Assessment of the pressuremeter modulus of the weathered granite rock based on the chemical weathering index

Seung-Hwan Lee[1], Y.-W. Song[2], J.-G. Kim[3] and C.-K. Chung[4]

[1,2,3,4] Department of Civil and Environmental Engineering, Seoul National University,
Gwanak-ro-1, Gwanak-gu, Seoul, Republic of Korea.

ABSTRACT

Highly weathered or decomposed granite rock layers, which can be classified as rock-soil transition materials, located under the residual soil layers in broad areas in South Korea. These layers are often used as the bearing strata of the foundations supporting many structures. In this study, site investigations, including the pressuremeter test, were conducted in two locations which have deep weathered granite zone. The chemical weathering indices, Vogt's ratio, chemical index of alteration, loss on ignition and mobile index were evaluated based on X-ray fluorescence analysis. The relationship between the pressuremeter modulus and each chemical weathering index was suggested and the pressuremter moduli estimated based on such relationships were compared with measured values. It is proposed that predictions with chemical weathering index give relatively good agreements with measured pressuremeter modulus based on linear semi-logarithmic relationship.

Keywords: highly weathered granite; weathering index; pressuremter

1 INTRODUCTION

Highly weathered or decomposed granite rock layers, which can be classified as rock-soil transition materials, underlie the residual soil layers in many broad areas in South Korea. These layers are often used as the bearing strata of the foundations supporting many structures. Estimating the geotechnical properties of the highly weathered granite layer is difficult, however, since rock core samples useful for the laboratory test can hardly be obtained, and the existing in-situ field tests have limitations in providing reliable results. So, the properties of the highly weathered rock applied to geotechnical structure are usually evaluated on an empirical basis, using the available previous geo-material database or the standard penetration test (SPT) results, which are not proper for rock materials.

Fresh rock should be decomposed from the fresh state to residual soil through weathering, so, the characteristics of the highly weathered rock are inbetween fresh rock and the residual soil. Therefore, the relative characteristics of the highly weathered rock can be determined based on the degree of weathering. Many researchers have tried to quantify the weathering and analyzed the correlation between the degree of the weathering and the geotechnical properties of the weathered rock (Irfan, 1996; Kim and Park, 2003; Price and Velbel, 2003; Chiu and Ng, 2014). The researches, however, focused on the average value density among fresh rock, slightly weathered rock, moderately weathered rock and highly weathered rock.

In this study, to characterize weathering profile of weathered granite and to evaluate the pressuremeter modulus of the weathered granite, two sites in South Korea were selected. Pressuremeter tests with various depths were conducted to evaluate the pressuremeter modulus (E_m) together with sampling. The chemical weathering indices were estimated based on X-ray fluorescence (XRF) analysis results. Using the weathering indices and pressuremeter modulus (E_m) of the highly weathered rock which were obtained in the two sites, the relationship between pressuremeter modulus (E_m) and each chemical weathering index was suggested. All the estimated pressuremeter moduli (E_m) were analyzed with each measured pressuremeter modulus (E_m).

Table 1. Chemical weathering indices.

Weathering index	Weathering index equation
Vogt's Ratio, VR (Vogt, 1927)	$(Al_2O_3 + K_2O)/(MgO + CaO + Na_2O)$
Chemical Index of Alteration, CIA (Nesbitt, 1982)	$100Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O)$
Loss on Ignition, LOI (Suoeka et al., 1985)	H_2O(+ and -)
Mobiles Index, I_{mob} (Irfan, 1996)	$(I_{fresh} - I_{weathered})/I_{fresh}$ $I = (K_2O + Na_2O + CaO)$

2 TEST METHOD

2.1 Test site

Two test sites in Goyang and Sejong with deep weathered granite zone were selected based on survey on the collected site investigation reports. In each site, three boreholes having 1 m apart spacing were drilled, which were TBH-1, TBH-2, TBH-3 in Goyang and NBH-1, NBH-2, NBH-3 in Sejong (Fig. 1).

