Shear Strength of the Volcanic Coarse-Grained Soil

by
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Japan is awarded with a total of about 144 volcanos distributed over the whole country from the south to the north. In Kyushu Island there are three main volcanos, namely Unzen, Sakurajima and Aso. The eruption of these volcanos has created the need to utilize these huge amounts of debris flow deposits as a construction material.

In this paper, the physical and chemical properties of debris flow deposits of the Unzen and Sakurajima Volcanos are examined by a series of laboratory tests and the results are compared for the evaluation of these debris flow deposits as a construction material.

1. Introduction

Unzen Volcano located at Nagasaki Prefecture began steam eruptions on November 17, 1990 after 198 years dormancy. Effusion of dacite had continued to grow for about 4 years. As a result, the total amount of the lava erupted, including pyroclastic flows deposits, reached approximately $0.2km^3$[1]. These huge amounts of pyroclastic and debris flow deposits are spreaded along the Mizunashi River at the foot of Unzen Volcano.

Furthermore Sakurajima Volcano, which located at Kagoshima Prefecture in the same Kyushu, has continued to erupt until now, the Nojiri River occurs frequently debris flows.

Thus the authors carried out some research to utilize the Unzen debris flow deposits as a construction material[2),3)]. In order to utilize these volcanic debris flow deposits, in other words volcanic coarse-grained soils, for construction material, physical and chemical properties must be examined, and more mechanical properties must be grasped in advane. In this paper the authors discuss some results of a series of soil laboratory tests for two volcanic coarse-grained soils.

2. Soil Sample

2. 1 Unzen Debris Flow Deposits[2)]

Figure 1(a) shows the sampling location of the Unzen volcanic debris flow deposits. This point is located at the lower end of the Mizunashi River at the foot of Unzen Volcano. At and around this point, rocks which consists of various particle diameter, 10cm or exceed 100cm of diameter, is dotted widely, but a coarse-grained soil is accumulated mainly. For the laboratory test, the deposits within 5cm diameter was picked up as the soil sample.

2. 2 Sakurajima Volcanic Debris Flow Deposits

In order to compare the soil properties of the Unzen deposits, the Sakurajima volcanic debris flow deposits is used.

Figure 1(b) shows the sampling location of the Sakurajima volcanic debris flow deposits. This point is located at the Nojiri River mouth originated at the Sakurajima Volcano. The Nojiri River is a famous place where debris flows frequently accumulated.

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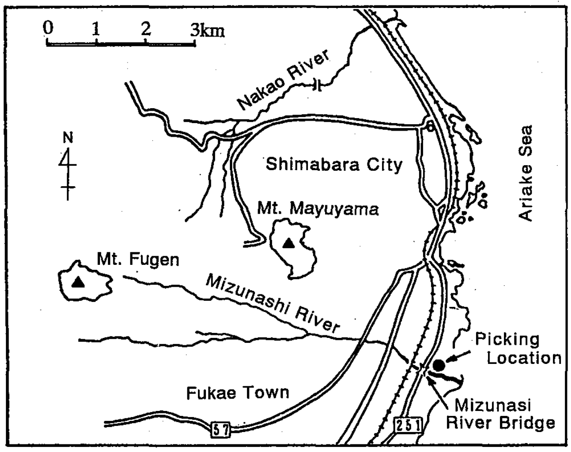


