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피스톤 샘플러와 대구경 샘플러로 채취한 시료의 특성에 관한 연구

A Study on the Sample Characteristics Obtained from Large Diameter Sampler and Piston Sampler

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Abstract

A large diameter sampler that can take undisturbed samples from soft ground was developed by KICT. In order to compare the quality of samples taken by the sampler with those of the traditional piston sampler, a series of laboratory tests were performed. Samples were taken at different sites such as Incheon, Gimhae, Yangsan and Busan. The results showed that the values of unconfined compression strength, secant modulus, pre-consolidation pressure, undrained shear strength, and shear modulus exhibited higher in samples taken by the large scale sampler. Strains at shear failure and volumetric strains were low for the new sampler. It was proved from the comparison that better quality samples could be obtained by the KICT sampler.

Keywords : Large diameter sampler, Piston sampler, Undisturbed sample

요 지

연약지반에서 비교란 시료를 채취할 수 있는 대구경 샘플러(KICT형 샘플러)를 개발하였다. 이 대구경 샘플러로 채취한 시료와 종래의 피스톤 샘플러로 채취한 시료의 질을 평가하기 위하여 인천, 김해, 양산, 부산에서 각각의 샘플러로 시료를 채취하였으며, 실내에서 일축압축시험, 압밀시험, 삼축압축시험 및 공진주시험을 수행하였다.
그 결과, KICT형 대구경 샘플러로 채취한 시료의 일축압축강도, 할선탄성계수, 선행압밀응력, 비배수전단강도, 전단계수가 수압식 피스톤 샘플러로 채취한 시료의 그것들보다 더 크게 나타났으며, 파괴시 변형률과 압밀시 발생되는 체적변형률은 작게 나타났다.

주요어 : 대구경 샘플러, 피스톤 샘플러, 비교란 시료

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1. Introduction

The ground investigation is one of the widely used methods to solve ground engineering problems as well as problems of various structural foundations. When it comes to such a ground investigation method, there are the standard penetration test, field vane test, pressuremeter test, and piezocone test, which are all performed in the field; it also includes the triaxial compression test, laboratory consolidation test, and direct shear test which are carried out in the laboratory after collecting the disturbed or undisturbed samples. Of these, the laboratory test is one of the most elementary methods, which is widely used to estimate the engineering characteristics of soil. However, the ground parameters calculated from the laboratory test have a problem that is considerably affected by the sample state, namely, the degree of disturbance. In order to improve the laboratory test results, undisturbed samples have to be collected from the field, but it is still difficult to collect the sand soil without any disturbance. To resolve such problems, a large number of researches on the effective sampling method are carried out in other countries.

However, in the domestic research environment, outdated boring technologies and sampling techniques are used to collect the samples, which determine the ground parameters without the consideration of the level of disturbance on those sample. Hence, the inaccurate test results are applied without compensating test values when determining the ground parameters used in designs, and there are questions arisen on the stability and economic efficiency of structures being constructed.

In this study, a large diameter sampler(also known as KICT-type large diameter sampler) is developed, which can minimize the sampling disturbance and collect the undisturbed samples from the sand soil ground as well as the clayey soil ground. The samples taken by the large diameter sampler are compared to samples collected by the traditional water pressure piston sampler in NX size, which is the most widely used in Korea.

2. Large Diameter Sampler Development

2.1 Backgrounds for Large Diameter Sampler Development

La Rochelle and Lefebvre(1970) took the clayey soil samples at Saint Lawrence, Canada by applying two different methods(the block sampler and 54 mm NGI piston sampler) and compared their physical characteristics. As a result, they found that disturbance occurs in the process of tube sampling. While there was not much difference in the apparent pre-consolidation pressure by sampler, the undrained shear strength and Young's modulus in the samples taken by the tube samples, which were measured from the uniaxial compression test, were about 50% lower than in those of the samples obtained by the block sampler. Besides, in case of the tube samples, the failure envelop obtained from the consolidation drained triaxial compression test and consolidation undrained triaxial compression test measuring the pore water pressure was considerably lower in the low confining stress range. Berre et al.(1969) collected the sea clayey soil of Norway by the use of the new 95mm NGI sampler and existing 54mm NGI sampler. From the results of the consolidation testing, there was not much difference in the pre-consolidation pressure by diameter, but the test result dispersion was significantly higher in the 54mm sampler from the testing results.