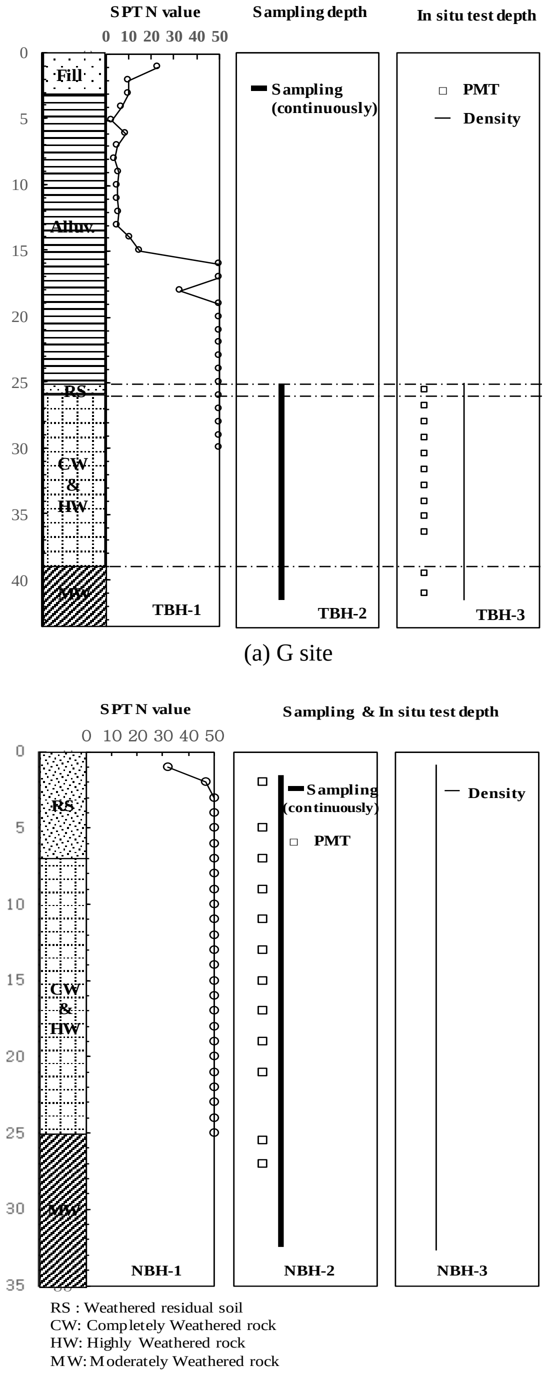
Boring investigation with standard penetration test was performed in the first borehole in each site to survey subsurface condition. In G site, Goyang site, the subsurface consisted of thick alluvial soil layer (22 m), 1 m thick residual soil, and 13 m thick completely or highly weathered rock. And in S site, Sejong, residual soil layer was 7 m, completely or highly weathered rock layer was 18 m.

Samples from the weathered residual soil to the moderately weathered rock were continuously retrieved in TBH-2 and NBH-2. The total core recovery of highly weathered rock was 90-100 % in both sites, and the rock quality designation of the moderately weathered rock was 30-50 % in G site and 67-100 % in S site respectively. All samples retrieved from the both test sites were used in XRF analysis to evaluate chemical weathering indices shown in Table 1.

2.2 In-situ test and chemical weathering indices

Pressuremeter tests (PMT) using Elastometer-2 developed by the OYO Corporation were conducted with depth in TBH-3 and NBH-2. To evaluate changes of pressuremeter modulus with the depth and degree of weathering, the test spacing was determined from 1.5 m to 2 m. Density logging, also, was performed in each site to measure in-situ unit weight, which were used to calculate effective vertical stress. All test depth were shown in Fig. 1.

The samples retrieved at the same depth where pressuremeter test was conducted in both sites were analyzed via XRF analysis. The major element composition ratio was needed to calculate the chemical weathering indices shown in Table 1 could be obtained through the XRF results. The chemical weathering indices were calculated using the molecular proportion of each oxide, which was converted from the percentage of the oxides based on weight. All the chemical weathering indices were analyzed with the pressuremeter modulus in each test site and relationships between pressuremeter modulus and each chemical weathering index were suggested. Using the relationship, pressuremeter modulus in both sites were estimated and compared with the measured pressuremeter modulus.



