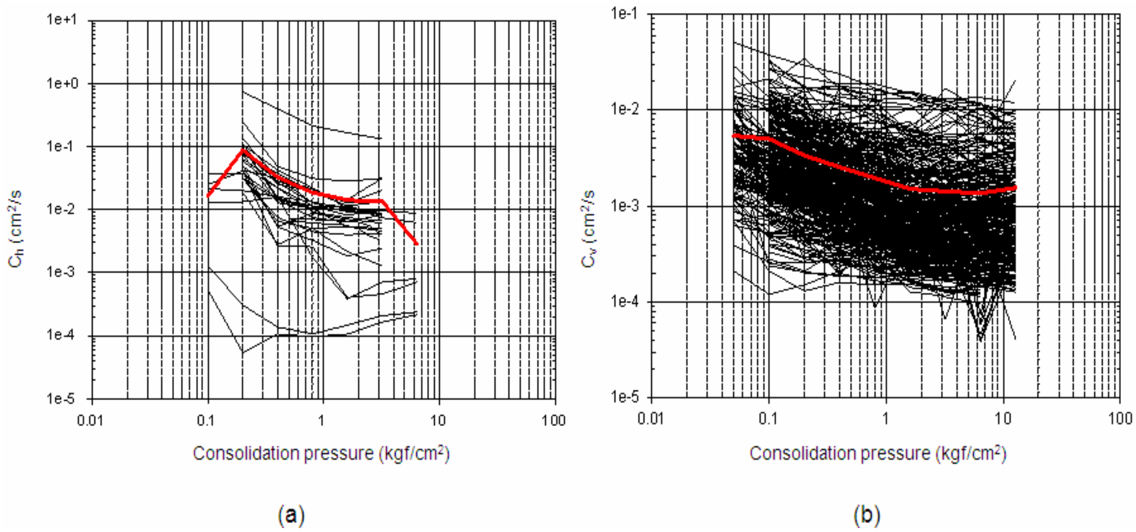


Figure 3. (a) P_c - C_v and (b) P_c - C_h.

Table 1. Consolidation coefficient and coefficient of permeability with various consolidation pressures.

Consolidation pressure P (kgf/cm^2)	Vertical consolidation coefficient C_v (cm^2/s)	Horizontal consolidation coefficient C_h (cm^2/s)	Vertical coefficient of permeability K_v (cm^2/s)	Horizontal coefficient of permeability K_h (cm^2/s)
0.1	0.000237 - 0.03476	0.000527 - 0.03750	1.58×10^{-8} - 6.01×10^{-6}	8.43×10^{-8} - 3.25×10^{-6}
0.2	0.000201 - 0.03450	0.000054 - 0.73053	5.24×10^{-8} - 3.40×10^{-6}	5.12×10^{-8} - 6.42×10^{-5}
0.4	0.000186 - 0.02389	0.000106 - 0.39351	2.98×10^{-8} - 2.92×10^{-6}	1.00×10^{-8} - 2.50×10^{-5}
0.8	0.000167 - 0.01880	0.000097 - 0.21197	2.36×10^{-8} - 2.91×10^{-6}	7.61×10^{-9} - 1.04×10^{-5}
1.6	0.000153 - 0.01570	0.000106 - 0.16454	1.55×10^{-8} - 1.46×10^{-6}	4.99×10^{-9} - 8.21×10^{-6}
3.2	0.000112 - 0.01680	0.000164 - 0.13118	8.09×10^{-9} - 6.06×10^{-7}	3.79×10^{-9} - 3.28×10^{-6}
6.4	0.000096 - 0.01350	0.000215 - 0.00875	3.52×10^{-9} - 2.39×10^{-7}	2.66×10^{-9} - 8.68×10^{-6}
12.8	0.000127 - 0.02070		1.90×10^{-9} - 1.99×10^{-7}	

relatively higher when reduction exponent equation ($y = y_0 + e^{-bx}$) was used.

Consolidation coefficients and coefficients of permeability

Figure 3a shows the variation of consolidation coefficient in vertical direction. Most of cases were in 0.0001 to 0.01 cm^2/s, and bold line indicates the average value. Generally, vertical consolidation coefficient (C_v) was known to be dramatically decreased when it was in near the preconsolidation stress area, then constant afterwards, and it was confirmed in Figure 3(a). In other words, the average vertical consolidation coefficient was increased up to consolidation pressure equal to 1.6 kgf/cm^2 and was tended to be constant after that.