Bozozuk(1970) obtained the sea clayey samples in the Ottawa area by the use of the 54mm NGI sampler and 124mm NGI Osterberg sampler, and compared some of their characteristics. According to the results, the average pre-consolidation pressure in the 124mm samples was about 40%

higher than in 54mm samples. On the other side, the results from the undrained triaxial compression testing after applying the anisotropic consolidation by the stress in site showed that the shear failure was lower in the 124mm samples, but the undrained shear strength was almost same.

Raymond et al.(1971) used the block sampler, Shelby tube sampler, Swedish 50mm sampler and 124mm Osterberg sampler to compare the Ottawa clayey soil samples. As a result, the uniaxial compression strength was the highest in the samples taken by the block sampler.

Consequently, it was found that the larger diameter the sampler has the better quality samples can be obtained, especially, by the block sampler. However, the block sampler has the limitation in terms of depth; as the excavation depth increases, the costs increase in order to install the protection walls and the work itself becomes more complicated.

2.2 KICT-Type Large Diameter Sampler Development

In 1975, Sherbrooke University in Canada developed the Sherbrooke sampler to take block samples in diameter of 25cm from the ground surface to minimize the risk factors and stress removal due to the trench excavation when collecting the block samples. From the results various laboratory tests with the samples collected by the Sherbrooke sampler and another set of samples taken by the block sampling method generated, they found that the behaviors of two sample sets were generally similar. However, the Sherbrooke sampler has a disadvantage that it can be applied only to some of specific soils.

In 1975, Laval University in Canada developed the Laval sampler, which can collect the samples in diameter of 20cm, and compared the mechanical behaviors of the sample taken by the Laval sampler with those of the samples from the block sampling method. The results implied that the behaviors of two samples looked similar. However, there was difficulty in cutting and pulling the samples when using the Laval sampler to collect them.

In this study, we developed the KICT-type large diameter sampler with which even the undisturbed sand soil samples can be collected while setting off the weakness stated before. While the principle of the triple tube core barelle sampling is adopted, the KICT-type large diameter sampler is set to play a role of cutting the samples and prevent the collected samples from outflowing by mounting a special closure device(refer to Fig. 1). Fig. 2 displays the KICT-type large diameter sampler developed in this study.

Fig. 1. Special closure device

Fig. 2. KICT-type large diameter sampler

3. Field Applicability of KICT-Type Large Diameter Sampler

3.1 Clayey Soil Ground

In order to evaluate the applicability of the KICT-type large diameter sampler, undisturbed samples were taken from Inchoen International Airport, Gyeongnam Gimhae Highway and Busan Gangseo Stadium. For the comparison purpose of the disturbance level of the samples taken, the undisturbed samples in NX size were taken by the water pressure piston sampler, near the sites where the KICT-type large diameter sampler took the samples.

Since the Gimhae Highway site and Busan Gangseo Stadium site were generally composed of the clayey soil layer, it was not much difficult to take undisturbed samples by the use of the water pressure piston sampler and KICT large diameter sampler.

As the upper ground of the Inchoen airport site was very soft and silty, there was a high chance to have the taken samples spilt out of the thin-wall tube when pulling the piston sampler out after taking the samples. The layer five meter below the ground surface was layered with hard clayey soil whose the N value was more than 10, resulted in a difficulty that the piston sampler thin-wall tube was not properly penetrated with the manual pressure. However, in case of the KICT large diameter sampler, the bottom of the sampling tube was completely sealed by the cutter to prevent the samples from spilling out when the samples were taken, and it was easy to take the samples even from the hard ground.

3.2 Sand Soil Ground

For the sand soil ground, same sampling procedure and field sites were performed and selected with the clayey soil ground to evaluate the applicability of the KICT-type large diameter sampler.