Fig. 1(a) Unzen volcanic debris flow deposits

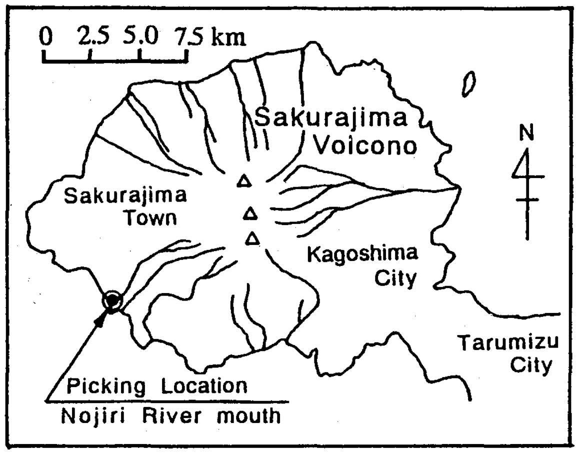


Fig. 1(b) Sakurajima volcanic debris flow deposits

3. Physical and Chemical Properties

3. 1 Density of Soil Particles

Table. 1 shows results of some density tests of the Unzen and Sakurajima deposits at in-situ and laboratory. The density of soil particles is 2.57g/cm^3 for the Unzen deposits, and 2.65g/cm^3 for the Sakurajima ones. Therefore it is clear that the density ρs for the Unzen deposits is a little bigger than the Sakurajima ones. This is considered as the difference of the chemical materials which will be mentioned later.

From the result of the density test by the sand replacement method for the Unzen deposits, the relative density Dr=56.6%, thus it can be said that the Unzen deposits is accumulated at the state of medium density.

Table 1 Density of soil particles

	Unzen	Sakurajima
Density of soil particle ρ_s	2.57g/cm^3	2.65g/cm^3
In-situ tests (the sand replacement method)		
Water contet w	5.05%	5.97%
Wet density ρ_t	1.650g/cm^3	–
Dry density ρ_d	1.569g/cm^3	–
Relative density Dr	0.566	–
Laboratory tests (JSF T161)		
Maximum density ρ_{dmax}	1.720g/cm^3	1.837g/cm^3
Maximum density ρ_{dmin}	1.408g/cm^3	1.418g/cm^3
Compaction test using a rammer (JSF T711, A-b)		
Maximum dry density ρ_{dmax}	1.849g/cm^3	–
Optimum water content w_{opt}	13.0%	–

3. 2 Grain Size

Figure 2 shows the grain size accumulation curve of the two deposits. The Unzen deposits with a maximum particle size diameter of 19mm is classified as SVg (Volcanic Sand including Gravel), which is well-graded, by Japanese Unified Soil Classification System[3]. The Sakurajima deposits particle size is a little smaller than the Unzen ones, but classified also as SVg as the Unzen ones.

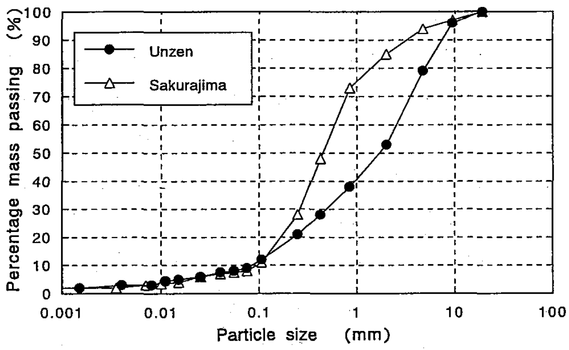


Fig. 2 Grain size accumulation curve

3. 3 Chemical Composition

Table. 2 shows results of chemical analysis of the Unzen deposits and the Sakurajima ash[4] instead of the Sakurajima deposits. For the Unzen deposits, SiO_2 is salient, and Al_2O_3 and Fe_2O_3 are much included. The Sakurajima ash is smaller by 6.51 mass% for amount of SiO_2 than the Unzen ones. For the amount of Al_2O_3 the Sakurajima ash is larger than the Unzen deposits.

The color of each deposits are whity light-brown for the Unzen one and pale black for the Sakura-

Table 2 Chemical analysis

Contents	Unzen (mass %)	Sakurajima (mass %)
SiO_2	64.60	58.09
Al_2O_3	16.50	17.97
Fe_2O_3	4.10	7.41
CaO	5.00	6.83
MgO	1.90	2.81
Na_2O	3.30	3.23
K_2O	2.18	1.55
TiO_2	0.47	0.76

jima one respectively by eye-observation. The reason behind the pale black color of the Sakurajima deposits is the presence of Fe (Iron).