Figure 3b was obtained through Rowe cell test. Horizontal consolidation coefficient was generally decreased with increasing consolidation pressure, and it was between 0.0001 to 0.1 cm^2/s.

Table 1 shows that horizontal and vertical consolidation coefficients due to consolidation pressure, C_h/C_v were 9.3 to 9.5 under consolidation pressure which is equal to 0.8 to 3.2 kgf/cm^2.

In the clay layer, the vertical coefficient of permeability was mostly in a range between 1×10^{-9} and 2×10^{-6} cm/s, and horizontal coefficient of permeability tends to decrease with increasing consolidation pressure. Anisotropy of the permeability coefficient was clearly found as k_h/k_v equal to 11.7 to 14.9.

Secondary compression index

Table 2 shows the secondary compression index with consolidation pressure. The average secondary compression index was linearly (R^2 = 0.97) which

Table 2. Secondary compression index with various consolidation pressure (*P*).

P (kgf/cm^2)	Secondary compression index			
0.05	0.0050	~	0.00160	(0.001111)
0.1	0.0020	~	0.00400	(0.001251)
0.2	0.0040	~	0.00800	(0.001984)
0.4	0.0070	~	0.01400	(0.003922)
0.8	0.0090	~	0.02640	(0.006744)
1.6	0.0010	~	0.02330	(0.009722)
3.2	0.0020	~	0.02150	(0.009903)
6.4	0.0045	~	0.01390	(0.009574)
12.8	0.0051	~	0.01020	(0.007970)

increased up to consolidation pressure equal to 1.6 kgf/cm^2, and then became constant. Mesri (1973) suggested that secondary compression index less than 0.001 for over consolidation clays, 0.005 to 0.03 for normal consolidation clays, and greater than 0.04 for organic soils. Mesri and Godlewaki (1997) claimed that primary consolidation and secondary consolidation were due to the same mechanism as a study of the relation between secondary consolidation index and compression index, so that it was not relevant with time, effective stress, and void ratio with respect to the particular soil.

Kim et al. (1999) reported that the empirical concept of C_v/C_c could define the behavior of secondary consolidation and it also could be economical and effective method to expect the secondary consolidation quantity, but it was also reported that the data in Korea was not enough. Kim et al. (1999) suggested secondary compression index equal to 0.0397 for marine clay in the southern coast of Korea. Mesri and Castro (1987) suggested 0.04 ± 0.01 for inorganic clay.

As a result, C_v/C_c ratio had a similarity to the previous data at the specific pressure. However, it was widely varied in a range between 0.001 and 0.077 with consolidation steps even in the same ground. Therefore, it was required as to be differentially applied due to the type of ground, the applied depth, and the stress history.

CORRELATION ANALYSIS

Linear regression analysis: Depth – preconsolidation pressure

Figure 4 shows that pre-consolidation pressure (P_c) is generally increased as varying with depth obtained through normal consolidation test (Figure 4a) and CRS, Rowe cell test (Figure 4b). A linear relation for P_c as a function of depth (D) after removing outliers was evaluated as $P_c = 0.06329D + 0.06520$ ($R^2 = 0.746$). It was shown as $P_c = 0.05804D + 0.23061$ ($R^2 = 0.811$) with CRS, Rowe cell test (Figure 4b), and $P_c = 0.06285D + 0.07814$ ($R^2 = 0.761$) with the integrated test result (Figure 4c).

Analysis of the relationship between compression index and modified compression index

It is impossible obtaining the undisturbed sample through laboratory consolidation tests, because the sample is inevitably disturbed when it is taken from a site and transported to the laboratory. The result of the consolidation test using disturbed sample usually shows the smoother angle of the curve, it is different from the result using undisturbed sample. Schmertmann (1955) suggested the modified method to account for dissimilarity.

In this study, the relationship between compression index and modified compression index was investigated to define the disturbances of a sample, and a correction factor was also evaluated. Figure 5 shows the result from the data analysis, and it was used to calculate the correction factor. The correction factor based on 95% confident interval was 1.1326 to1.1616, and the average correction factor was 1.1471. The relationship between compression indices from the laboratory test and the site was defined as $C_c' = 1.1470C_{c(lab)}$.