(a) G site

(b) S site

Fig. 1. Subsurface information and test depth

3 RESULT AND DISCUSSION

3.1 Pressuremeter modulus and chemical weathering index

All of the pressuremeter modulus and chemical weathering indices are shown in Table 2. Pressuremeter moduli of highly weathered granite are in the range from 239.5 MPa to 2301.9 MPa and from 85.7 MPa to 498.1 MPa in G-site and S-site respectively. Pressuremeter moduli of G-site are higher than those of S-site, because of the effect of depth. So, the pressuremeter moduli normalized by vertical effective stress calculated were utilized. Weathering indices of highly weathered granite of G-site are generally higher than those of S-site except for LOI, which indicates that the granite of G-site are more weathered than those of S-site.

Table 2. Pressuremeter moduls and chemical weathering index

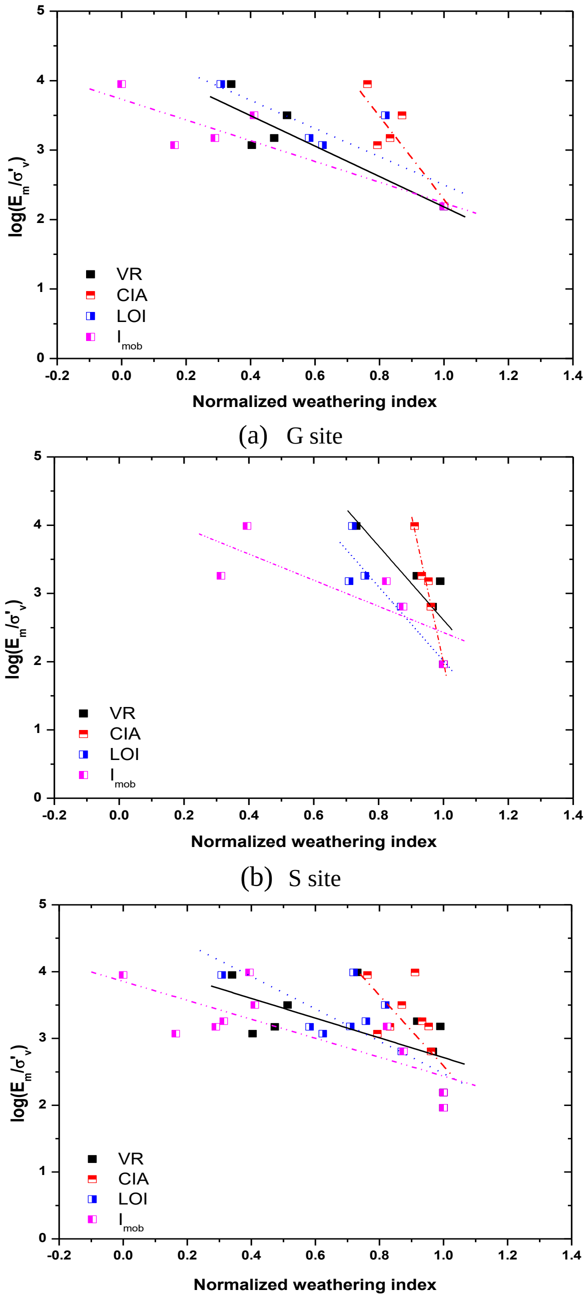
Test site	Subsurface layer	Depth (m)	E_m (MPa)	VR	CIA	LOI	I_{mob}
G site	RS	25.5	40.6	3.79	66.09	2.65	0.62
	HW or CW	27.0	368.1	2.13	57.98	1.82	0.26
		28.0	514.7	1.66	54.04	1.45	0.15
		29.5	455.7	1.59	53.21	1.35	0.13
		30.5	527.1	1.76	54.22	2.45	0.18
		31.5	438.5	1.37	51.24	1.38	0.06
		33.0	239.5	1.46	52.01	1.13	0.07
		34.0	397.0	2.27	60.22	3.05	0.35
		35.5	2301.9	1.99	57.70	1.96	0.28
		36.5	1569.0	1.88	58.18	2.26	0.25
		38.0	881.4	1.62	53.91	1.40	0.14
	MW	39.5	-	0.95	51.61	2.11	0.04
		41.0	4243.5	1.29	50.43	0.82	0.00
S site	RS	2.0	29.9	2.18	58.52	3.83	0.28
		5.0	7.80	1.80	55.54	3.08	0.21
	HW or CW	7.0	88.3	1.61	51.90	2.59	0.12
		9.0	85.7	1.68	54.16	2.88	0.19
		11.0	94.0	1.94	54.11	2.56	0.23
		13.0	205.5	1.51	50.51	2.02	0.10
		15.0	458.7	1.82	51.30	2.25	0.09
		17.0	478.7	1.63	53.66	2.73	0.01
		19.0	498.1	2.16	53.27	1.99	0.17
		21.0	283.7	1.40	52.67	2.37	0.17
		23.0	-	1.29	51.53	2.62	0.12
		24.5	-	1.50	52.17	1.75	0.13
	MW	25.5	822.4	1.35	51.31	1.62	0.13
		27.0	5711.0	1.28	49.89	2.81	0.03
		28.5	-	1.52	49.72	1.96	0.00

