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Effect of Degree of Weathering on Dynamic Properties of Weathered Granite Soils

Woong Jong Park
Korea Electric Power Corporation, Seoul, Korea

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EFFECT OF DEGREE OF WEATHERING ON DYNAMIC PROPERTIES OF WEATHERED GRANITE SOILS

Park, Woong Jong
Manager, Transmission Construction Dept.
Korea Electric Power Corporation
Gangnam-gu, Seoul, KOREA

ABSTRACT

The strength-deformation characteristics of weathered granite soils are determined by the characteristic of bedrock before the weathering and weathering environment. Generally, the degree of weathering is changes with depth and affects the dynamic properties of soil. But there are very few studies of the effect of degree of weathering on dynamic properties of soils in Korea. In this study, dynamic tests were performed with resonant column after preparing the specimens which were remolded with disturbed soils, and the effect of degree of weathering on dynamic properties, such as shear modulus, damping ratio is considered. In addition, the relationships among shear strain, normalized shear modulus(G/G_{max}) and normalized damping ratio(D/D_{min}) are compared with other studies.

INTRODUCTION

The weathered granite soil is the most common type of soil in Korea. The stress-stain behavior of the weathered granite soil is dependent on the characteristics of mother rock and weathering condition. As a result, the stress-strain behavior of the weathered granite soil is greatly affected by the soil particle interaction and its dynamic characteristic is affected by the degree of weathering.

In this study, the weathered granite soil in Korea was remolded by the static compaction method to perform a series of resonant column tests. The test results were analyzed to verify how the dynamic characteristic of the weathered soil is affected by the weathering degree of soil.

THEORETICAL BACKGROUND

<u>The stress-strain behavior of soil under dynamic loading condition</u>

Fig. 1 shows the stress-strain behavior of soil under dynamic loading condition. The following characteristics can be derived from Fig. 1.

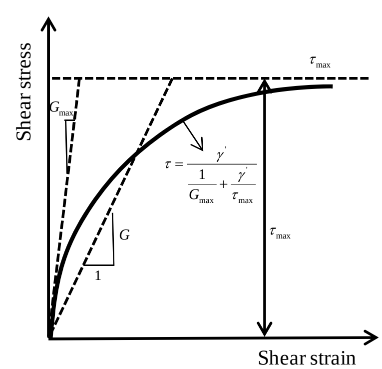


Fig. 1. The stress-strain behavior of soil under dynamic loading condition

1) The shear modulus of soil is decreased as the shear strain of soil is increased.

2) At the low strain level below the threshold strain, the shear modulus has the maximum value independent on the shear strain.

3) At the high strain level above the threshold strain, the shear modulus is a function of the maximum shear modulus and the shear strain.

The threshold strain is the strain level of about 10^{-4} % ~ 10^{-3} % where the shear modulus starts to decreasing as the shear strain is increased even though it is different from the type of the soil and various conditions.

<u>Dynamic characteristics of the weathered granite soil</u>

The dynamic shear modulus of soil under earthquake loading decreases with depth of soil strata, that is, the modulus increases as the degree of weathering is smaller and it converged to the constant value where the soil strata reaches to the bedrock (Davis, 1995).

The normalized shear modulus of the weathered soil has a uniform value independent of the soil sample disturbance. This result corresponds with previous research that the variation of the normalized shear modulus of almost all the geomaterials is not affected by the soil sample disturbance. As a result, it is concluded that the disturbed soil sample can be used for the evaluation of the variation of the normalized shear modulus against the shear strain level. Furthermore, the normalized shear modulus of the weathered granite soil in Korea coincides well with that of the non-plastic soil suggested by Seed-Idriss(1970) as shown in Fig. 2 (Kim, 1997).

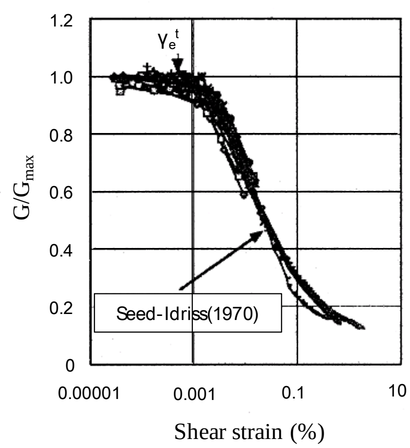


Fig. 2. Normalized shear modulus versus shear strain (Kim, 1997)

TEST APPARATUS AND CONDITIONS

<u>Test apparatus</u>

The Stokoe type resonant column test device used in this study has the fixed-free system and the torsion impulse is generated from the coil-magnetic system. The resonant column test can be used to perform a series of tests for the strain range from 10^{-5} % to 10^{-1} % continuously. Fig. 3 shows the representative frequency-response curve.