Figure 6 shows the linear relation between the modified compression index and the compression index after removing outliers. Coefficient of determination was relatively large as being equal to 0.96.

Analysis of the relationship between compression and swelling indices

The ratio between compression index and swelling index (C_s/C_c) was studied to define the correlation of two indices. Figure 7 show the result of the date analysis for removing outliers. The ratio of two indices was found as 0.1250 to 0.1363 with average equal to 0.1307 ($C_s = 0.1307C_c$). For the case of raw data, the correlation was evaluated as normal distribution obtained by Kolmogorov-Smirnov's method because significance probability (0.094) was higher than significance level. The average value and standard deviation were calculated through the statistical analysis to the all considered data in this study. A

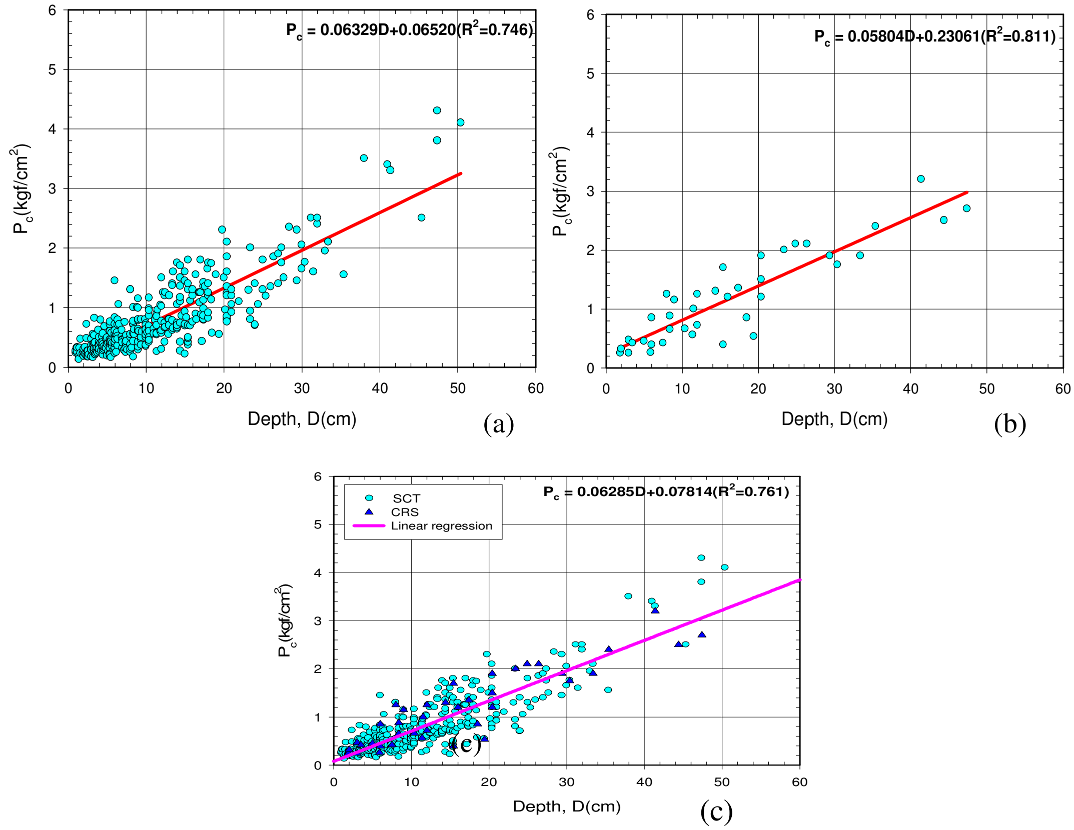


Figure 4. Depth-P_c relationship after removing outliers: (a) Odometer test, (b) CRS, Rowe cell test and (c) integrated test.