4. Mechanical Properties

4. 1 Specimen Preparation and Methods

In order to obtain a mechanical properties of the volcanic coarse-grained soils, namely the Unzen and the Sakurajima deposits, two consolidated -undrained ($\overline{CU}$) and consolidated-drained (CD) triaxial compressive tests were carried out. For the Sakurajima deposits the $\overline{CU}$ test only was carried out.

The samples used in these tests were prepared by the soil passed 2mm sieve. As for density condition of the specimens, two densities of 1.57g/cm^3 and 1.76g/cm^3 on 95% of the maximum compaction density ρ_{dmax} as for in-situ density and at 95% of the maximum density respectively were adopted. In this connection, the value of in-situ density is 85% of the ρ_{dmax}.

The specimen was molded in a mold of 50mm of diameter and 125mm of height by adding a little back pressure. In order to get rid of air water was injected from lower part of the specimen to achieve complete saturation.

The cell pressure σ_c was adjusted to a value of 49 to 196 kPa respectively on consolidation process before the shear process.

The shear speed is about 1%-strain for $\overline{CU}$ test and about 0.5%-strain for CD test per minute in both test by the strain control method on the shear process.

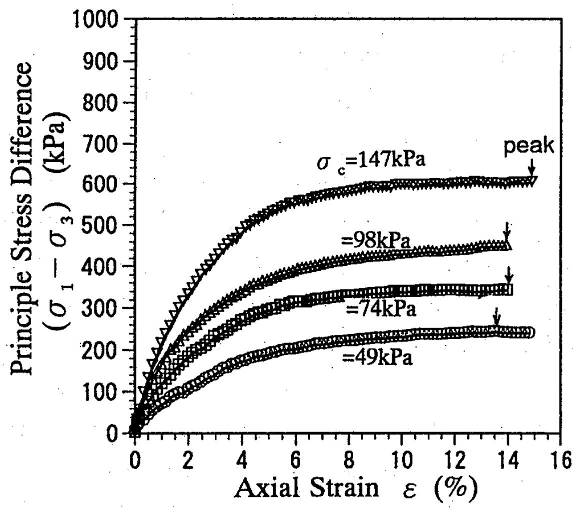
4. 2 Consolidated Undrained ($\overline{CU}$) Triaxial Test

(1) The In-situ Density Condition

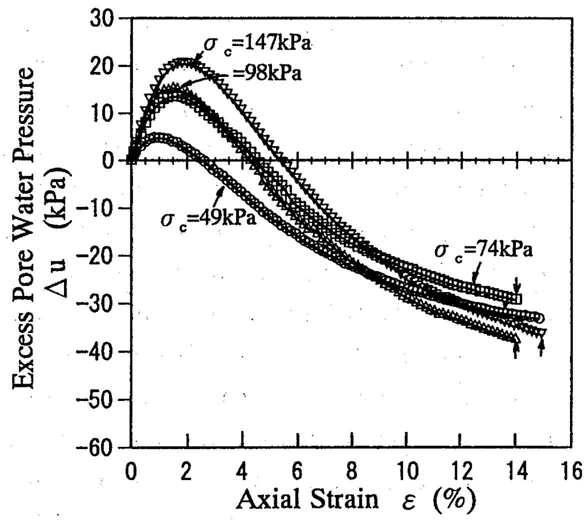
Figures 3(a), (b) and (c) show the results of $\overline{CU}$ test for the Unzen deposits at the in-situ density ρ_d =1.57g/cm^3. In Fig. 3(a) the principal stress difference (σ_1-σ_3) is rising gradually with the progress of axial strain ε. The value of (σ_1-σ_3) increases with the progress of cell pressure σ_c, but an apparent peak of (σ_1-σ_3) is not shown for each condition of σ_c. In Fig. 3(b) the excess pore water pressure Δu increases positively at early period up to about 5% of ε, after that Δu changes negatively. This change of Δu meanes that the specimen volume shrinks at early stage and dilates after that. The value of Δu increases in the direction of plus with the rising of the cell pressure σ_c.