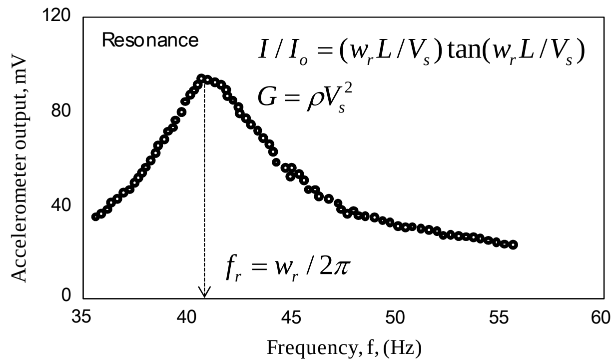


Fig. 3. Representative frequency-response curve

<u>Preparation of the specimen and test conditions</u>

The weathered granite soil specimen for the tests was gathered in Seoul area and Table 1 shows the properties of soil along the depth. As the soil depth was deeper, the content ratio of fines and the ignition loss were decreased, and the SPT value and the unit weight increased. The specific gravity of soil was about 2.6 and was almost the same along the depth.

The remolded soil sample was prepared from the static compaction method to simulate in-situ stress condition and a series of resonant column tests were performed. The dimensions of the soil samples were the diameter of 7.1cm and the length of 14.2cm.

Table 1. Properties of soil along the depth

Depth (m)	Gs	Fine contents (%)	Unified Classification	Degree of weathering	γ_d (g/cm^3)	I_p	SPT value	I_g (%)
5.0	2.59	21.2	SW-SM	CW	1.62	NP	29	2.89
7.0	2.59	14.2	SW-SM	CW	1.60	NP	46	2.41
15.0	2.60	7.3	SW-SM	CW	1.66	NP	50/5	1.28
20.0	2.59	1.8	SW	HW	1.80	NP	50/4	0.63

[*1] CW : Completely Weathered Soil, HW : Highly Weathered Rock(Geological Society)
[*]2 Ig : Ignition Loss(JSSMFE(1979), Murata and Yasufuku(1987))

The shear strain was changed from 10^{-5} % to 10^{-1} % to evaluate the dynamic characteristics of the granite weathered soil in various strain level. The confining pressures of 50, 100 and 150 kPa were applied to the each specimen. The soil samples were consolidated for 8 hours before tests.

TEST RESULTS AND DISCUSSION

Variation of the shear modulus and the damping ratio according to the shear strain and confining pressure

Fig. 4 and 5 show the test results of the variation of the shear modulus and the damping ratio according to the shear strain and confining pressure. Test results show that the shear modulus decreased along the depth after the shear strain was exceeded the threshold strain.

The shear modulus is greatly affected by the shear wave velocity as shown in Eq. (1) and the shear wave velocity is affected by the natural frequency. The relationship between the frequency and the stiffness of specimen is defined in Eq. (1)

$$\omega = 2\pi f = \sqrt{\frac{K}{I}} \tag{1}$$

As the shear strain is increases, the stiffness and the natural frequency of specimen are decreases then the shear wave velocity and the shear modulus are decreases consequently. However, the shear modulus increases as the confining pressure is increased for two reasons. Firstly, it is difficult to shear the specimen at the high confining stress. Secondly, the shear wave velocity which is greatly dependant on the shear modulus is increased as the confining pressure is increased (Stokoe et al., 1978).

However, the test results show that damping ratio of soil was increased when the shear strain was larger than the threshold strain but it decreased as the confining pressure was increased. It is because the shear wave in the soil includes water and air is only able to propagate through a structure composed of soil particles, and the propagation of the shear wave is easier when the confining stress is larger because the relative ratio of the water and air in the soil is decreased.

The shear modulus and the damping ratio against the confining pressure converge to some value along the depth because the density is increased and the interaction between the soil particles is larger along the depth.

In this study, the test results show that the shear modulus at the shear strain of 0.01% was 0.26~0.30 times smaller than the maximum shear modulus and the damping ratio was 2.7~3.0 times larger than the minimum damping ratio.