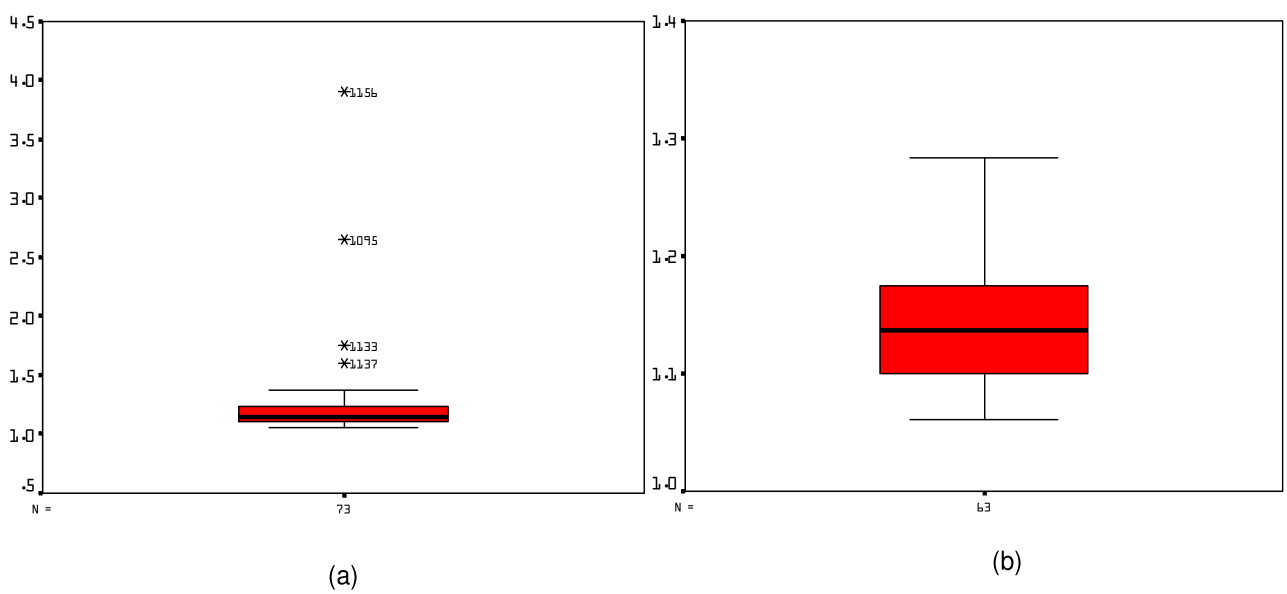


Figure 5. The result of statistical analysis to modified compression index: (a) A box plot of the raw data and (b) A box plot after removing outliers.

representative value was selected after removing outliers by using the box plot. Table 3 shows the result for compression index and swelling index through statistical analysis.

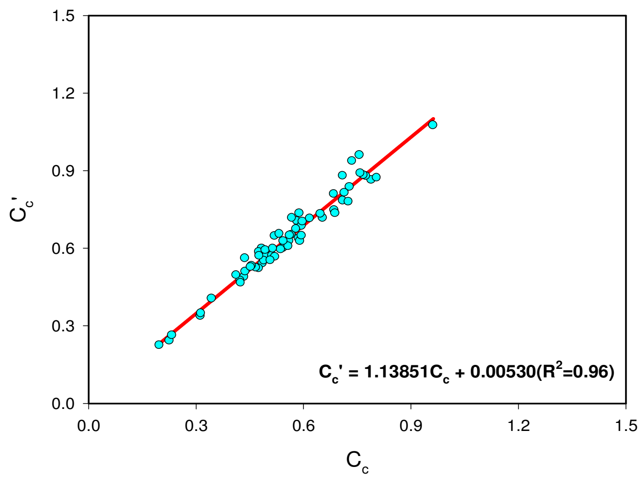
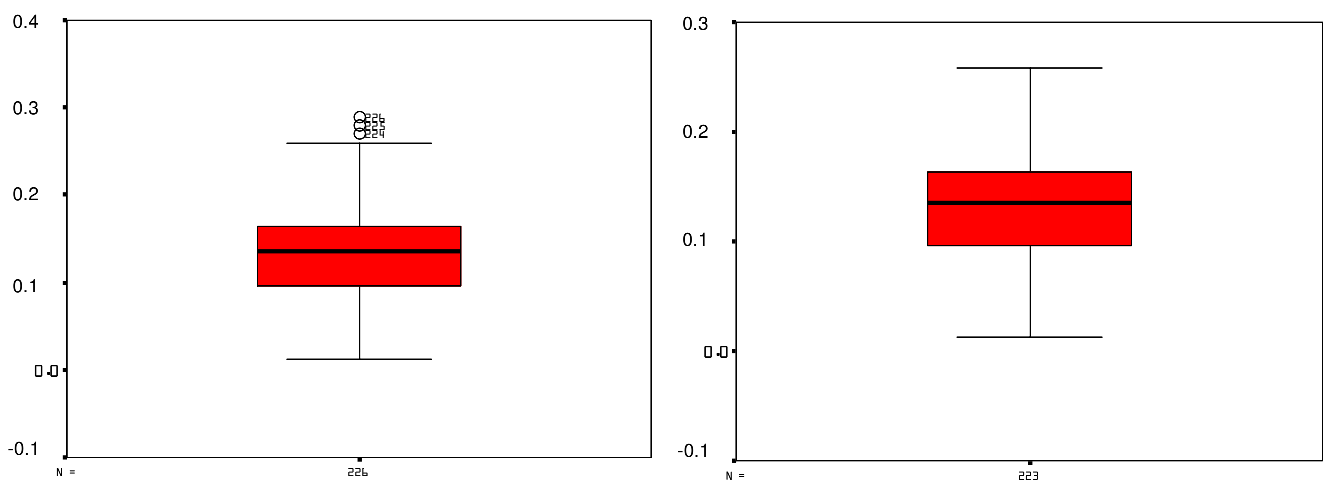


