Geotechnical Characterization of Weathered Granite Soils in Korea

韓國에 分布하는 花崗岩 風化土의 土質工學的 特性

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요 지

우리나라의 화강암 풍화토(CW와 RC 풍화등급)의 불교란시료에 대한 일련의 토질물성 및 역학적 특성실험이 수행되었다.

화강암 풍화토는 크게 CW 및 RS 풍화등급으로 나뉘어지며, 풍화가 많이 진행됨에 따라서 토질물성이 매우 예민하게 변화하고, 일축압축강도 및 전단강도지수도 급격히 감소할 뿐만 아니라, 또한 변형특성은 풍화가 많이되고 침수됨에 따라서 화강암풍화토가 점차로 ductile하고 plastic하게 변해가는 특성이 있다.

또한 화강암 풍화토는 침수가 됨에 따라서 특이한 성질이 있는 것으로 관찰되었다: (1) 전단강도(특히 점착력) 및 일축압축강도가 급격히 감소할 뿐만 아니라, (2) 물과의 반응시에 화강암 풍화토의 입자가 쉽게 약해져서 더욱 작은 입자크기로 분해된다.

Abstract

A series of laboratory tests (physical and mechanical index and engineering design) were conducted on undisturbed granite soils of CW and RS weathering grades in Korea.

From these testes it can be concluded that most of physical and mechanical index values are very sensitive to change in weathering grade from CW to RS. Engineering design tests indicate that the unconfined compressive strength and the shear strength parameters are significantly reduced and that the soil becomes ductile and plastic with increasing weathering and saturation.

It was found that weathered granite soils have the special characteristics when water saturated: (i) they significantly lose their shear strength(especially cohesion) and unconfined compressive strength; (ii) they are fragile and their grains break down in water as observed in grain size analysis.

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1. Introduction

Soils weathered from granites occur throughout South Korea and cover approximately 35% of the country. The weathered granite soils are known as 「Problematic」 material to Korean engineers, since many civil engineering works are experiencing difficulties in zones where granite soils are encountered.[17, 28, 29, 30, 33, 36, 38, 42]

Therefore, there is a need to study the geotechnical characteristics of undisturbed granite soils in Korea. Unfortunately, little has been studied about them so far, probably due to easily disturbed character of weathered granite soils during sampling and testing.

Korean granites were emplaced during Mesozoic era(60－200 m. y.)[41]. As a result of many cycles of weathering and erosion after the formation of granites, the present depth of weathered granite soils in Korean granitic terrain remains at a relatively shallow depth of 10m.[16, 19] The weathered granite soils consist mainly of Completely Weathered (CW grade) material with a shallow cover of Residual Soil (RS grade) material.[4, 5, 8, 9, 18, 20－22, 31, 32]

CW material is immature soil containing some partially decomposed feldspars within it and showing still its original textures of small scale feature (i. e. grain boundaries and microfractures). The material can not be indented by thumb, but sometimes can achieve the hand penetrometer value ranging over 380 kPa. It is excavated by hand with difficulty, and is partly disintegrated by agitation in water. The material is highly permeable, i. e. 10^{-5}m/sec or better.

RS material is mature soil having almost completely decomposed feldspars and hardly showing its original texture. The material can be indented by thumb with moderate effort, and generally can achieve the hand penetrometer value ranging 240 to 350 kPa. It is easily excavated by hand, and is completely disintegrated by agitation in water. The material is moderately to slightly permeable, i. e. 10^{-5} to 10^{-9} m/sec.

In addition, many site investigation reports indicate that CW and RS materials are relatively sharply distinguished by the standard penetration resistance, called the "N" value, which is widely used at site investigation to assess the engineering properties of sandy soils; for 30cm penetration of the split－spoon sampler RS soil of loose to dense generally needs less than 50 hammer blows while CW soil of very dense requires more than 50 hammer blows. Thus the engineering properties of CW material generally can not be assessed by the conventional standard penetration test due to its dense nature.[13, 23, 24, 35, 37]

One of the main reasons for distinguishing between CW and RS grades in weathered granite soils is based on their different engineering characteristics of soil mass. As CW granite is immature soil, inherent rock structures of large scale feature (i. e. joints) still remain. Thus engineering properties of CW soil mass are known to be often influenced by the relic joints, being generally weaker than intact soil material, rather than intact soil material itself.[7, 12] On the other hand, RS granite is mautre soil showing no distinct original rock structure. Engineering properties of RS soil mass mainly depend on those of intact soil material.

2. Mineralogy and Texture

Korean granites consist of mainly three minerals; namely quartz(30~35%), feldspars (60~65% : plagioclase, 25~30% : potash feldspar, 30~35%), biotite(2~3%). The processes of weathering are mainly subdivided into chemical decomposition and physical disintegration.