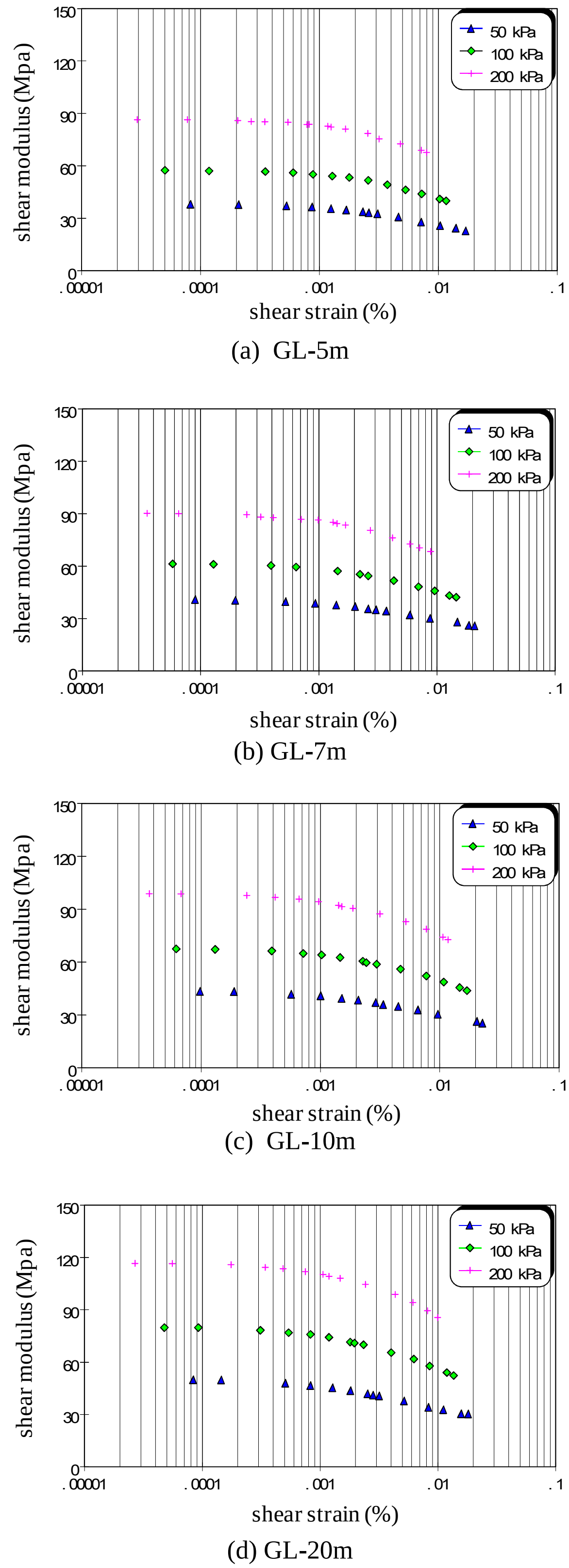
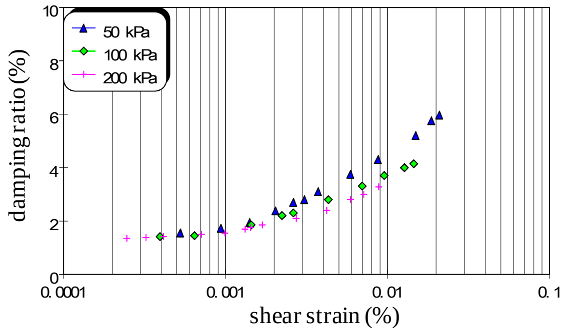
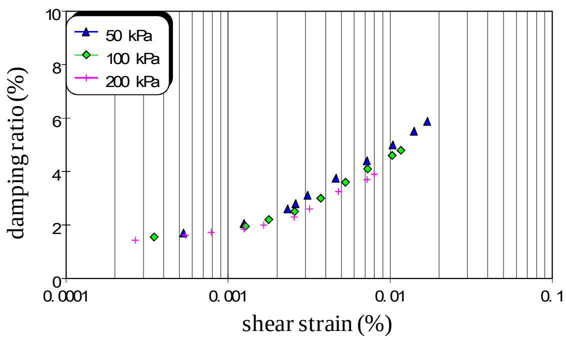


