Jour. of the KGS, Vol. 20, No. 7. September 2004, pp. 99~105

Consolidation Test Method Considering Sample Deformation Due to Stress Release by Sampling

시료채취에 의한 응력해방시 시료변형을 고려한 압밀시험

Kim, Jae-Young[1] 김 재 영
Takada, Naotoshi[2]

요 지

포화점토가 보오링공에서 불교란시료로써 채취되면, 부의 간극수압이 체적팽창을 억제한다. 이 점토시료에는 지반중에서 작용한 평균주응력이 등방적으로 작용하며, 이 평균주응력은 수직응력보다 작고, 수평응력보다 크다. 그러므로 시료는 비배수조건하에서 수직으로 늘어나고, 수평으로 수축하게 된다. 통상적인 압밀시험은 이와 같이 변형된 시료를 그대로 사용하여 압밀링 크기와 똑같이 성형한 후 수행한다. 따라서 지반중의 유효상재압이 재하되면, 이 압력이 수평응력보다 크기 때문에 압밀량이 늘어나게 된다. 즉 압밀시험공시체는 현장의 압밀거동을 정확하게 나타내지 못하고 항상 아래에 위치하게 된다. 이 논문에서는 상기와 같은 시료변형의 영향을 고려하여, 압밀시험 공시체에 유효상재압이 재하되었을때 수평방향으로 비배수 변형하여 압밀링 내경에 밀착해도록 하였다. 그리고 제안하는 시험법의 적용성과 결과를 통상적인 압밀시험결과와 검토하였다.

Abstract

When a saturated clay is sampled from a borehole in an undisturbed manner, the exerted negative pore water pressure restricts the volume expansion. The vertical and horizontal stresses to which the clay was subjected in the ground are smaller and larger than this isotropically confining stress equivalent to the mean principal stress in the ground, respectively. Therefore the sample expands vertically and shrinks laterally under an undrained condition. In the ordinary consolidation test, the sample thus deformed is trimmed to fit the inside of the consolidometer ring. Thus, the specimen generates larger consolidation displacement due to confining larger horizontal stress when in-situ effective pressure is loaded. The specimen does not reproduce the in-situ consolidation behavior. In this paper, considering sample deformation, the test specimen is made to expand laterally to fit the inside of the ring in the undrained manner when the in-situ effective pressure is loaded. And applicability of this proposed test procedure was verified; results from the conventional consolidation test procedure are also discussed.

Keywords : Clay, Consolidation test, Expansion, Sampling, Stress release

1. Introduction

Natural clay deposits are usually in one-dimensional consolidation state, where the clays are subjected horizontally to the earth pressure at rest. When a fully saturated clay in this state is sampled in an undisturbed

1 Member, Ph., Doc., Sambo Engrg. Co., Ltd. (geokimjy@korea.com)
2 Prof., Osaka City Univ., Dept. of Civil Eng.

manner, all the stresses are released after sampling. However, the exerted negative pore water pressure restricts the volume expansion, resulting in extension towards the vertical direction and in shrinkage towards the horizontal direction under an undrained manner as shown in Fig. 1. This is because the negative pore water pressure exerted in this clay sample is usually equal to the mean principal effective stress, which is smaller and larger than the in-situ vertical and horizontal stress in the ground, respectively. In the ordinary consolidation test method, the deformed sample is trimmed just to fit the inside of the consolidometer ring. Thus, the specimen generates larger consolidation displacement than that under in-situ conditions because the exerted larger horizontal stress increases the mean principal stress when the overburden pressure is loaded. Consequently, the specimen in the ordinary consolidation test does not exactly reproduce the in-situ consolidation behavior of the clay. One of the authors measured the vertical extension of the undisturbed samples taken by a thin walled tube sampler for alluvial clay and pleistocene clay by means of extension measuring gage (Takada and Hamada, 1993). The extension strains were about 1% for the alluvial clay and 1.5-1.8% for the Pleistocene clay. Based on the measurement, the consolidation test specimen diameter should be less than the inside diameter of the consolidometer ring by 0.5% or 0.75-0.9% so that the specimen expands laterally to the inside diameter of the consolidometer ring in the undrained (constant volume) manner when the in-situ effective overburden pressure is loaded. The measurement of the extension strain was also made for laboratory constituted clay samples with different plasticities consolidated from slurry in a cylindrical mold when they were removed from the mold. Based on this measurement, several series of consolidation tests using specimens with smaller diameter than the inside diameter of consolidometer ring trimmed from these laboratory constituted samples were conducted. Test results were compared with the ordinary standard consolidation test results. The comparison shows that the f-log p (f = 1+ e : volume ratio or specific volume) relation obtained by the specimens with smaller diameter occupies the upper region than those by the ordinary standard test method. It was proposed by some researchers (Schmertman, 1953) that the f-log p relation of the normally consolidation range should be shifted to upper position to correct the effect of sample disturbance. However, the effect of the sample deformation due to stress release after being sampled on the consolidation test results was found to be significant, and the suitable test method considering this effect must be developed (Interpretation and application of ground survey and soil test results, 1998).