Figures 4(a), (b) and (c) show the results of $\overline{CU}$ test for the Sakurajima deposits on the same density as Unzen ones. The value of ρ_d=1.57g/cm^3 is equivalent to the relative density ratio Dr=42.2% for the Sakurajima deposits. From the value of Dr for the Unzen deposits 56.6%, thus on comparing these two ralative density ratios, it may be seen that the Dr of the Sakurajima deposits is a little smaller than one of the Unzen deposits. In Fig. 4(a) the principal stress difference (σ_1-σ_3) is rising gradually with the progress of the axial strain ε, but the value of (σ_1-σ_3) is smaller at every σ_c than the one for the Sakurajima deposits shown in Fig. 3(a). The change of Δu in Fig. 4(b) shows the same tendency with the Unzen deposits shown in Fig. 3(b), but the change of Δu is larger in positive direction, and is smaller in negative direction. This means that the Sakurajima deposits present notably negative-dilatancy, namely the shrinking of volume.

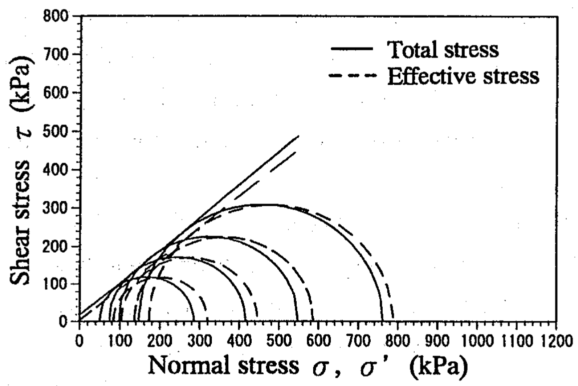
From the Mohr's stress circle which shown in Figs. 3(c) and 4(c), the angle of shear strength ϕ_{cu}, ϕ' and the cohesion c_{cu}, c' are obtained respectively. The excess pore water pressure at the peak shows the value of minus by the dailatancy of plus as mentioned above, and it is seen that ϕ' and c' for the effective stress condition are both lower than ϕ_{cu} and c_{cu} for the total stress one. These shear strength parameters are listed in Table 3.