Figure 6. The relationship between the modified compression index and the compression after removing outliers.



(a) (b)

Figure 7. The result of statistical analysis to modified compression index: (a) A box plot of the raw data; (b) A box plot after removing outliers.

Table 3. Compression index and swelling index before and after removing outliers.

Properties	Cases	Mean	SD	CoV	Range	95% confidence interval	
						LL	UL
C_c	Before filtering	0.68180	0.2464	0.36140	0.129 ~ 2.050	0.6655	0.6981
	After filtering	0.66840	0.2229	0.33350	0.129 ~ 1.270	0.6535	0.6832
C_s	Before filtering	0.08450	0.0329	0.38930	0.012 ~ 0.203	0.0803	0.0887
	After filtering	0.08240	0.0299	0.36290	0.012 ~ 0.161	0.0785	0.0863

Note: Lower Limit (LL), Upper Limit (UL)

The average value of compression index was 0.6684 and of swelling index was 0.0824 so that the relationship ($C_s = C_c/8$) between two indices were the same with both before and after removing outliers.

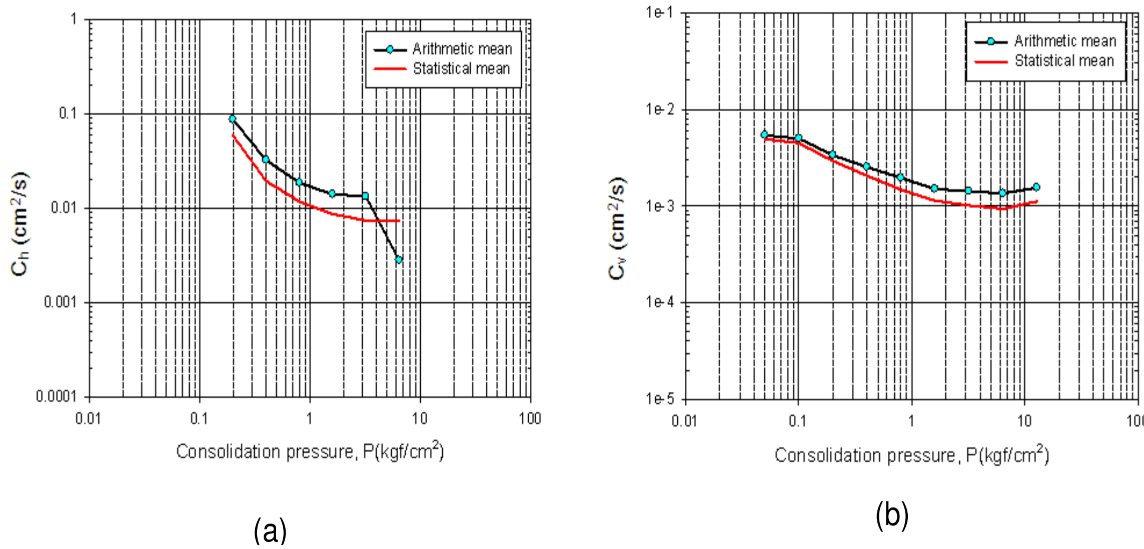


Figure 8. (a) P-C_v relationship after removing outliers and (b) P-C_h relationship after removing outliers.