2. Measurement of Vertical Extension of Undisturbed Samples

Vertical extension of the undisturbed samples was measured by means of an overcoring manner. The extension gage as shown in Fig. 2 consists of stainless steel pipes, 3 mm of inside diameter, 4 mm of outside

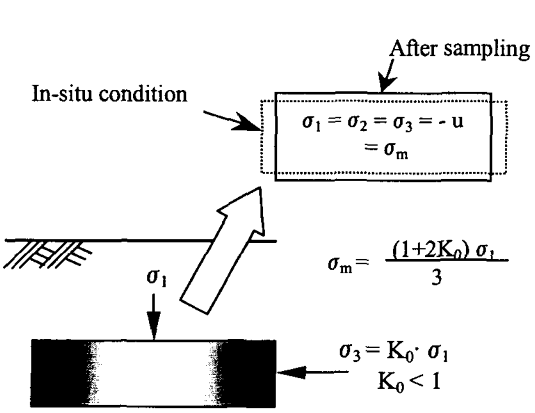

Fig. 1. Anisotropic deformation of saturated clay sample

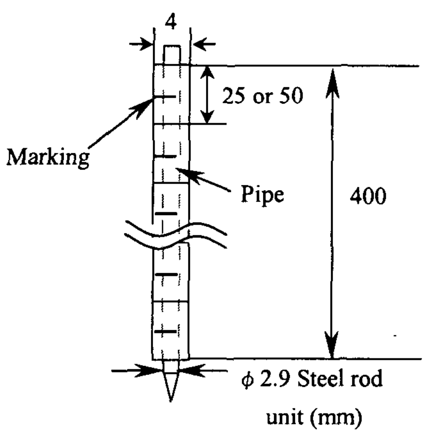

Fig. 2. Extension measuring gage

diameter and 25 or 50 mm long, through which a hard steel rod, 2.9 mm of diameter and 40 cm long, passes. Marking is made on the center of each pipe, by which the extension of the sample is measured. The extension gage is inserted in the pipe of the installation equipment as shown in Fig. 3, which is attached to the drill rod. The installation equipment is lowed in the bore hole, and at the bottom of the bore hole, steel rod, 4 mm of diameter, pushes out the extension gage to penetrate the bottom of the bore hole. After installation, sampling by thin-walled tube (75 mm of inside diameter and 1.5 mm of wall thickness) is made in the ordinary sampling manner. The sample after removal from the sampling tube is carefully cut in the longitudinal axis to expose the extension gage, and distances between the markings on the stainless steel pipes are measured by means of a reading microscope to 0.01 mm. Measurements were made at Obiraki, northwest region in Osaka city, and Neyagawa alluvium plain, Osaka prefecture. Results are shown in Table 1, in which data previously obtained by one of the authors (Takada and Hamada, 1993) at Suminoe, south-west region in Osaka city, are also presented for reference. Soil profiles at sampling locations are presented in Fig. 4. Extension strain is defined as the ratio of the increase of distance between the markings on the pipes of the extension gage to the original distance. The extension strain of alluvial deposits shows 0.96 to 2.00%. Silty clay having low plasticity shows a little large extension strain. The extension strain of Pleistocene clay O123 sample from Obiraki is 1.19%, which is smaller than those from Suminoe. At Suminoe, extension strains of the Pleistocene clay were sampled both by means of the stationary piston sampler and Denison type sampler. Due to high strength of this clay, penetration of one half of the entire sampling tube length (1 m) of the stationary piston sampler was employed; the