From the results of collecting samples with the KICT-type large diameter sampler from Kijang-gun Busan, Yangsan Gyeongnam, and Suncheon Jeonnam, the sample collection rates were almost 100%, showing no difficulty during collecting samples. However, the sand soil sampling by the water pressure piston sampler had difficulties based on this study. The thin-wall tube were not perfectly penetrated through the sand layer and the upper part of the thin-wall tube was distributed.

4. Samples Disturbance Analysis

By the use of the samples taken by the KICT large diameter sampler, the uniaxial compression test, consolidation test, triaxial compression test and resonant column test were carried out.

4.1 Test Procedure

4.1.1 Uniaxial Compression Test

In this study, the uniaxial compression test was performed under the axis strain rate of 1%/min, after a specimen with 5cm diameter and 10cm height was formed from the samples taken by the KICT-type large diameter sampler and the water pressure piston sampler.

The uniaxial compression tester used in this study manufactured by Shingang Jungmil Inc. is composed of the electrical compression device, load cell, and Liner Variable Displacement Transducer(LVDT). The electrical compression device can control the axis strain between 1.0 and 4.5mm/min and the load cell measures loading up to 50kg in 0.01kg sensitivity. And the measured values are displayed in digital mode. LVDT measures the vertical strain rate in 0.01mm sensitivity.

4.1.2 Consolidation Test

This research conducted the standard consolidation test in accordance with KSF 2316 Regulations.

The consolidation tester is composed of the consolidation box, loading device and measurement. There are two consolidation boxes; fixed consolidation box and flexible consolidation box. The fixed consolidation box was used in this study. The load is delivered to the specimen via the loading device, which is based on the principle of lever. And, the measurement device is designed to automatically measure the consolidation sinkage in 0.01mm sensitivity using LVDT.

4.1.3 Triaxial Compression Test

In this study, the equal consolidation undrained shear test was carried out to analyze the disturbance level of the samples taken. The jigsaw was used to form the specimen with a diameter of 5cm and a height of 10cm, and the specimen was saturated at the back pressure of 100kPa. For the saturation ratio, it was considered to be saturated if the factor B measured is more than 0.98. In addition, it was sheared at the compressive strain velocity of 1%/min. The confining stress was set to 40, 50, 60 and 65kPa equivalent to the effective loading in the field in the consideration of the sampling location and sampling ground layer.

This study adopted the automatic triaxial compression tester designed by Dr. C. K. Chan in the US, which supports the static loading and repetitive loading. This tester measures the axial stress, confining stress, axial strain, volumetric strain and pore pressure, which are changing during testing, with individual transducers, and automatically saves the results into the computer. The vertical pressure and confining pressure are automatically controlled according to the numerical values input in the computer.

4.1.4 Resonant Column Test

To perform the resonant column test with Drnevich apparatus, the undisturbed sand soil samples were frozen in the large-size freezing chamber maintaining the temperature of -5℃ for more than 96 hours. At this step, in order to prevent the samples from being expanded due to freezing, the top and bottom surfaces of samples were sealed with the tube caps, which were firmly fixed using the connection bar and bolts. As a result, the expansion phenomenon was seldomly found in the sample freezing process as shown in Fig. 3, and it became hardened enough to form a specimen.

The specimen was formed by slowly penetrating the specimen formation tube of diameter 5cm and height 13cm by the oil jacky as shown in Fig. 4. At this point, the saw was used to cut out the soil around the header part of the specimen formation tube to minimize the friction and disturbance due to the tube penetration. It took a long time to form a specimen in this way. Therefore, all the works were carried out in the large freezing chamber to prevent the samples from defrosting while forming the specimen.

After the formed specimen was placed on the bottom plate and the resonant column testing device was installed, then it was consolidated with the isotropic confining pressure of 3kPa by air pressure. As the dynamic characteristics of soils are changed by the consolidation time, the same confining time was applied. After the consolidation processing, the shear modulus was calculated at the low strain state and the shear strain rate of less than 10^{-3}%. The resonant column test was performed by increasing the confining pressure by 3, 6 and 12 Pa in order.