Quartz is generally regarded as stable and resistant to chemical weathering although some etch pits induced by solution may be visible in the scanning electron micrograph.[1)]Feldspars are the most abundant weathered minerals in granite, but are the second most susceptible minerals to chemical weathering after biotite. They break down to a variety of clay minerals, with plagioclase decomposing sooner than orthoclase.[26)] To the naked eye, the feldspars appear to become cloudy then powdery, gradually losing their lustre and translucency as they weather. Biotite is the first mineral to be affected by the weathering agents[6)], but its breakdown is rather slow and partially weathered micas often remain long after the feldspars have disappeared.[18)] Often the oxidation of iron in biotite causes the surrounding minerals to turn from yellowish brown to red.

Granite soils representing CW to RS grades, which are subjected to a series of laboratory tests, were observed by visual observation of hand specimens and by microscopic study of thin-sections to identify their mineralogical and textural characteristics.

2.1 Visual Observation of Hand Specimens

To the naked eye with the aid of a X10 power hand lens, the CW and RS materials can be fairly well distinguished by various visual and mechanical(manual) recognitions summarised in Table 1.

The CW granite shows that original texture is present, while the RS granite shows that original texture is absent.

2.2 Microscopic Study of Thin-Sections

For microscopic study, specimens were observed under a microscope of X50 magnification and the thin section microphotographs were taken under crossed nicols. For the preparation of thin sections undisturbed specimens of CW to RS grades were impregnated with an Araldite mixuture (Araldite (AY 18) 100g and Hardner (HZ 18) 75g) because of their friable nature. First, the specimen was soaked with the mixture in a vaccum chamber at room temperature for 24 hours. After that the specimen is baked at temperatures increasing from 50℃ to 100℃ for another 24 hours. Then completely hardened specimens were treated by the same procedure for the standard thin section preparation.

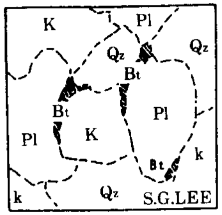
Table 2 illustrates the typical appearance of the undisturbed Korean granite soils of CW and RS weathering grades when viewed through a microscope. The change in mineralogy is described as a percentage difference from the original fresh (「F」 weathering grade) rock. Textural changes are all described in units of millimetres.

3. Methods of Sampling and Testing for Laboratory Tests

A series of laboratory tests were conduc-

Table 1 A weathering classification scheme for the weathered granite soils of CW and RS grades, using X10 magnification at most (modified from Lee & de Freitas[21]).

Fresh granite (F)



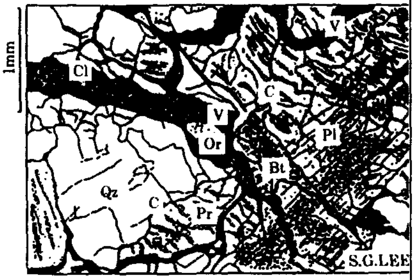
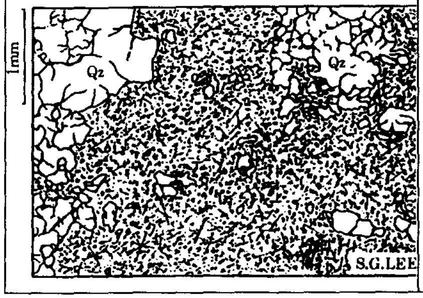
Typical features of hand specimens	Weathering grade (Abbreviation)	Visual description:		Manual recognition:
		degree of chemical decomposition	degree of physical disintegration	
	Completely weathered (CW)	Biotites, all plagioclases and most potash feldspars are completely decomposed (clayey), some potash feldspars are highly decomposed (gritty to clayey). Original texture is present.	All microfractures* and grain boundaries tend to be open. Original texture is present.	Can be readily peeled by a knife, can be readily indented by geological pick or knife, can not be indented by thumb, can be excavated by hand with difficulty, can be partly disintegrated by agitation in water, can easily absorb most of water. (Dense to very dense: approximate range of UCS** is 50−120 kPa for moisture content range 7.84−21.00%. HPV *** is sometimes achieved ranging over 380).
	Residual Soil (RS)	All biotites, feldspars are completely decomposed (clayey). Original texture is absent.	The existence of microfractures and grain boundaries are hardly distinguishable due to the absence of original texture.	Can be readily peeled by a knife, can be indented by thumb with moderate effort, can be easily excavated by hand, can be completely disintegrated by agitation in water, can slightly to moderately absorb some water. (loose to dense: approximate range of UCS is 30−50 kPa for moisture content range 12.24−22.10%. HPV is generally achieved ranging 240−350).

KEY : Qz = Quartz; K = Potash(K) feldspar;
Pl = Plagioclase; Bt = Biotite;
▨ : Chemical decomposition
\ : Discolouration
✗ : Physical disintegration(microcracks)

(*Note : not describing fracture and cleavage of minerals.)

(Note : UCS**, Unconfined Compressive Strength; HPV***, Hand Penetrometer Value (kPa)).

Table 2 Typical mineralogical changes and textural changes associated with the undisturbed Korean granite soils of CW and RS grades. These changes were observed using a microscope of X50 magnification.