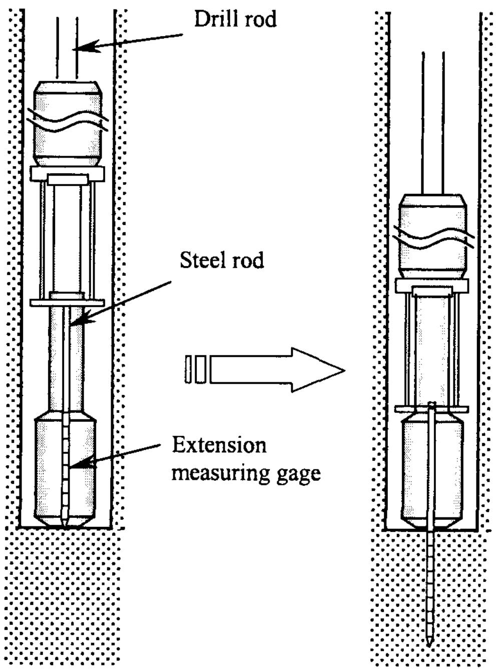

Fig. 3. Insertion of extension measuring gage in the bore hole

Table 1. Vertical extension strain and physical properties of samples

Location	Depth (m)	Sampler	Extension strain (%) Range	Extension strain (%) Average	Soil	Sample name	w (%)	w_L (%)	w_P (%)
Obiraki	15.5 - 16.2	Hydraulic piston	0.81 - 1.53	1.30	Alluvial clay	O62	60	62	35
	19.5 - 20.4		0.79 - 1.49	1.19		O101	63	101	36
	24.5 - 25.5		1.22 - 2.38	1.91	Silt	O54	22	54	28
	39.5 - 39.8		0.73 - 1.41	1.19	Pleistocene clay (Ma12)	O123	71	123	44
Neyagawa	3.5 - 4.0	Denison type	1.12 - 2.64	2.00	Sandy clay	–	–	–	–
	7.4 - 8.2		0.98 - 2.40	1.51	Silty clay	N42	42	42	23
	35.5 - 36.2		0.71 - 2.75	1.42	Pleistocene clay (Ma12)	N68	49	68	31
	37.5 - 38.2		0.74 - 2.49	1.28		N72	48	72	33
Suminoe	15.3 - 16.1	Stationary piston	0.78 - 1.27	1.03	Alluvial clay	–	34	45	25
	39.5 - 40.0		1.30 - 2.69	1.98	Pleistocene clay (Ma12)	–	60	95	28
	42.6 - 43.4	Denison type	0.63 - 1.40	0.96		–	70	100	33

w : natural water content

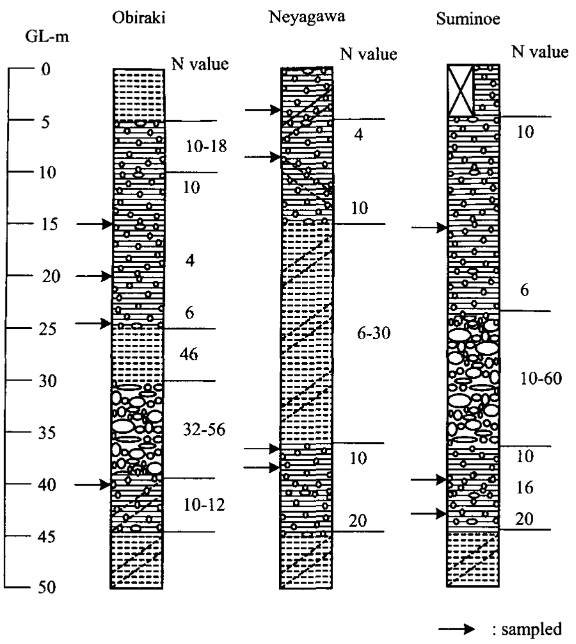

Fig. 4. Boring logs

quality of this sample was higher than that by the Denison type sampler. The extension strain of the sample by Denison type sampler is lower due to possible disturbance.