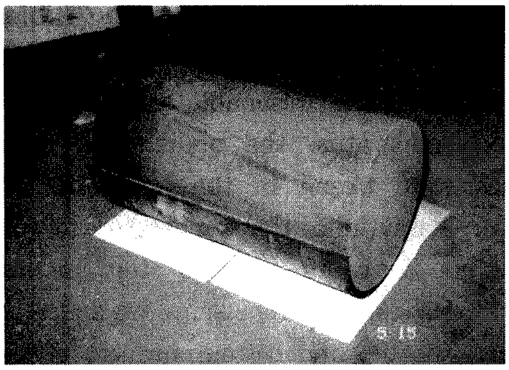


Fig. 3. Frozen specimen

Fig. 4. Specimen forming

4.2 Test Results

4.2.1 Basic Properties

The natural water content ratio, specific gravity, Atterberg limits and particle distributions were tested using the samples taken from the Inchoen International Airport site, Gimhae Decatur Highway and Gangseo Stadium. Table 1 shows the experimental results.

Table 1. Basic properties of the taken samples

Sampling Location	Depth (m)	Natural Water Content Rate W_n(%)	Liquid Limit W_L(%)	Plastic Limit W_P(%)	Plastic Index I_P(%)
Inchoen Int'l Airport	3	38	25	NP	-
	4	34	25	NP	-
	5	32	27	14	13
Gimhae Hwy	4.5	63	41	21	20
	7	74	44	25	19
Gangseo Stadium	6.5	21	37	21	16
	9	30	40	23	17

(a) Samples I

Sampling Location	Depth (m)	Special Gravity Gs	Uniformity Coefficient Cu	Curvature Coefficient Cg	USCS
Inchoen Int'l Airport	3	2.64	3.3	1.7	ML
	4	2.65	4.6	1.0	ML
	5	2.71	13.5	1.3	CL
Gimhae Hwy	4.5	2.67	12.2	1.2	CL
	7	2.68	13.1	1.0	CL
Gangseo Stadium	6.5	2.66	-	-	CL
	9	2.67	-	-	CL

(b) Samples II

As shown in Table 1, the silty clayey(ML) was distributed down to 5 meters from the ground surface in the Inchoen International Airport site, and around 5 meters, the layer was changed into the hardened clayey at the plastic limit 13 and the N value 10. In the Gimhae Hwy, which was used as the farmland before, from 1 meter deep from the ground surface to 10 meters down, the clayey soil layer was distributed whose the plastic index is 20 and the N value is 2~3. Also, the Gangseo Stadium in Busan was the farmland; there were silty sands from the ground surface to 6 meters down, and the clayey layer with the N value 2~3 was distributed between 6m from the ground surface and 10m.

The Gimhae Hwy. and Busan Gangseo Stadium sites were largely composed of the clayey soil layer. This brought no difficulty in taking the undisturbed samples by using of the both water pressure piston sampler and KICT large diameter sampler. However, at the Inchoen International Airport site, the upper layer was so soft and silty that there were some concerns that the samples might be spilt out of the thin-wall tube when pulling the water pressure piston sampler out, and the thin-wall tube was not properly jetted by water pressure in the hard clayey soil layer. However, the KICT-type large diameter sampler designed in this study prevented the taken samples from spilling out by having the bottom of the sampling tube sealed with the cutter. And, no problem was found in taking the samples from the hardened ground as it takes the undisturbed samples by applying the rotating-excavation onto the ground.

From the field tests described before, it was found that the KICT-type large diameter sampler developed in this study was efficiently used in the hardened ground with the N value more than 10 as well as on the soft ground.

4.2.2 Uniaxial Compression Test Results

Fig. 5 represents the results from the uniaxial compression test done on the samples taken from the Inchoen International Airport site and Gimhae Hwy. site by the KICT large diameter sampler and water pressure piston sampler.

Fig. 5 shows that the unconfined compression strength in samples taken by the KICT large scale sampler was higher than that of the samples obtained by the water pressure piston sampler, and the strain rate when demolishing was shown to be lower in the samples obtained by the KICT large scale sampler. However, the difference in the secant modulus was far significant comparing to above differences.