Typical features of thin section	Weathering grade (Abbreviation)	Typical mineralogical change	Typical textural change
(a) 	Completely weathered(CW)	70~90% of potash feldspar and biotite, and all of plagioclase are changed to mainly clay minerals. All microcracks and grain boundaries are iron-stained.	Rock is disintegrated in to fine particles, but original rock texture is stilll preserved. Most microcracks and grain boundaries are open up to 0.1-2mm. Some openings are filled with clay minerals.
(b) 	Residual soil (RS)	Most potash feldspar and biotite and all plagioclase are changed to clay minerals.	original rock texture is destroyed. Many openings are filled with clay minerals.

KEY : Qz = Quartz; Bt = Biotite ; Potash feldspar (Pr = Perthite, Or=Orthoclase); P1 = Plagioclase; C1=Clay infilling; C = Crack; V=Void

Note : Chemical weathering is indicated by an ornament of dots the intensity of which reflects the intensity of weathering. Physical weathering is represented by a well-developed and anastomosing network of microcracks.

ted to study the influence of weathering on physical and mechanical properties and engineering design parameters of the Korean granite soil : Six physical and mechanical index tests comprise natural moisture content, specific gravity, dry density, porosity, particle size distribution and consistency limits. Two engineering design tests consist of unconfined compression test and shear box test.

Samples for laboratory tests were collected from four sites: Seoul, Palgong, Eonyang and Pusan. The former one consists of coarse-grained granite and the others of medium-grained granite.

For laboratory tests, undisturbed block samples representing CW and RS grades in each study area were prepared from surface exposures. [3] Eight CW to RS block samples of approximately 30cm×20cm×20cm in size were carefully collected from surface exposures by using a plough and a spade and stored in a polystyrene container, and sealed with vynyle and tape.They were transported carefully to a laboratory and tested within a few days. In general, the test procedure was based on the method suggested by the ISRM[10, 11] and B.S. 1377[2], and is briefly described below.

Specimen sizes were chosen for physical index tests as follows: For bulk and dry densities and porosity, the bulk volume of undisturbed soil specimen was determined by using constant volume sampling ring(6 cm dimeter, 2cm·thick) from undisturbed soil blocks. For specific gravity pulverised powders of a grain size of 100μm were prepared. Values for natural moisture content and dry density were determined from oven-dry weight and the weight at natural moisture content. Oven-dry weight was measured after the specimen had been dried for 48 hours at a temperature of 105℃. Specific gravity was calculated by using the density bottle method. Particle size distribution analysis was carried out using the pipette and wet and dry sieving methods. The latter two methods were intended for comparision: the wet sieving is recommended as a British standard [2]; the dry sieving as a Korean standard.[13, 14] Liquid limits were determined by using a cone penetrometer: the plastic limits were also estimated, using the thread rolling method.

For unconfined compression tests, two cylindrical undisturbed specimens (approximately 3.5 cm diameter and 7cm length) were prepared from each of the eight undisturbed blocks, representing CW and RS grades, in the laboratory by careful hand and knife trimming. One specimen from each block was tested in natural moisture conditions and the other one in soaking conditions. The natural moisture condition was a moisture range of 7.84% to 22.10%. The soaking condition was obtained by application of steady, low, back pressure during immersion in water for 2 hours, however, its moisture content was not measured. During the tests, all specimens were enclosed in rubber membranes. This prevented changes in humidity and facilitated the collection of specimens after failure in order to examine the mode of failure and the soaking condition. The unconfined compression tests were conducted using an autographic triaxial comprssion apparatus with an electrically controlled gear-loading system(Marui Co. Ltd, Japan).

For shear box tests, six undisturbed

specimens were prepared from each of the eight undisturbed blocks, representing CW and RS grades. For casting undisturbed specimens, rings of 6cm diameter and 2 cm thick were carefully pushed into the blocks, both sides of the samples in the rings were carefully trimmed by hand using a knife and then the samples were placed in the shear box using a tool. The shear box tests were carried out in both natural and soaked moisture conditions to identify the influence of soaking on the shear strength characteristics. The natural moisture content of the specimens ranged from 7.84% to 22.10%. For the determination of soaking conditions, tap water of approximately three times the specimen volume was poured in and left to penetrate the specimen. The moisture content was not measured. The tests were conducted under normal loads of between 29kPa and 54 kPa and at a shearing rate of 0.7mm/min. The shearing rate was chosen according to the calculations with the published values of permeability(3×10^{-5} to 3×10^{-7}m/sec) and compressibility(2.8×10^{-5} to 10.3×10^{-4}m^2/kN)of weathered granite soils[27] in order to cause no excess pore pressure development. Shear strength parameters were measured using a direct shear box (Maruto Co. Ltd., Japan).

4. Results and Discussions of Laboratory Test

4.1 Physical Characteristics(Natural moisture content, specific gravity, density and porosity)

The results for physical characteristics are summarised in Table 3. Each Value represents the average of three determinations.

Table 3 Laboratory test results.