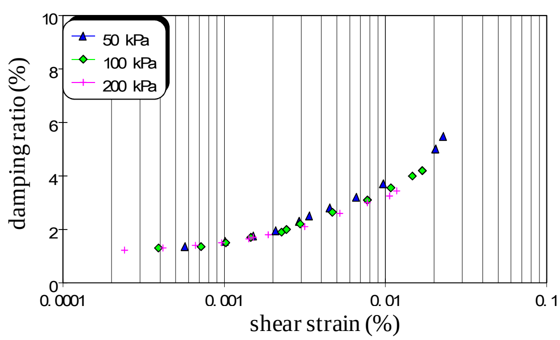
Fig. 4. Variation of shear modulus according to the shear strain and confining pressure



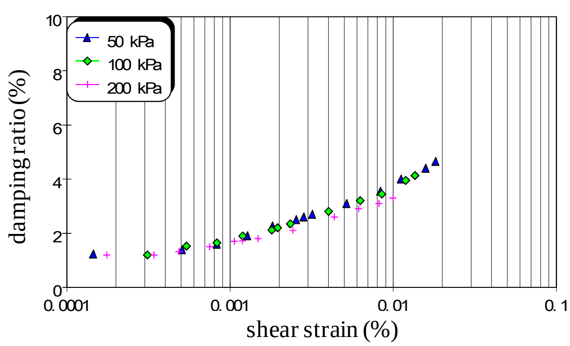
(a) GL-5m



(b) GL-7m



(c) GL-10m



(d) GL-20m

Fig. 5. Variation of damping ratio according to the shear strain and confining pressure

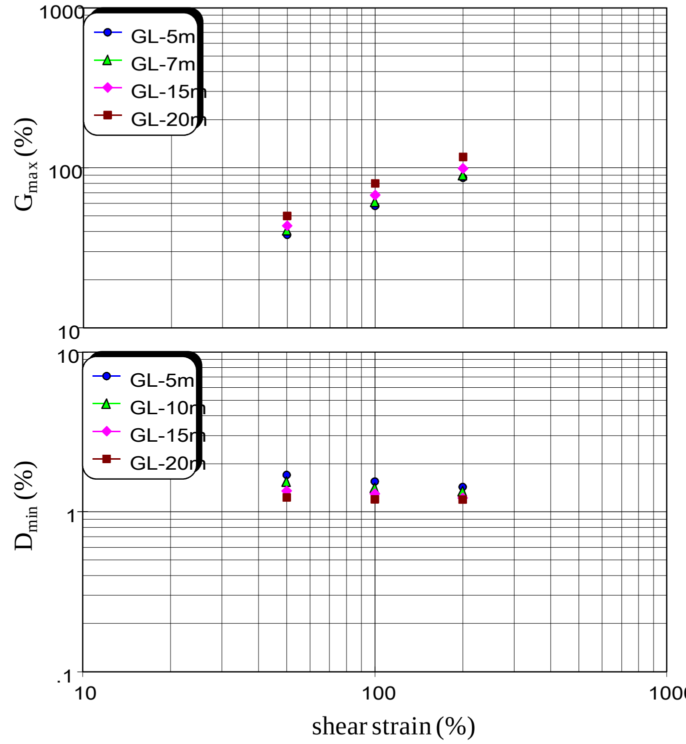


Fig. 6. Variation of the maximum shear modulus and minimum damping ratio according to the confining pressure

<u>Variation of the maximum shear modulus and the minimum damping ratio according to the confining pressure</u>

Fig. 6 shows the test results of the variation of the maximum shear modulus and minimum damping ratio according to the confining pressure. As shown in the previous studies, the test results show that maximum shear modulus increased and the minimum damping ratio decreased as the confining pressure or the depth increased. Fig. 6 also shows that the maximum shear modulus difference according to the depth tends to decrease as the confining pressure is increased.

Seed(1970) suggested the relationship between the confining pressure and the maximum shear modulus below the threshold strain as shown in Eq. (2).

$$G_{max} = 1000K_{2(max)}(\overline{\sigma_0})^{0.5} \quad (K_{2(max)} : 30 \sim 75(\text{sand})) \qquad (2)$$

The test results of $K_{2(max)}$ against the confining pressure for all the depth are shown in Fig. 7. It shows that the $K_{2(max)}$ obtained in this study ranges from 53.7 to 83.0 for the disturbed specimen of weathered granite soil and $K_{2(max)}$ increased along the depth then it was converged as the confining pressure increased. For depth of 20m, $K_{2(max)}$ was somewhat larger than the sand.