3.2 Relationship between pressuremeter modulus and chemical weathering index

Quantitative variation of pressuremeter modulus normalized by vertical effective stress were compared with chemical weathering indices divided by the value of residual soil, and their relations were fitted with linear semi-logarithmic regression as shown in Fig. 2. Considering the inconsistency of testing depths of two tests and high variation of the estimated values, the results are averaged into every two - three meters thickness. The regression equation is as follows, and the results are shown in Table 3.

$$\log(E_m / \sigma_v^{'}) = A + B\frac{WI_{HW}}{WI_{RS}} \tag{1}$$

Where, A and B denote fitting constants, WI is chemical weathering index and subscript denotes subsurface layer.



(a) G site

(b) S site

(c) G and S site

Fig. 2. Linear semi-logarithmic regression of pressuremeter modulus and chemical weathering index

Table 3. Results of linear semi-logarithmic regression.

Site (collected data)	Weathering index	Fitting constants A	B	R	R^2
G site	VR	4.37	-2.19	0.88	0.78
	CIA	8.28	-5.99	0.85	0.72
	LOI	4.53	-2.03	0.82	0.66
	I_{mob}	3.73	-1.49	0.88	0.77
S site	VR	8.04	-5.43	0.81	0.66
	CIA	23.82	-21.83	0.98	0.97
	LOI	7.45	-5.44	0.91	0.82
	I_{mob}	4.34	-1.92	0.80	0.63
G and S site	VR	4.19	- 1.48	0.61	0.38
	CIA	7.87	-5.29	0.67	0.45
	LOI	4.90	-2.42	0.76	0.58
	I_{mob}	3.85	-1.42	0.78	0.62

3.3 Estimation of pressuremeter modulus

Pressuremeter moduli are estimated using the suggested equation shown in Table 3. Cross validation is applied to identify applicability of the suggested regression equations as shown in Fig. 3. Pressuremeter moduli of G-site are estimated using the suggested regression model of S-site. The average ratio of measured pressuremeter modulus to estimated one is smaller than 1, which means that the model of S-site overestimates the pressuremeter modulus of G-site. On the other hand, the model of G-site underestimates the pressuremeter modulus of S-site, the average ratio is over 1 as shown in Table 4.

Pressuremeter moduli of the both site, also, are estimated using the regression equations based on G-site and S-site as shown Fig. 4. Average ratio of measured pressuremeter modulus to estimated values is close to 1, which can be interpreted that using suggested regression equation based on the data of both site improves the accuracy. So, by using the more data, pressuremeter modulus could be more reasonably estimated through the chemical weathering index.