3. Consolidation Test on Laboratory Constituted Samples

The specimen consolidation test in the current standard test method is trimmed so that it has the same diameter as the inside diameter of the consolidometer ring. Based on the above consideration, the test specimen should have a smaller diameter than the inside diameter of the consolidometer ring, and when the in-situ overburden pressure is loaded on it, it expands to the same diameter as the inside diameter of the consolidometer ring. In this section, the consolidation test considering the sample deformation due to stress release is presented using laboratory constituted clay samples.

3.1 Specimen Preparation

Clay samples were prepared by consolidating slurry clays remolded with water so that the water content was around twice the liquid limit. Two seabed clays passing the 0.425 mm sieve collected from Osaka bay area, N105 and H77, and the mixture of H77 and kaolinite clay powder, HK57, were used. Their liquid limits and plastic limits are shown in Table 2. Slurry clays were consolidated in a cylinder of 30 cm of diameter under 39.2 kPa (0.4 kgf/cm^2). After consolidation, the clay sample was trimmed to the specimen of 10 cm of diameter and 4.5 cm high. Five specimens were prepared and were loaded in the consolidometer ring of 10 cm of inside diameter from the preconsolidation pressure of 39.2 kPa to 156.9 kPa (1.6 kgf/cm^2) at the load increment ratio of unity.

Four specimens among the five were removed from the consolidometer ring and their diameters were quickly measured. From measured diameters, the vertical sample extension was calculated on the assumption of undrained (constant volume) conditions. Vertical extension strains obtained for three clays are 1.64-1.81% as shown in Table 3. There seems no substantial difference in extension strain between clays with different plasticities.

These four specimens of 10 cm of diameter were regarded as the stress released samples. Provided the mean extension strain be 1.8%, lateral shrinkage is 0.9%. This indicates that the consolidation test specimen trimmed from these samples with vertical extension of 1.8% should be a size of 59.46 mm of diameter and 20.36 mm of height providing the same specimen volume

Table 2. Liquid and plastic limits

Soil	w_L (%)	w_P (%)
N105 (Osaka south port)	105	35
H77 (Osaka north port)	77	33
HK57 (Osaka north port + kaolinite)	57	32

Table 3. Extension strain of laboratory constituted samples

Soil	Sample No.	Extension strain (%)	
		Range	Average
N105	000519	1.77 - 1.80	1.79
	000531	1.79 - 1.81	1.80
	000616	1.79 - 1.80	1.80
H77	991211	1.63 - 1.86	1.75
	991227	1.63 - 1.74	1.70
	001007	1.62 - 1.66	1.64
HK57	991203	1.51 - 2.01	1.78
	000119	1.76 - 1.86	1.81
	000131	1.77 - 1.79	1.78

Table 4. Size of recompression specimens

Diameter (mm)	59.8	59.6	59.4
Height (mm)	20.14	20.27	20.41

of 60 mm of diameter and 20 mm of height specified in the JGS (Japanese Geotechnical Society) consolidation test standard is employed.

Specimens were trimmed to the sizes as shown in Table 4. They have the same volume as the specimen having 20 mm height and 60 mm diameter. The specimen of 59.6 mm diameter is the most appropriate one and the rest two are for comparison. These specimens are named RCOMP (recompressed specimen). The specimen of 60 mm diameter was subjected to the ordinary standard consolidation test and is named STD. The rest one of the specimens of 10 cm diameter was continued to be consolidated to 1225.3 kPa (12.8 kgf/cm^2) at the load increment ratio of unity. Consolidation process of this specimen was regarded as the in-situ consolidation in this test series and is named INST (in-situ consolidation). Test specimens of smaller diameter than 60 mm are subjected to the following test procedure.