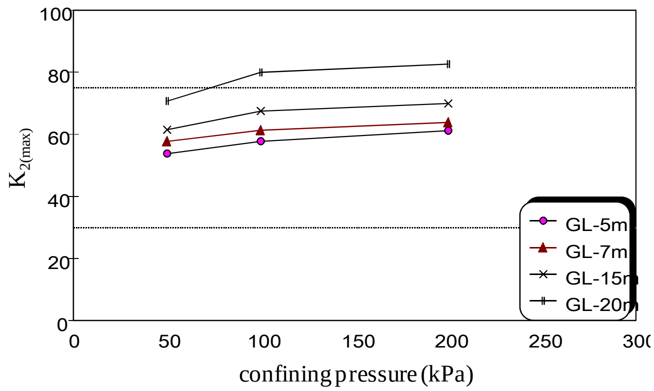


Fig. 7. Relation between $K_{2(max)}$ and the confining pressure

Variation of the maximum shear modulus and minimum damping ratio according to the depth

Fig. 8 shows the test results of the variation of the maximum shear modulus and the minimum damping ratio along the depth which normalized to the values at GL-5m. Then the maximum shear modulus and the minimum damping ratio of the disturbed specimen of the weathered granite soil in Korea can be determined using Eq. (3) and Eq. (4), respectively.

$$\frac{G_{\max}}{G_{\max,\, z=5}} = 0.0209(z-5)+1 \qquad (3)$$

$$\frac{D_{\min}}{D_{\min,\, z=5}} = -0.0158(z-5)+1 \qquad (4)$$

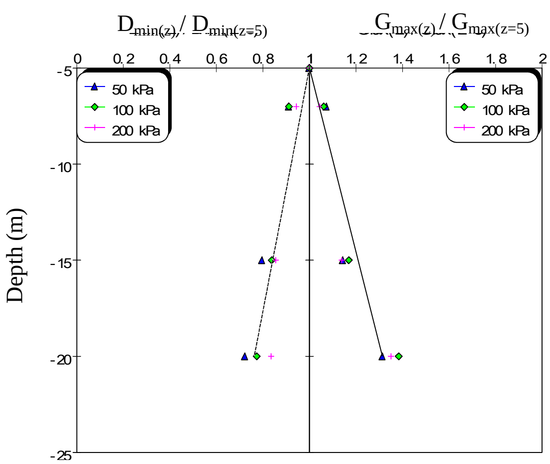


Fig. 8. Variation of the normalized maximum shear modulus and the normalized minimum damping ratio along the depth

Variation of the maximum shear modulus and minimum damping ratio according to the ignition loss

The ignition loss that was used to define the degree of weathering in this study is linearly decreases along the depth as shown in Fig. 9, so it can be known that the degree of weathering is closely related with the depth. Fig. 10 shows the test results of the variation of the maximum shear modulus and the minimum damping ratio which were normalized to the values at GL-5m against the ignition loss.