It was found that the secant modulus was found considerably higher in the samples taken by the KICT large sampler than that of the samples obtained by the water pressure piston sampler. G. Holm and R. D. Holtz(1977) stated that the disturbance of samples gives greater impact on the secant modulus than on the undrained shear strength. The results from this test were the same as the research results from what G. Holm and R. D. Holtz(1977) performed.

Based on the emprical method by Horiuchi et al. (1987) as shown in Fig. 6(separating the disturbed sample from the undisturbed based on E_{50}/q_u), the quality of samples taken by the KICT large diameter sampler with that of the conventional piston sampler was determined.

Consequently, while the both samples taken at the Inchoen International Airport and Gimhae Hwy. by the KICT large scale sampler correspond to the undisturbed area. On the other hand, it was shown that all the samples taken by the water pressure piston sampler correspond to the disturbed area.

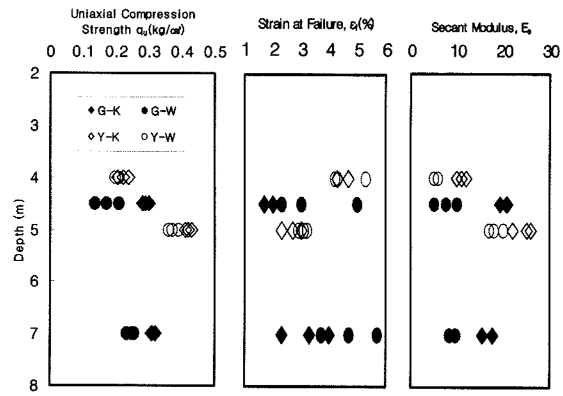


Fig. 5. Uniaxial compression strength test by sampler & sampling depth.

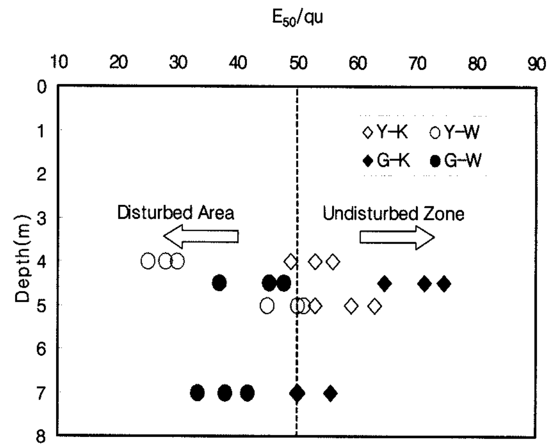


Fig. 6. Sample quality evaluation by the method Horiuchi(1987) proposed

4.2.3 Consolidation Test Results

Table 1 showed the consolidation testing results from the samples taken at the Incheon International Airport, Gimhae Hwy. and Busan Gangseo Stadium sites.

As shown in Table 2, the pre-consolidation pressure of the samples taken by the KICT large scale sampler was 10~25% higher than that of the samples obtained by the water pressure piston sampler, and accordingly the over-consolidation ratio(OCR) was shown to be higher in samples taken by the KICT large diameter sampler. Based upon such testing results, it was concluded that the KICT large scale sampler disturbs samples relatively less than the water pressure piston sampler.

Table 3 summarizes the assessment on the relative disturbance degree of the samples taken by using Eq. (1) proposed by Shogaki et al.(1996).

$$\varepsilon_v = \frac{e_0 - e_1}{1 + e_0} \times 100 \qquad (1)$$

where ε_v, e_0, and e_1 represent the volumetric strain ratio, the initial void ratio and the void ratio, respectively when the effective overburden pressure is applied in site.