3.2 Consolidation Test Method

To allow lateral expansion of the specimen without frictional resistance at the specimen ends when the specimen is loaded, both ends of the specimen were lubricated with thin rubber membranes and grease as shown in Fig. 5. Pore water is drained radially through the filter papers and porous stones in the center of the loading plate and base plate. Filter papers and rubber membranes have several concentric cuts not to disturb the literal expansion of the specimen. Compressibility of both rubber membranes and filter papers is taken into account to calibrate the measured consolidation time-compression curves. Fig. 6 shows time-compression curves of 2 rubber membranes and 4 filter papers obtained in the consolidometer. This combination of materials is the actual test condition. The compression occurs instantly when they are loaded, and the creep deformation follows in a manner of straight line in semi-logarithm plotting. Fig. 7 shows the relationship of compression of the rubbers and filter papers against the load. Calculation is made by

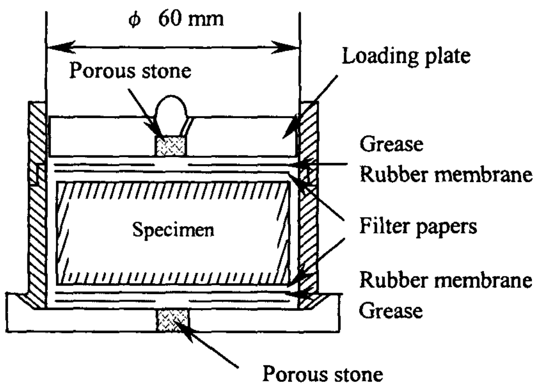

Fig. 5. Arrangement of specimen, filter paper and rubber membrane

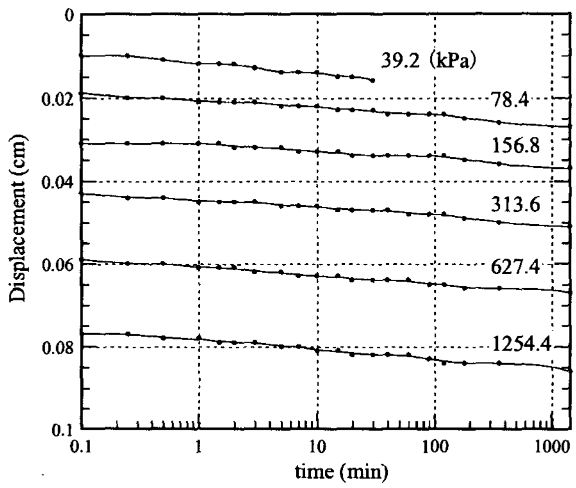

Fig. 6. Time-compression curves of filter papers and rubber membranes

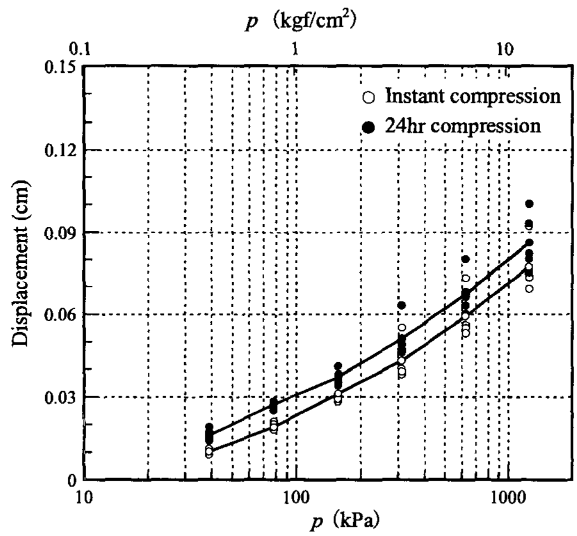

Fig. 7. Load-compression of filter papers and rubber membranes

subtracting the compression of rubbers and filter papers presented in Fig. 6 from the measured consolidation displacement at the corresponding time and consolidation load.

The initial load of 39.2 kPa (0.4 kgf/cm^2) is applied with a load duration of 30 min. After that, the loading schedule consists of the load increment ratio of unity and the load duration of 24 hr.

3.3 Test Results

Figs. 8 to 10 show comparisons of the f-log p relations obtained. Since the initial water contents of specimens (at 39.2 kPa) scatter slightly, the mean water content was employed in calculating the volume ratio. The f-log p relation by the standard test method (STD) occupies lower region, and the f-log p relation of the in-situ specimen (INST) upper region, while those of recompressed specimens (RCOMP) locate between them. Among three recompressed specimens, f-log p of the specimen with the 59.6 mm diameter is the most close to that of INST specimen. The reason why the f-log p relations by the standard test method occupy the lower region is because the larger mean principal stress due to the larger lateral stress generates the larger volume compression.