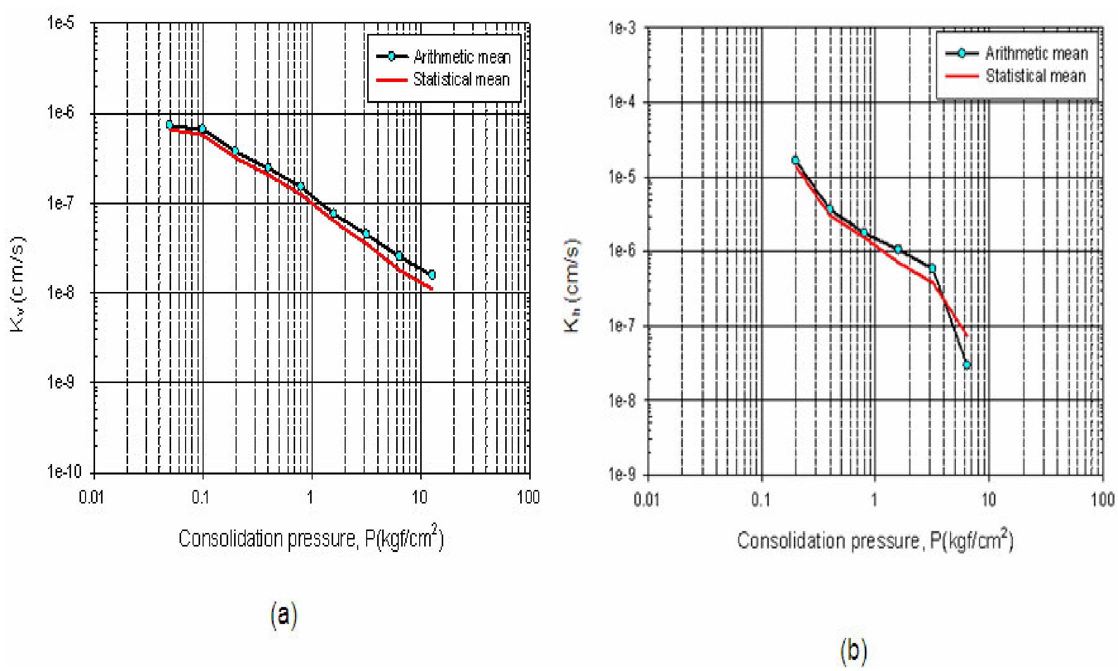


Figure 9. (a) P-K_v relationship after removing outliers and (b) P-K_h relationship after removing outliers.

Correlation analysis between consolidation pressure and consolidation parameters

Table 4 shows the relation between vertical and horizontal consolidation coefficients and vertical and horizontal coefficients of permeability was investigated through statistical analysis. The results are shown in Figures 8 and 9. The average values using the date after removing outliers for both consolidation coefficient and coefficient of permeability were generally smaller than using raw data. The consolidation coefficients seemed to be decreasing up to consolidation pressure equal to 3.2 kgf/cm^2, but were relatively constant afterwards. It was confirmed that the coefficient of permeability was decreased linearly with increasing consolidation pressure.

In Busan area, vertical and horizontal consolidation

Table 4. Consolidation coefficient and coefficient of permeability with various consolidation pressures (P).