Table 2. Comparison of pre-consolidation stress, compression index and over-consolidation rate by sampler type

Sampling Location	Sampling Depth	Sampler Type	Pre-Consolidation Stress (kg/cm^2)	OCR
Incheon International Airport	4m	KICT	1.35	3.4
		Piston Sampler	0.96	2.4
	5m	KICT	1.75	3.5
		Piston Sampler	1.35	2.7
Gimhae Hwy.	4.5m	KICT	0.65	1.6
		Piston Sampler	0.55	1.3
	7m	KICT	0.80	1.2
		Piston Sampler	0.72	1.1
Gangseo Stadium	6.5m	KICT	1.00	2.2
		Piston Sampler	0.59	1.3
	9m	KICT	1.07	1.8
		Piston Sampler.	0.62	1.0

As seen in Table 3, the volumetric strain ratio in the samples taken by the large scale sampler was lower than that of the samples obtained by the water pressure piston sampler. Consequently, it was found that the samples taken by the KICT large scale sampler were less disturbed than those by the water pressure piston sampler.

Table 3. Sample quality evaluation by the method proposed by Shogaki

Sampling Location	Sampling Depth	Sampler Type	On-site Pore Water Rate (e1)	Volumetric Strain ε_v(%)
Inchoen International Airport	4m	KICT	0.788	1.2
		Water Pre.	0.782	1.6
	5m	KICT	0.755	1.4
		Water Pre.	0.740	2.3
Gimhae Highway	4.5m	KICT	1.624	1.0
		Water Pre.	1.559	2.8
	7m	KICT	1.821	6.4
		Water Pre.	1.778	7.4
Gangseo Stadium	6.5m	KICT	1.284	3.1
		Water Pre.	1.279	4.4
	9m	KICT	1.153	3.2
		Water Pre.	1.145	6.0

4.2.4 Triaxial Compression Test Results

Table 4 shows the triaxial compression testing results from the samples taken at the Incheon International Airport, Gimhae Hwy. and Busan Gangseo Stadium sites.

Table 4. Comparison of Undrained Shear Strength & Volumetric Strain Ratio by Sampler Type When Confining Stress Is Effective Overburden Pressure in Site

Sampling Location	Sampling Depth	Sampler Type	Undrained Shear Strength (kPa)	Volumetric Strain (%)
Inchoen International Airport	4m	KICT	80.5	0.96
		Water Pre.	68.0	1.14
	5m	KICT	106.0	1.42
		Water Pre.	95.5	1.64
Gimhae Hwy.	4.5m	KICT	31.4	0.82
		Water Pre.	30.6	1.25
	7m	KICT	51.4	2.44
		Water Pre.	38.2	1.83
Gangseo Stadium	6.5m	KICT	88.1	1.89
		Water Pre.	75.0	4.60
	9m	KICT	95.5	1.25
		Water Pre.	82.1	2.39

As seen in Table 4, the undrained shear strength of the samples taken by the large diameter sampler was about 15% higher than those obtained by the water pressure piston sampler, and the volumetric strain in the consolidation process was found lower. Accordingly, it was concluded that better quality samples could be obtained by the KICT large diameter sampler than by the water pressure piston sampler.

When the results shown in Table 4 are evaluated based upon the sample quality evaluation standards proposed in NGI, the samples taken by the KICT large diameter sampler correspond to the category good~very good to excellent, but the samples by the water pressure piston sampler correspond to category good~fair(refer to Table 5). In addition, as the sample quality evaluation standard suggested by Lascsse and Berre(1988), samples taken by the both KICT large diameter sampler and water pressure piston sampler were determined to convey a high quality(refer to Table 6). Therefore, it can be found that the better quality samples could be obtained by the KICT large diameter sampler than by the water pressure piston sampler.

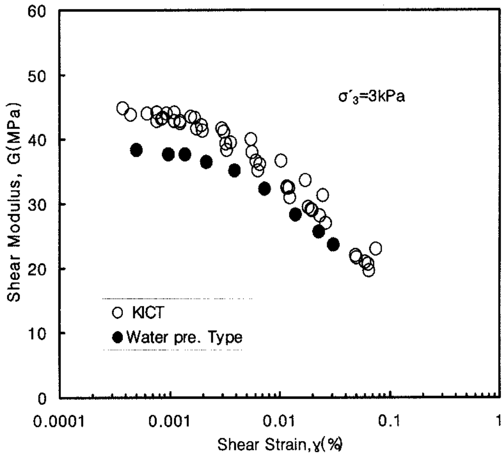
Table 5. Sample quality evaluation standards proposed by NGI proposed by Lacsse & Berre