	Physical characteristics					Mechanical characteristics							Engineering design parameters					
Location and type of sample	Natural moisture content (%)	Specific gravity	Desity (g/cm³)		Porosity (%)	Particle size distribution (%)				Consistency limits(%)			Uniaxial Compressive strength (kPa)**		Deformation modulus (MPa)***		Shear box test Friction angle(°) (Cohesion (kPa))	
			Bulk	Dry		Clay	Silt	Sand	Gravel	Liquid limit	Plastic limit	Plasticity index	(Natural)	(Soaked)	(Natural)	(Soaked)	(Natural)	(Soaked)
Bulam																		
CW	14.77	2.633	1.551	1.351	48.69	1	16	65	18	N.P.*	N.P.	N.P.	54	10	4.0	0.14	43(19)	40(13)
RS	13.17	2.626	1.400	1.237	52.89	2.5	23.5	54	20	40.5	33.7	6.8	38	0	3.36	0	42(8)	39(4)
Palgong																		
CW	13.69	2.661	1.730	1.522	42.80	2.5	23	59.5	15	35.3	30.3	5.0	106	20	6.93	0.74	49(32)	46(15)
RS	22.10	2.672	1.551	1.270	52.47	6	31	45	18	50.5	35.1	15.4	50	22	3.48	0.71	45(20)	41(14)
Eonyang																		
CW	7.84	2.633	1.719	1.594	39.46	0.5	12	70.5	17	N.P.	N.P.	N.P.	170	35	13.95	1.46	51(30)	50.5(12)
RS	12.24	2.621	1.650	1.470	43.91	0.9	19.6	61.5	18	N.P.	N.P.	N.P.	120	60	6.66	3.01	48(27)	45.5(8)
Pusan																		
CW	21.00	2.630	1.609	1.330	49.43	1.7	19.8	65.5	13	36.0	33.9	2.1	114	34	9.42	1.0	47(31)	44(22)
RS	14.80	2.625	1.491	1.299	50.51	2.7	28.8	52.5	16	45.5	39.6	5.9	30	11	1.0	0.35	45(15)	42(7)

(NOTE : N.P. *, Not possible;
kPa** = kN/m^2 = 10^{-2} kg/cm^2;
MPa*** = MN/m^2 = 1000 kN/m^2=10kg/cm^2)

4.1.1 Natural moisture content

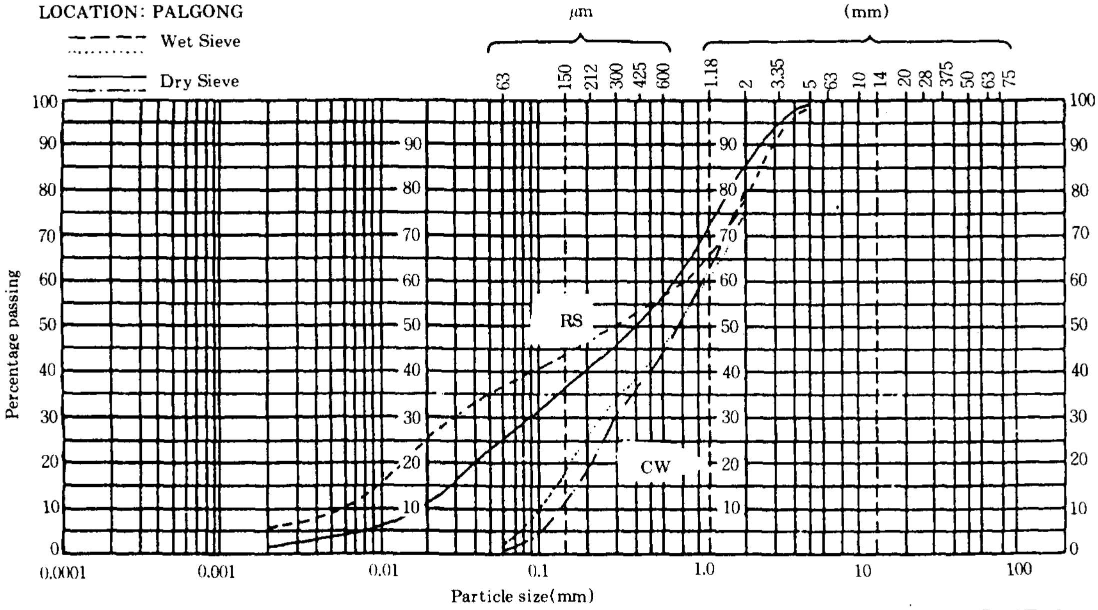
Natural moisture content (MCn) was measured as the weight of natural water as a percentage of the oven-dry weight. There is an increasing trend of the natural moisture content with increasing weathering grade: 7.84% to 21.00% in CW specimen and 12.24% to 22.10% in RS specimen. The trend is often erratic due to the presence of a shallow water table or local seepages at the sites where specimens were collected, e. g. CW and RS soils from Bulam and Pusan.

4.1.2 Specific gravity

Specific gravity (Gs) was calculated as the ratio of the weight of solid particles to the weight of an equal volume of water. In general, specific gravity decreases slightly with increasing weathering; 2.630 to 2.633 in CW soil and 2.621 to 2.626 in RS soil, but occasionally increases in the RS sample from Palgong where hydrothermal mineralisation (e. g. pyrite) is dominant. Furthermore the CW and RS specimens from Palgong have higher values than those from other sites. These are probably due to the intense accumulation of iron oxide in the weathered soil, which has been drived from oxidation of pyrite in the rocks.