In the practical settlement calculation using the test result by the ordinary standard test method, it is recommended that the f-log p relation in the normally consolidation range be shifted to the line drown through the point of the consolidation yield stress (preconsolidation stress in this case) and the initial volume ratio. By the way, from above context, the over consolidation range obtained by the ordinary standard test method has little meaning. This correction is adopted in the Recommendation for Design of Building Foundation (Architectural Institute of Japan, 1998).

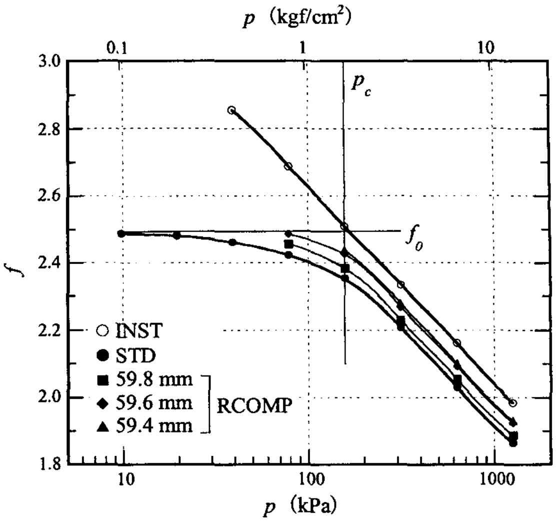

Fig. 8. Comparison of f-log p relations (N105)

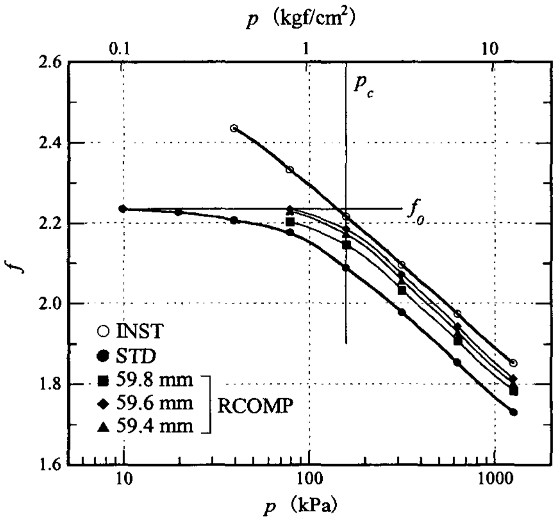

Fig. 9. Comparison of f-log p relations (H77)

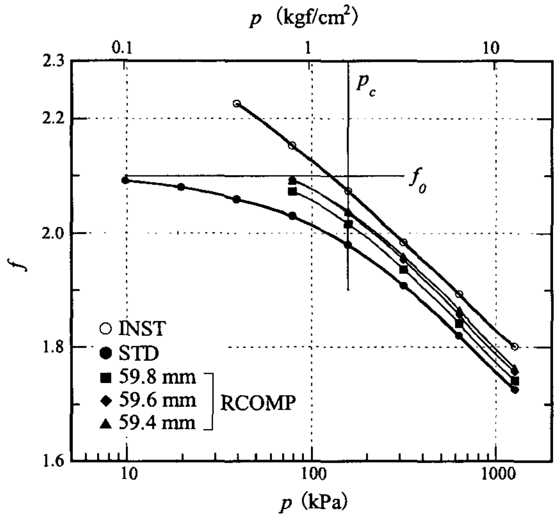

Fig. 10. Comparison of f-log p relations (HK57)

4. Consolidation Test on Field Samples

Undisturbed field samples from Obiraki shown in Table 1 are subjected to consolidation test with the consideration of stress release. Samples of O62 and O101 were used; they were homogeneous along the entire sample length. Specimen diameters are 59.8, 59.6 and 59.4 mm for recompressed specimens, together with the specimen with diameter of 60 mm for the standard test. Loading schedule for the recompressed specimens is the same as that of the laboratory constituted samples previously described.