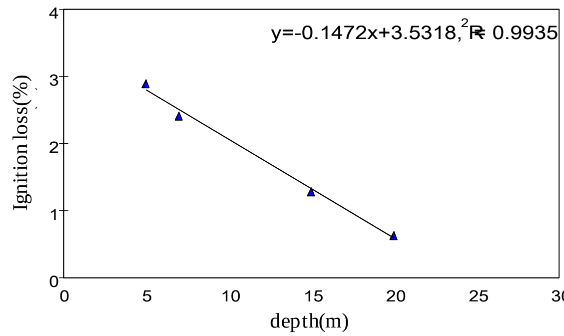


Fig. 9. Variation of the ignition loss along the depth

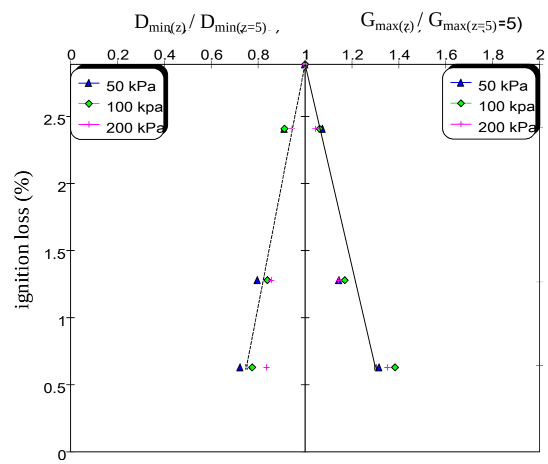
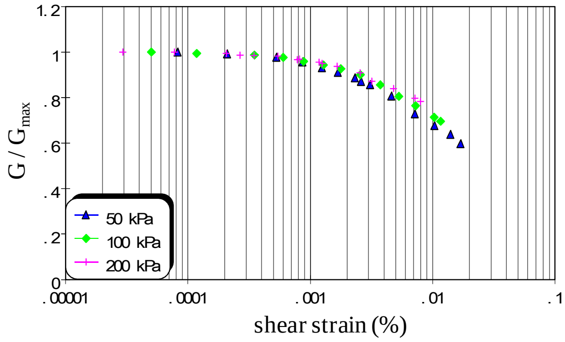


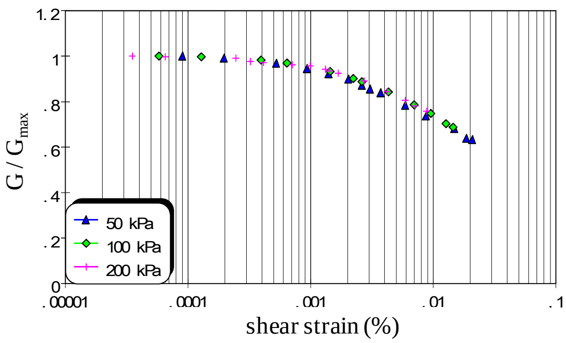
Fig. 10. Variation of the normalized maximum shear modulus and the normalized minimum damping ratio according to the ignition loss

Variation of the normalized shear modulus and the normalized damping ratio

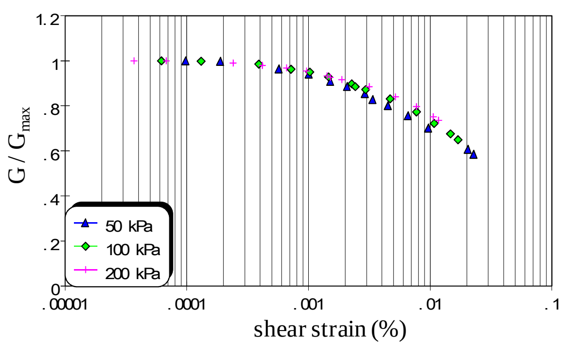
The threshold strain of a specimen can be obtained from the relation between the normalized shear modulus and the shear strain. Fig. 11(a) ~ (d) show the test results of the normalized shear modulus against the shear strain according to the confining pressure at each depth. It shows that the threshold strain is about 10^{-4} % ~ 10^{-3} % and it tends to increase as the confining pressure or the depth increases. As a result, the elastic range of a specimen is wider as the confining pressure or the depth is increased.