4.1.3 Density (bulk and dry)

Bulk (γ) and dry(γ_d) densities were considered as the ratio of the weight at natural moisture content and the oven−dry weight to the bulk volume of specimen, respectively. Table 3 shows that the bulk density is



CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	COBBLES
	SILT			SAND			GRAVEL			

Fig. 1 Results of particle size distribution.

higher than the dry density in all specimens. Bulk density progressively decreases with increased weathering grade from CW to RS: 1.551 to 1.730 g/cm^3 in CW sample and 1.400 to 1.650g/cm^3 in RS sample. The variation in dry density with changing weathering grades follow a similar pattern to that of bulk density; 1.330 to 1.594g/cm^3 in CW specimen and 1.237 to 1.470g/cm^3 in RS specimen.

4.1.4 Porosity

Porosity (n) was determined as the ratio of the volume of voids to the total volume of soil. As weathering increases the porosity increases gradually from CW to RS samples: 39.46% to 49.43% in CW soil and 43.91% to 52.89% in RS soil.

4.2 Mechanical Characteristics(particle size distribution and consistency limits)

The results of Mechanical characteristics are summarised in Table 3.

4.2.1 Particle Size Distribution

The typical results of particle size distribution, illustrated in Figure 1, suggest that the curves are well graded and they become bi-modal with increasing weathering, and that there is a significant increase in fine particles with wet sieving. The significant difference in the results of wet and dry sieving methods implies that the properties of granite soils should therefor be determined in accordance with grain size distribution after wet sieving

The proportions of clay, silt, sand and gravel in wet sieving are summarised in Table 3. These results show that the CW and RS soils are texturally distinguishable; the CW soil has a higher sand content (59.5% to 70.5%) than the RS soil (45% to 61.5%), while the latter has more silt and clay (20.5% to 37%) than the former (12.5% to 25.5%). The proportion of gravel is similar in CW and RS specimens(13% to 20%)

4.2.2 Consistency Limits

The plasticity index (PI) was calculated by subtracting the plastic limit (PL) from the liquid limit (PI). Consistency limits could not be determined in the less weathered granite soil with caly and silt of less than 20% in content, e. g. CW and RS specimens from Eonyang, and CW specimen from Bulam. However they could be calculated in the intensely weathered granite soil with clay and silt of greater than 20% in content. Liquid limits, plastic limits and the plasticity index tend to increase with weathering -35.3% to 36%, 30.3% to 33.9%, 2.1% to 5.0% in CW sample and 40.5% to 50.5%, 33.7% to 39.6%, 5.9% to 15.4% in RS sample, respectively. The unified soil classification system, based on liquid limits and the plasticity index, generally classifies CW soil as non-plastic or occasionally ML, and RS soil as CL-ML, with the exception of CL in the specimen from palgong.

4.3 Unconfined Compression Test

The typical results of unconfined compression tests are shown in Figure 2.

4.3.1 Unconfined compressive strength

Unconfined compressive strengths(UCS) were calculated by dividing the maximum load at failure by the corrected cross-sec-

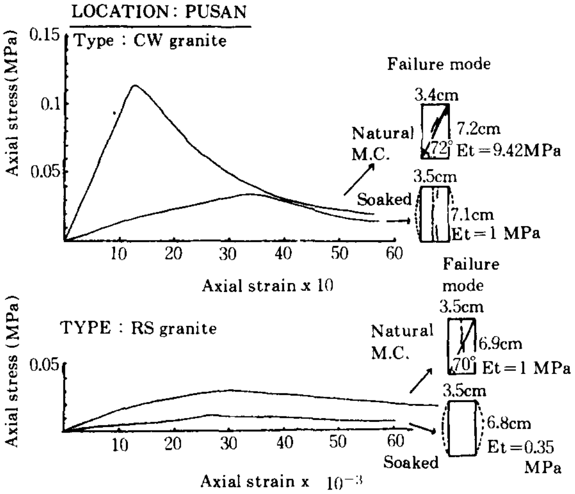


Fig.2 Results of unconfined compression test, showing the relation between axial stress and strain in natural moisture and soaked conditions, and the modes of failure under unconfined compression test of soil.

tional area of the specimen at failure and they are summarised in Table 3.

The unconfind compressive strength in natural moisture conditions in higher in CW specimens, ranging 54 to 170 kPa, than in RS specimens, ranging 30 to 120 kPa. When soaked, the uniaxial compressive strength is significantly reduced to 10 to 35 kPa and 0 to 22 kPa in the CW and RS specimens respectively. The unexpectedly high value (60kPa) of the soaked RS specimen from Eonyang is probably due to insufficient soaking, caused by its relatively low permeability, as revealed by examination after failure. Therefore, the value of this soil was not considered when calculating the soaking effect on the unconfined compressive strength.