Figs. 11 and 12 show the f-log p relations. Since the initial water contents of specimens for each sample slightly scatter (less than 1%), calculation of volume ratios was made by using the mean initial water content. The f-log p relations of recompressed specimens

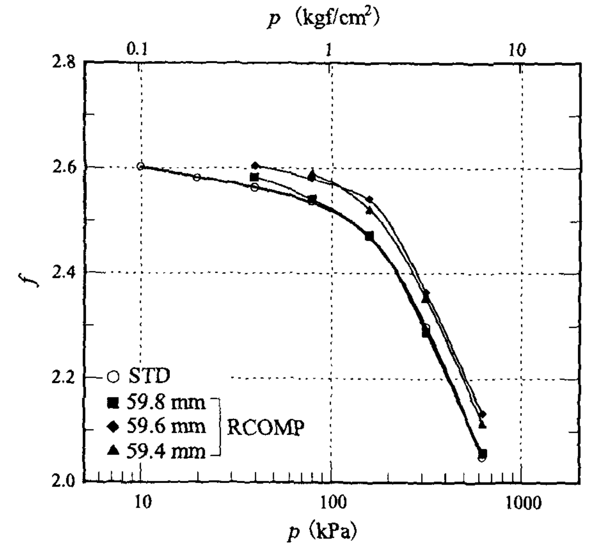

Fig. 11. Comparison of f-log p relations (Natural clay sample O62)

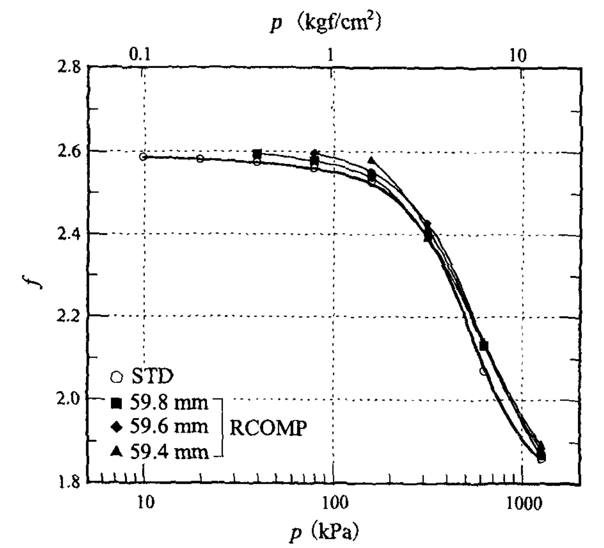

Fig. 12. Comparison of f-log p relations (Natural clay sample O101)

(RCOMP) occupy the upper region than that by the standard test method (STD). This is the same tendency as that of the laboratory constituted samples. Among the three specimens, in each figure, the specimen having diameter of 59.6 mm is the most appropriate one in accordance with the extension strain measurement; the f-log p relation of this specimen occupies the most upper region.

5. Conclusion

To reproduce the in-situ consolidation behavior, the specimen with consolidation test was smaller in diameter than the diameter inside the consolidometer ring. Therefore, the specimen expands laterlly to fit the inside of the consolidometer ring when the in-situ pressure is loaded. Several series of test showed that the f-lop p relations generated by the smaller diameter specimen than the inside diameter of consolidometer ring occupy the upper region than that by the current standard test method as expected.

In the practical settlement calculation using the test result by the standard test method, it is recommended that the f-log p relation in the normally consolidation range be shifted to the line drown through the point of the consolidation yield stress (pre-consolidation stress in this context) and the initial volume ratio. This correction is adopted in the Recommendations for Design of Building Foundation (Architectural Institute of Japan 1988).

References

1. *Interpltation and application of ground survey and soil test results* (1998), Japanese Geotechinical Society, pp.229-233 (in Japanese).
2. Kim J. and Takada N. (2001), "Consolidation test method to reflect sample deformation due to stress release", *Journal of JSCE*, No. 680 / III-55, pp.263-268 (in Japanese).
3. Kim J. (2003), Q&A, *Korean Geotechinical Society*, Vol.19, No.5, pp.55-58.
4. Takada N. and Hamada T. (1993), "Measurement of deformation of clay sample after sampling", *Proc. of annual convention of JSCE*, III-456 (in Japanese).
5. *Recommendation Design of Building Foundation* (1988), Architectural Institute of Japan, pp.137-138 (in Japanese).

(received on Jul. 2, 2004, accepted on Sep. 22, 2004)