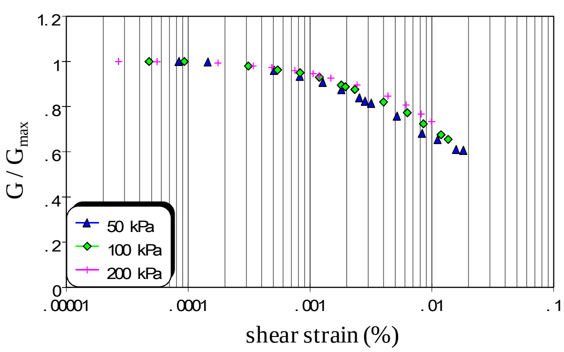
(a) GL-5m



(b) GL-7m

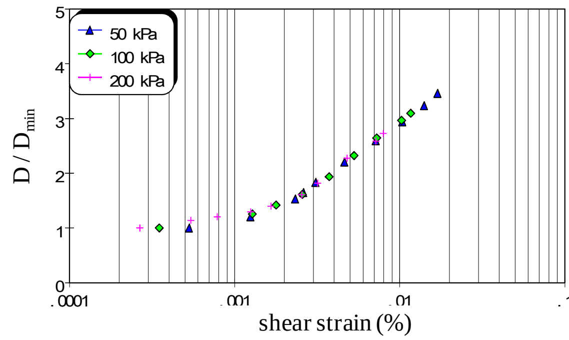


(c) GL-10m

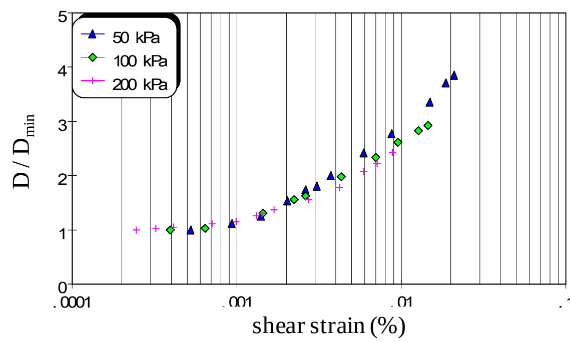


(d) GL-20m

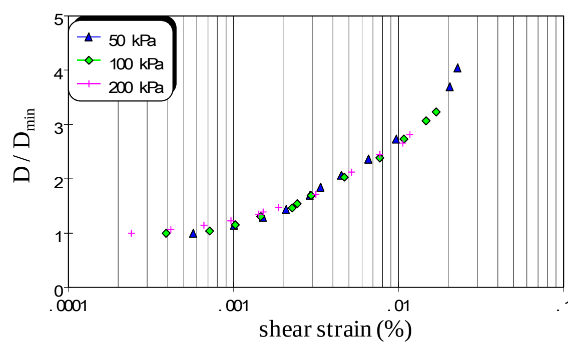
Fig. 11. Variation of the normalized shear modulus against the confining pressure and degree of weathering



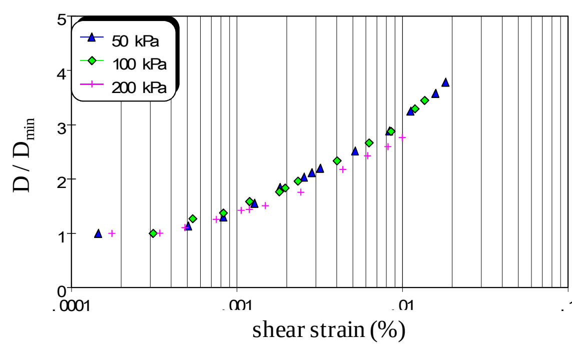
(a) GL-5m



(b) GL-7m



(c) GL-10m



(d) GL-20m

Fig. 12. Variation of the normalized damping ratio against the confining pressure and degree of weathering

Fig. 12(a) ~ (d) show the test results of the normalized damping ratio against the shear strain according to the confining pressure at each depth. It shows that the normalized damping ratio increases as the shear strain is increased and decreased as the confining stress is increased. The threshold strain tends to increase as the confining pressure or the depth is increased.

<u>Comparison with the existing studies</u>

Fig. 13 and Fig. 14 show the relation of the damping ratio and the normalized shear modulus according to the shear strain at all degrees of soil weathering. The existing curves of various researchers were compared in the same figure.

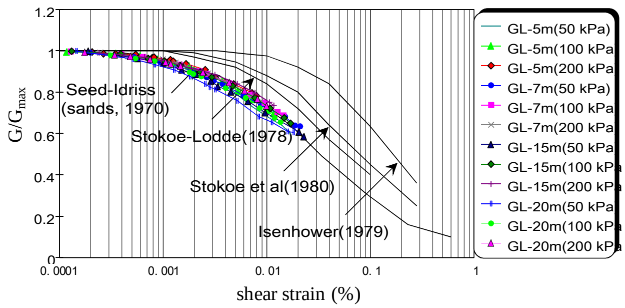


Fig. 13. Comparison of measured and existing shear modulus versus shear strain curve

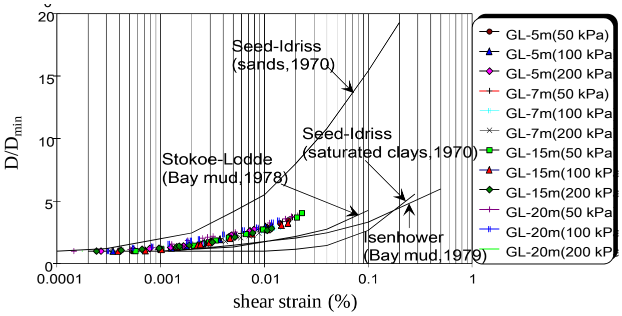


Fig. 14. Comparison of measured and existing damping ratio versus shear strain curve

The curve of Seed and Idriss(1970) was obtained with the results of the non-plastic soil and the saturated clay. The relation suggested by Stokoe and Loddle(1978), and Isenhower(1979) are derived from test results using the San Francisco Bay mud. The same results with those of Kim et al(1997), which suggest that the normalized shear modulus of the weathered granite soil accord with the results of Seed and Idriss(1970) for non-plastic soil, could be obtained at all depths. Therefore, it is estimated that the result of Seed and Idriss(1970) can be adopted as the characteristics of the weathered granite soil in South Korea.