The unconfined compressive strength of undisturbed granite soils at natural moisture content is rarely found in literature, probably due to the difficulty in sampling and testing of undisturbed granite soils, although Krank & Watters[16] showed 0~5200 kPa for CW specimens and 0~200 kPa for RS specimens.

4.3.2 Axial Stress－Strain Curve

The axial stress－strain curve is shown in Figure 2 where the stress was calculated by dividing the load by the corrected cross－sectional area of the specimen. The curve of the soaked RS specimen from Bulam could not be plotted due to the fact that when soaked, the specimen had failed by uncontrolled bulging from its own－weight before the test.

The CW specimens and natural－moisture specimens were deformed showing an obvious peak stress, while the RS specimens and soaked specimens were deformed without any evident peak stress and their maximum stresses were observed after relatively large displacements.

The modulus of deformation (E) was measured as the slope of the axial stress－strain curve at 50% peak strength, and they are summarised in Table 3. The results show that the modulus of deformation in the natural moisture condition is higher in CW specimen, ranging 4.0 to 13.95MPa than in RS specimen, ranging 1.0 to 6.66 MPa. With soaking, the modulus of deformation was significantly reduced to 0.14 to 1.46 MPa and 0 to 0.71 MPa in the CW and RS specimens, respectively. In this calculation the value of the soaked RS specimen from Eonyang was not considered for the reason expained previously in the Section of unconfined compressive strength.

4.3.3 Modes of failure

The typical modes of failure are illustrated in Figure 2. The natural-moisture specimens usually failed in a more brittle manner, showing development of a few shear joints with an angle of 70°~77° from the vertical to the load axis and joints horizontal to the load axis. On the other hand, the soaked specimens failed more often in a more ductile manner, forming barrelling and seldom showing distinct failure planes. The trend of the axial strain-stress curve and the difference in failure mode indicate that undisturbed granite soils become more plastic with increasing weathering and soaking. This tendency was also observed in the results of the shear box test described below.

4.4 Shear Box Test

The typical results of shear box tests are presented in Figure 3, and shear strength parameters are summarised in Table 3.

4.4.1 Shear stress and horizontal-vertical displacement

In Figure 3, the shear stress-horizontal displacement curve of CW specimen generally shows a distinctive peak point, which occurs after a relatively small horizontal displacement. On the other hand, the curve of the RS specimen shows that the shear stress increases gradually with horizontal displacement, seldom showing a distinctive peak point and that the maximum shear stress occurs after a relatively large horizontal displacement. The maximum shear strength, at the same normal load, is generally greater in CW sample than in RS sample. When the specimen was soaked the peak of the shear stress-horizontal displacement curve became less evident and the maximum shear stress was lower, this being observed after a larger horizontal displacement. The avove results suggest that the soil becomes more plastic with increasing weathering and soaking. This trend coincides with the trend observed in the unconfined compressive strength test.

It is observed from the shear stress-vertical dispalcement curves that dilatency is generally more significant at low normal loads and is more apparent in CW specimen than in RS specimen. This tendency towards dilatency is less in the soaked specimen than in the natural-moisture specimen.

4.4.2 Shear strength parameters

Table 3 shows that the internal friction angle(Φ') and the apparent cohesion (c'), in terms of effective stress, are higher in CW soil (43° to 51° and 19 to 32 kPa) compared to RS soil (42° to 48° and 8 to 27 kPa), respectively in natural moisture conditions.

Although the results are thought to be in terms of effective stress, it was noted that by soaking the specimen, the shear strength paramenters are reduced. The reduction percentage of Φ' and c' on soaking tends to be slightly higher in RS specimens than in CW specimens. The c' values are much more affected by soaking than the Φ' values in both CW and RS specimens: 7% and 5% for Φ', and 53% and 45% for c' in the average values for RS and CW soils, respectively. This implies that the shear rates recommended by Lumb[27] may not be adequate for drained conditions in these samples.