Volumetric Strains(%)	Sample Quality
< 1	very good to excellent
1~2	good
2~4	fair
4~10	poor
>10	very poor

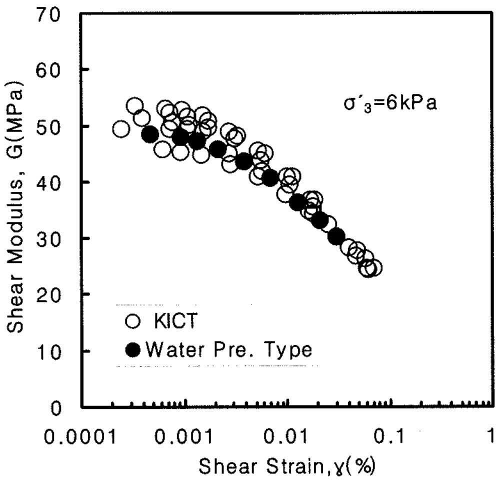
Volumetric Strains(%)	Over-consolidation Ratio
2.1~4.0	1.0~1.2
1.2~3.3	1.2~2.0
0.5~2.0	3.0~8.0

4.2.5 Resonant Column Testing Results

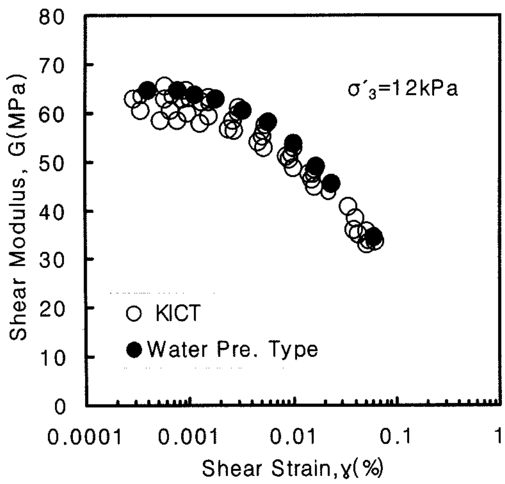
When the confining stress was 3kPa as shown in Fig. 7, the shear modulus in the samples taken by the KICT large scale sampler was higher by 5 MPa at maximum than those obtained by the water pressure piston sampler.



(a) When confining stress is 3kPa



(b) When confining stress is 6kPa



(c) When confining stress is 12kPa

Fig. 7. Inter-relations between the shear strain and shear modulus by confining stress

However, when the confining stress was 6 and 12 kPa, the shear modulus of the samples taken by the both KICT large diameter sampler and water pressure piston sampler was almost identical. Namely, it was found that less disturbance occurred in the samples taken by the KICT large diameter sampler than in those by the water pressure piston sampler, and as the confining stress increased, the disturbance effect of samples decreased.

5. Conclusion

From the results of comparing and analyzing the field applicability of the KICT large diameter sampler designed in this study and the water pressure piston sampler in NX size and the disturbance degree of the samples taken by these two samplers, the following conclusions can be summarized.

(1) The KICT sampler was more appropriate than the NX-size water pressure piston sampler in order to obtain samples from the hardened layer as well as from the less adhesive ground.

(2) The unconfined compression strength and secant modulus by the KICT sampler was higher than the water pressure piston sampler. However, strains at shear failure by the KICT sampler were lower than the NX-size water pressure piston sampler.

(3) Based on the sample quality evaluation based on the method Horiuchi et al.(1987), the KICT sampler had no disturbance.

(4) The pre-consolidation pressure by the KICT sampler was higher than the water pressure piston sampler.

(5) Based on the analysis on the sample disturbance degree by Shogaki(1996), the KICT sampler was less disturbed.

(6) The undrained shear strength by the KICT sampler was higher than the water pressure piston sampler. When samples were consolidated, the volumetric strains by the KICT sampler were lower than the water pressure piston sampler.

(7) Based on the resonant column testing, the shear modulus by the KICT sampler was higher than the water pressure piston sampler.

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