The normalized damping ratio in Fig. 14 was located in the middle between the results of Seed-Idriss(1970) for the non-plastic soil and those for the saturated clay. The increase of damping ratio proved to be low because the influence of the interaction between the soil particles in the weathered granite soil becomes larger as the depth is deeper and the confining stress is larger.

Fig. 15 shows the relation between the damping ratio and the normalized shear modulus according to the general shear strain. Most of the points in Fig. 15 was shown to be located in the middle between two curves suggested by Seed and Idriss(1970). The results seem to lie on the line of Seed and Idriss(1970) for the sand as the degree of weathering is high and the confining stress is low. The results, on the other hand, came close to the curves for the clay as the degree of weathering is low and the confining pressure is high.

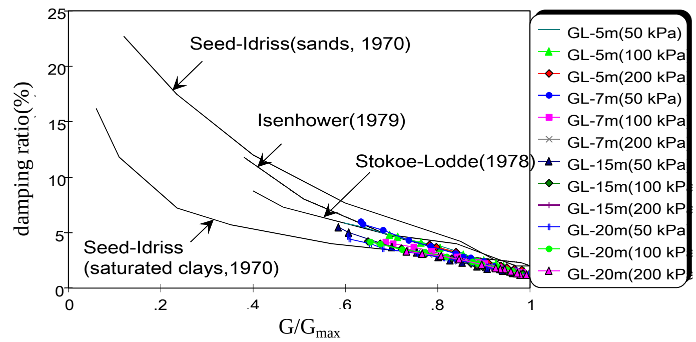


Fig. 15. Comparison of measured and existing relation between shear modulus and damping ratio

CONCLUSIONS

The influence of the degree of weathering on the dynamic characteristic of the weathered soil was studied by using the Stokoe type resonant column test device. The results were also compared with the existing studies. The following are the conclusions drawn in this study.

1) It was shown that the degree of weathering was low along the depth, because the ignition loss used to define the degree of weathering in this study decreases linearly along the depth. The ignition loss was also found to have the linear relation with the maximum shear stress and the minimum damping ratio.

2) The maximum shear modulus increased and the minimum damping ratio decreased as the confining pressure increased. The maximum shear modulus increased at a constant ratio according to the depth as the confining pressure increased. The minimum damping ratio, however, tends to have little difference along the depth as the confining pressure increased.

3) It was shown that the $K_{2(max)}$ of the weathered granite soil in this study, used to define the relation between the confining stress and the maximum shear modulus, ranges from 53.7 to 83.0. $K_{2(max)}$ increased along the depth and converged as the

confining pressure increase. In the case of the depth of 20m, $K_{2(max)}$ was somewhat larger than that for the sand.

4) The same results with those of Kim et al(1997), which suggest that the normalized shear modulus of the weathered granite soil correspond with the results of Seed and Idriss(1970) for the non-plastic soil, were obtained in the full depths. The normalized damping ratio was located in the middle between the two curves of Seed and Idriss(1970) for the non-plastic soil and the saturated clay.

5) Most of the points which represent the relation between the damping ratio and the normalized shear modulus according to the general shear strain were shown to be located in the middle between the two curves suggested by Seed and Idriss(1970). The results seems to lie on the line of Seed and Idriss(1970) for the sand as the degree of weathering is high and the confining stress is low. The results, on the other hand, came close to the curves for the clay as the degree of weathering is low and the confining pressure is high.

6) In this study, the test results showed that the shear modulus at the shear strain of 0.01% was 0.26~0.30 times smaller than the maximum shear modulus and the damping ratio was 2.7~3.0 times larger than the minimum damping ratio. The threshold strain, which was about 10^{-4}~10^{-3}%, tended to increase as the confining pressure or the depth increase.

7) More tests need to be performed to determine the dynamic characteristics of the weathered granite soil in South Korea, which is largely dependent on the characteristics of the mother rock and the weathering condition.

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