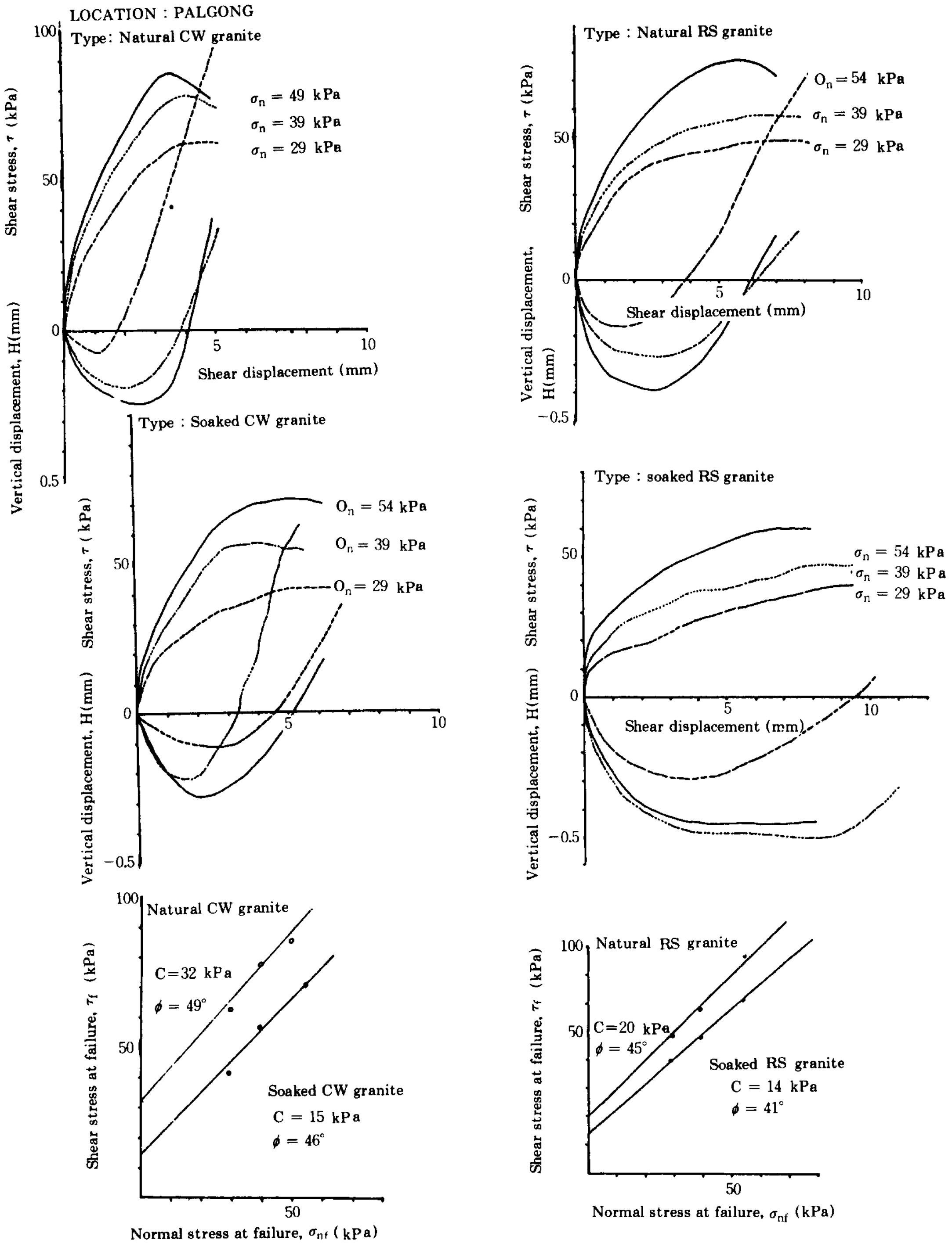


Fig.3 Results of direct shear box test, showing the relations between shear stress, horizontal displacement and vertical displacement under constant normal stresses, and the failure envelopes.

The Φ′ values (39° to 51°) obtained in this study are generally higher than the published Φ′ values (25° to 40°), whereas the c′ values (4 to 32 kPa) are similar to the published c′ values (0 to 50 kPa),[27, 40] One of the reasons for the higher Φ′ values is suspected to be due to relatively low normal loads (29 to 54 kPa) used in this study compared to the strength of weathered grainte soils. Onodera et al.[34] indicated that the failure envelope derived from the direct shear test on undisturbed granite soils is not a straight line but a concave curve. The curve can be divided into two straight lines, one at lower normal loads (50 to 250kPa) having a high Φ′ value (48°) and the other at higher normal loads (350 to 600 kPa) having a low Φ′ value(40°)

5. Conclusions and Recommendations

1. It was observed that as granite soils become weathered, component minerals are chemically decomposed and physically disintegrated from silty sand to clayey silty sand and original texture gradually disappears. The curves of particle size distribution suggest that the grainte soil is well graded and becomes bi-modal with increasing weathering. These results affect the physical and mechanical properties and the engineering design parameters in various ways. The summary is shown in Figure 4. They may be arranged in two groups according to their variation with increasing weathering grade from CW to RS:

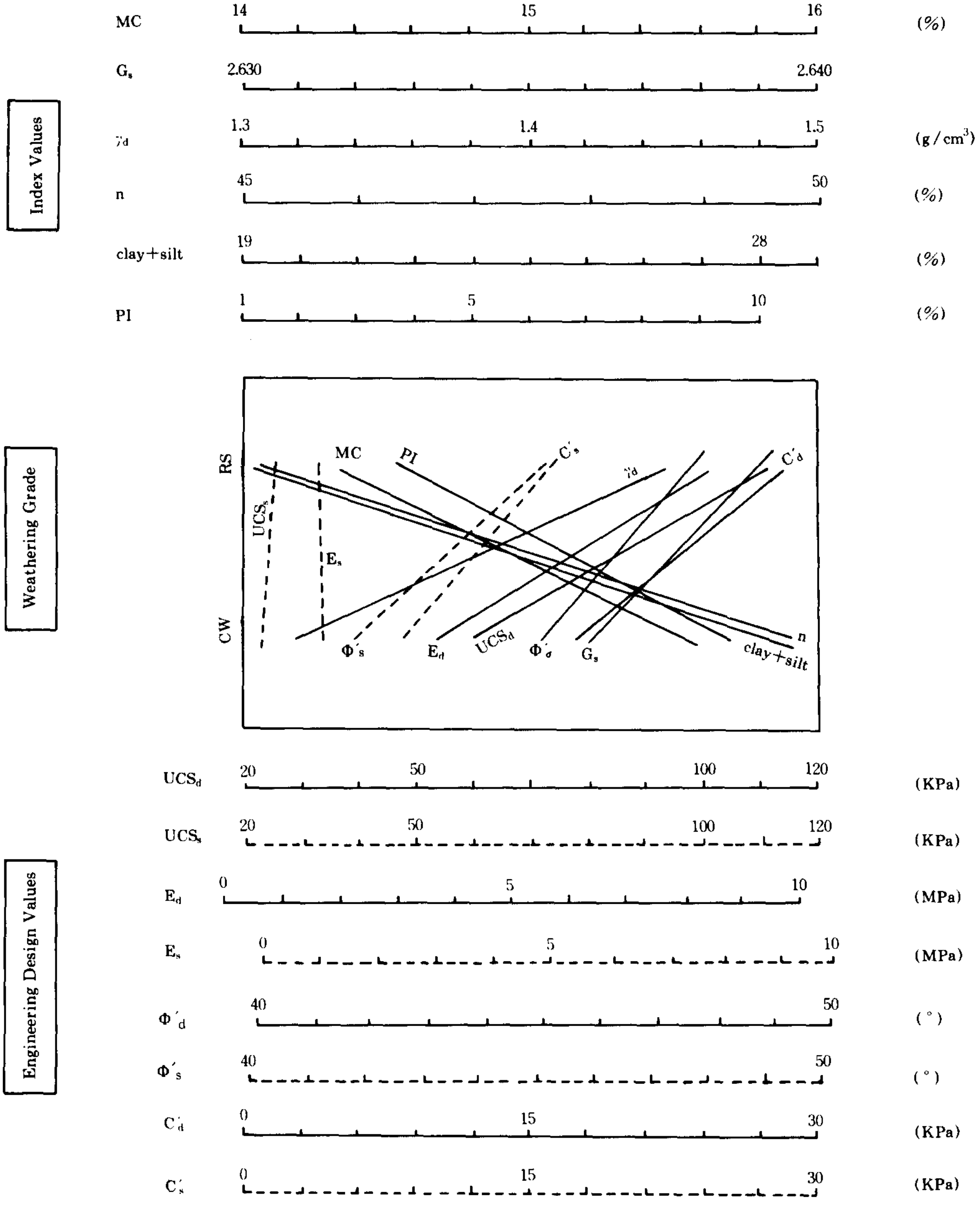
a) Some properties gradually decrease with increasing weathering, i. e. specific gravity, unconfined compressive strength, deformability, internal friction angle and cohesion:

b) others gradually increase with increasing weathering, i. e. natural moisture content, porosity, the amount of fine particles in grain size analysis and consistency limits.

2. In addition to the intensity of weathering, water content also significantly influences the engineering design parameters of granite soils. Engineering design tests (unconfined compression and shear box) indicate that the unconfined compressive strength is significantly reduced and that the soil becomes ductile with increased weathering and soaking.

3. The special characteristics of granite soils have been recognised in this research: (i) they significantly lose their shear strength (especially cohesion) and unconfined compressive strength with soaking: (ii) they are fragile and their grains break down in water as observed in grain size analysis −the wet grain size analysis shows a considerable increase in the amount of fine particles over that produed during a dry grain size analysis.

4. Weathered granite soils can be fairly well distinguished into two groups of CW and RS grades according to their intensity of weathering, (see Tables 1 and 2). The physical and engineering characteristics of CW and RS materials are significantly different as revealed in Figure 4. Furthermore the engineering characteristics of CW and RS masses are known to be significantly different; those of CW mass are often controlled by the weakness planes of relic joints while



✳ KEY :

MCn, Natural Moisture Content ; Gs, Specific Gravity: γ and γ_d, Bulk and Dry Density; n, Porosity; clay + silt, Proportion of Fine Particles, clay and silt; PI, Plasticity Index; UCS_n and UCS_s, Unconfined Compressive Strength in natural moisture and soaked conditions; E_n and E_s. Modulus of Deformation in natural moisture and soaked conditions; Φ', Internal Friction Angle; C', Apparent Cohesion.

Fig. 4 Summary of the variations in physical and mechanical index and engineering design values with weathering. The points mean the average values of CW and RS soils.

those of RS mass ae generally determined by its intact nautre. Thus in geotechnical engineering points of view it is necessary to consider seperately the weathered granite soil into at least two grades of CW and RS according to its intensity of weathering.

5. With regards to relic joints of large scale feature in CW mass their engineering properties need to be studied in future on Korean granite soil mass of CW grade.

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