Cases	*P* (kgf/cm^2)	C_v (cm^2/sec)		C_h (cm^2/sec)		C_h/C_v	K_v (cm/sec)		K_h (cm/sec)		K_h/K_v
		Mean	Range	Mean	Range		Mean	Range	Mean	Range	
Raw data	0.05	0.005408	0.00021 ~ 0.05102	–	–		7.22E-07	2.81E-08 ~ 6.97E-06	–	–	
	0.1	0.005016	0.00012 ~ 0.03746	–	–		6.59E-07	1.42E-08 ~ 6.01E-06	–	–	
	0.2	0.003363	0.00013 ~ 0.03450	0.087405	0.000054 ~ 0.73100	25.990	3.73E-07	3.26E-08 ~ 3.40E-06	1.63E-05	5.12E-09 ~ 6.42E-05	43.660
	0.4	0.002537	0.00016 ~ 0.02389	0.032337	0.000106 ~ 0.39400	12.740	2.44E-07	1.77E-08 ~ 2.92E-06	3.64E-06	1.00E-08 ~ 2.50E-05	14.908
	0.8	0.001955	0.000086 ~ 0.01880	0.018601	0.000097 ~ 0.21200	9.513	1.51E-07	1.50E-08 ~ 2.91E-06	1.76E-06	7.61E-09 ~ 1.04E-05	11.677
	1.6	0.001505	0.000127 ~ 0.01570	0.014076	0.000106 ~ 0.16500	9.352	7.51E-08	9.48E-09 ~ 1.46E-06	1.06E-06	4.99E-09 ~ 8.21E-06	14.060
	3.2	0.001419	0.000066 ~ 0.01680	0.013435	0.000164 ~ 0.13100	9.465	4.48E-08	9.62E-09 ~ 6.06E-07	5.87E-07	3.79E-09 ~ 3.28E-06	13.106
	6.4	0.001356	0.0000339 ~ 0.01350	0.002815	0.000215 ~ 0.00875	2.075	2.53E-08	3.19E-10 ~ 2.39E-07	2.95E-08	2.66E-09 ~ 8.68E-08	1.163
	12.8	0.001548	0.000041 ~ 0.02070	–	–		1.57E-08	1.50E-09 ~ 1.99E-07	–	–	
Statistical analysis	0.05	0.004943	0.000630 ~ 0.02202	–	–		6.60E-07	9..90E-08 ~ 2.99E-06	–	–	
	0.1	0.004487	0.000383 ~ 0.01820	–	–		5.73E-07	6.08E-08 ~ 2.45E-06	–	–	
	0.2	0.002929	0.000281 ~ 0.01340	0.058985	0.01320 ~ 0.13120	20.140	3.18E-07	4.90E-08 ~ 1.27E-06	1.37E-05	4.98E-07 ~ 2.95E-05	43.183
	0.4	0.002066	0.000224 ~ 0.00965	0.019414	0.00266 ~ 0.04774	9.396	2.06E-07	3.93E-08 ~ 8.25E-07	3.02E-06	1.03E-07 ~ 9.53E-06	14.659
	0.8	0.001476	0.000207 ~ 0.00761	0.011801	0.00174 ~ 0.03120	7.993	1.25E-07	2.61E-08 ~ 5.73E-07	1.54E-06	8.81E-08 ~ 5.30E-06	12.331
	1.6	0.001139	0.00017 ~ 0.00587	0.008727	0.00038 ~ 0.02802	7.661	6.29E-08	1.49E-08 ~ 2.45E-07	7.10E-07	3.22E-08 ~ 1.43E-06	11.299
	3.2	0.001017	0.000131 ~ 0.00600	0.007407	0.00046 ~ 0.01996	7.282	3.53E-08	8.77E-09 ~ 1.35E-07	3.81E-07	1.54E-08 ~ 8.83E-07	10.817
	6.4	0.000937	0.000096 ~ 0.00506	0.007465	0.00618 ~ 0.00875	7.969	1.79E-08	3.03E-09 ~ 6.62E-08	7.41E-08	6.14E-08 ~ 8.68E-08	4.137
	12.8	0.001119	0.000148 ~ 0.00482	–	–		1.11E-08	2.22E-09 ~ 4.64E-08	–	–	

Table 5. Nonlinear correlation between consolidation coefficient and coefficient permeability respect to consolidation pressure.

Soil parameters	Nonlinear regression formula	Coefficient of determination
Vertical consolidation coefficient	$C_v = \dfrac{-10.9511 + 283.1613P + 623.3157P^2}{1 - 14103.6281P + 6.673 \times 10^5 P^2}$	0.998
Vertical coefficient of permeability	$K_v = \dfrac{9.8696 \times 10^{-7} - 3.5434 \times 10^{-9}P}{1 + 8.9839P}$	0.991
Horizontal consolidation coefficient	$C_h = \dfrac{-0.01858 - 0.04868P}{1 - 7.4005P}$	0.999
Horizontal coefficient of permeability	$K_h = \dfrac{-5.2468 \times 10^{-6} - 9.067 \times 10^{-7}P}{1 - 6.9748P}$	0.999

Table 6. Consolidation parameters to soft ground in Busan area.