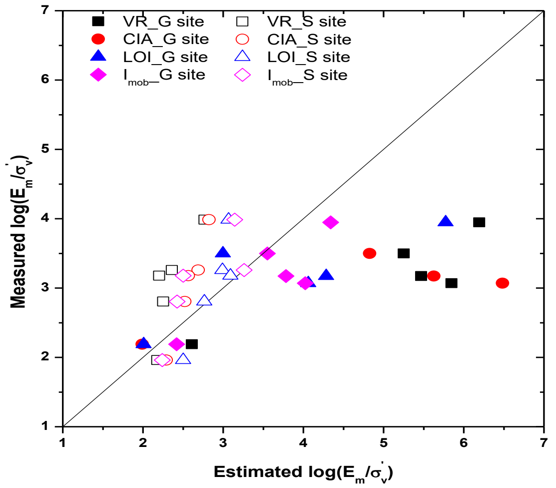


Fig. 3. Cross validation of G-site and S-site

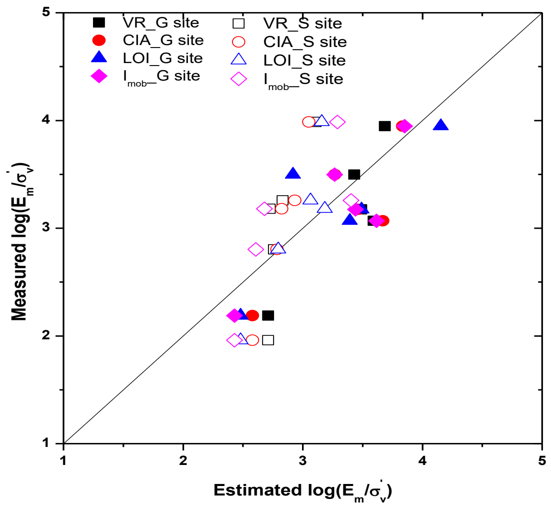


Fig. 4. Estimation of pressuremeter modulus using regression equations based on G-site and S-site data

Table 4. Ratio of measured E_m to estimated E_m.

Site	Collected data	Ave. Measured / Estimated			
		VR	CIA	LOI	I_{mob}
G site	S site	0.65	0.68	0.89	0.88
	G and S site	0.93	0.94	0.97	0.95
S site	G site	1.28	1.17	1.04	1.11
	G and S site	1.07	1.06	1.02	1.05

4 CONCLUSION

In this study, the relationship between pressuremeter modulus and chemical weathering index for higly are suggested using the test results obtained from two test site. The equations to estimate the pressuremeter modulus are suggested by using linear semi-logarithmic regression with VR, CIA, LOI and I_{mob}. The measured pressuremeter modulus, also, estimated by applying the suggested equations, the applicability of the equations was identified with the ratio of measured pressuremeter modulus to estimated values. Pressuremeter modulus could be the more reasonably estimated through the chemical weathering index. The more data, however, is still in need to improve the accuracy of estimating pressuremeter modulus based on the eqaution.

ACKNOWLEDGEMENTS

This research was supported by a grant(19SCIP-B119960-04) from Smart Civil Infrastructure Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

REFERENCES

Chiu, C.F., and Ng, C.W.W. (2014). Relationships between chemical weathering indices and physical and mechanical properties of decomposed granite. Engineering Geology, 179, 76–89.

Irfan, T. Y. (1996). Mineralogy, fabric properties and classification of weathered granites in Hong Kong. Quarterly Journal of Engineering Geology and Hydrogeology, 29(1), 5-35.

Kim, S., and Park, H.-D. (2003). The relationship between physical and chemical weathering indices of granites around Seoul, Korea. Bulletin of Engineering Geology and the Environment, 62(3), 207–212.

Nesbitt, H. W. (1979). Mobility and fractionation of rare earth elements during weathering of a granodiorite. Nature, 279, 206-2.

Price, J.R., and Velbel, M.A. (2003). Chemical weathering indices applied to weathering profiles developed on heterogeneous felsic metamorphic parent rocks. Chemical Geology, 202(3–4), 397–416.

Sueoka, T., Lee, I. K., Muramatsu, M., & Imamura, S. (1985). Geomechanical properties and engineering classification for decomposed granite soils in Kaduna district, Nigeria, Proc., Geomechanics in Tropical Lateritic and Saprolitic Soils, Brasilia, 1, 175-186.

Vogt, T. (1927). Sulitjelmafeltets geologi og petrografi. Norges Geologiske Undersokelse. 121, 1-560.