Consolidation parameters	Unit	Representative value or correlation equation	95% confidence interval		Note
			UL	LL	
C_c	–	0.668	0.6535	0.6832	
C_s	–	0.082	0.0785	0.0863	
P_c	kgf/cm^2	Pc = 0.06285D + 0.07814	–	–	Oedometer, CRS, Rowe cell tests
	–	1.861	1.6553	2.0662	Above 4 m
OCR		0.852	0.9224	0.9823	4 ~ 22 m
		0.830	0.7833	0.8760	Below 22 m
C_v	cm^2/s	0.00102 ~ 0.00148			
C_h	cm^2/s	0.00741 ~ 0.01180	–	–	Cosolidation pressure $P = 0.8 \sim 3.2$ kgf/cm^2
K_h	cm/s	$6.29 \times 10^{-8} \sim 1.25 \times 10^{-7}$	–	–	
K_v	cm/s	$3.81 \times 10^{-7} \sim 1.54 \times 10^{-6}$	–	–	

Note: Lower Limit (LL), Upper Limit (UL).

coefficient ratio (C_h/C_v) was 2.08 to 25.99 for raw data, in which a high variability was found. The ratio after removing outliers was evaluated as 7.28 to 9.40 under consolidation pressure equal to 0.4 to 0.64 kfg/cm^2. The ratio between vertical and horizontal coefficient of permeability (K_h/K_v) was 4.14 to 43.18, which also showed a high variability. The ratio after removing outliers was 10.82 to 14.66 under consolidation pressure equal to 0.4 to 3.2 kgf/cm^2, in this case there was no significant change found.

The correlation between consolidation pressure, consolidation coefficient and coefficient of permeability was presented in Table 5 and expressed as the objective function describing three variables ($y = (a + bx)/(1 + cx)$) or the objective function describing five variables ($y = (a + bx + cx^2)/(1 + dx + ex^2)$). The coefficient of determination was very close to 1 for most cases as 0.991 to 0.999 so that the correlationship of two coefficients was very high.

THE RESULT OF DETERMINED CONSOLIDATION PARAMETERS

Table 6 summaries the consolidation parameters in Busan area determined through statistical analysis and regression analysis.

CONCLUSION

(1) As a result, the ratio between swelling index and compression index was 1/8 after analyzing approximately the 900 test data sets. The relationship between two parameters was $C_s = 0.1307C_c$ even after removing

outliers so that the relationship was still evaluated as $C_s = C_c/8$. Correction constant (modified compression index/compression index) for slope of both laboratory consolidation curve and virgin consolidation curve in site was $C_c^{'} = 1.1471C_{c(lab)}$ with 95% confidence interval.

(2) C_v/C_c ratio had a little similarity to previous data under a particular pressure but it was widely varied with consolidation steps as a range between 0.001 and 0.077. Therefore, differentiated application was necessary as to depth or stress of a specific ground to account for C_v/C_c ratio.

(3) Preconsolidation pressure was increased with depth as to be $P_c = 0.06969D + 0.05573$ ($R^2 = 0.56$) and it was $P_c = 0.06285D + 0.07814$ ($R^2 = 0.761$) after removing outliers. Overconsolidation ratio was tended to be different with depth but it had a high coefficient of determination with depth when the relationship was negative exponent as $OCR = 0.9195 + 7.584e^{-0.833D}$ ($R^2 = 0.53$).

(4) Consolidation coefficient ratio was relatively consistent with consolidation pressure as C_h/C_v equal to 2.08 ~25.99 but it was shown to be 7.28 to 9.40 under a specific consolidation pressure after removing outliers. Coefficient of permeability seemed remarkably to be anisotropy and its ratio (k_h/k_v) was 11.7 to 14.9 before removing outliers and 10.82 to 14.66 after removing outliers. It was investigated that coefficient of determination using rational function formula with both 3 and 5 variables has the highest value for two consolidation parameters.

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