(a) Stress-strain curve

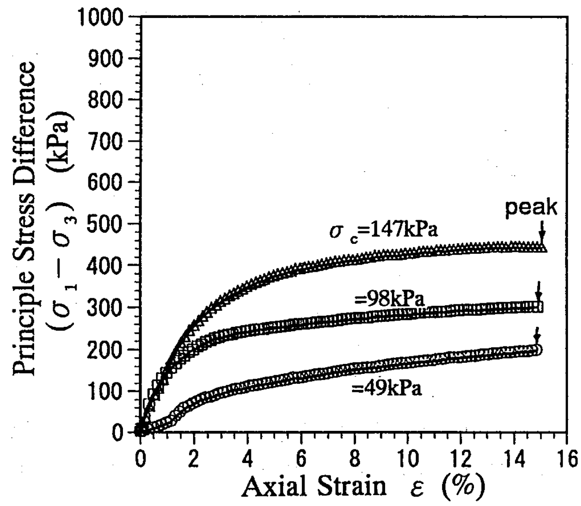


(b) Excess pore water pressure

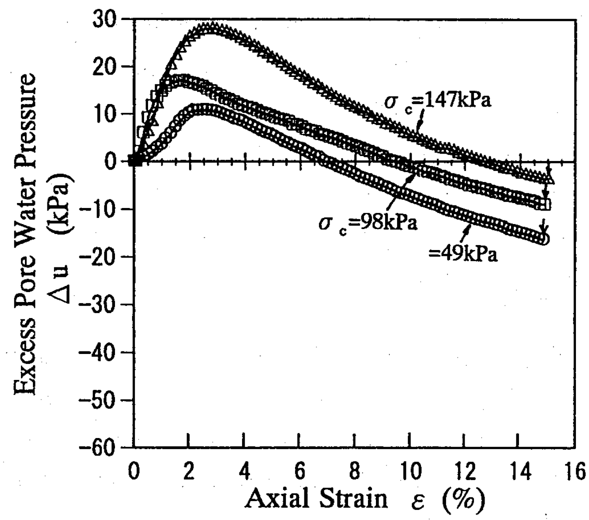


(c) Mohr's circle

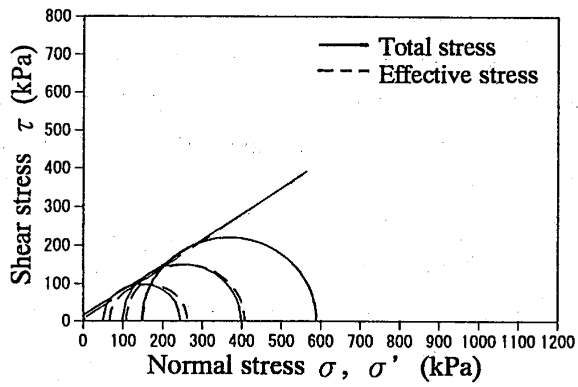
Fig. 3 Results of $\overline{CU}$ test for the Unzen deposits (In-situ density condition)



(a) Stress-strain curve



(b) Excess pore water pressure



(c) Mohr's circle

Fig. 4 Results of $\overline{CU}$ test for the Sakurajima deposits (In-situ density condition)

(2) The Compaction Density Condition

Figures 5(a), (b) and (c) show the results of $\overline{\mathrm{CU}}$ test for the Unzen deposits at the compaction density of ρ_d=1.76g/cm^3. This density is equal to the 95% of the maximum dry density by the compactin test using a rammer. Expressing in other word, this density is equivalent to the value of the relative density D_r=110.3%.

The stress-strain curve is shown in Fig. 5(a). The peak of the principal stress difference appears at the point of 4 to 6%-strain. Comparing with the result for the in-situ density condition shown in Fig. 3(a), it is seen that peaks of the principal stress difference are one and half times or twice relatively and slopes of the curve are growing at early piont.

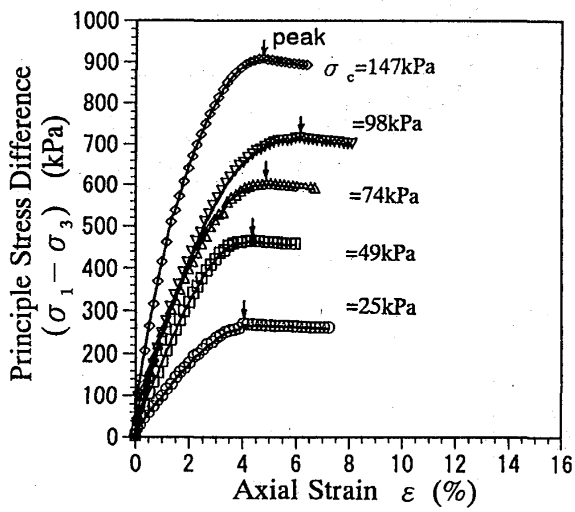
The excess pore water pressure Δu and the axial strain ε are related as shown in Fig. 5(b). This ralation seems to denote the same tendency with Fig. 3(b). Although inflection points are 1 to 2%-strain in the side of plus in Fig. 3(b), they are approximately 1%-strain in Fig. 5(b). And the value of Δu for the compaction density condition is smaller than one for in-situ density condition. It can be said that the compressive strain quantity at the shearing stage becomes small because the density of the compaction density condition is bigger than one of the in-situ density condition.

4. 3 Consolidated-Drained (CD) Triaxial Test

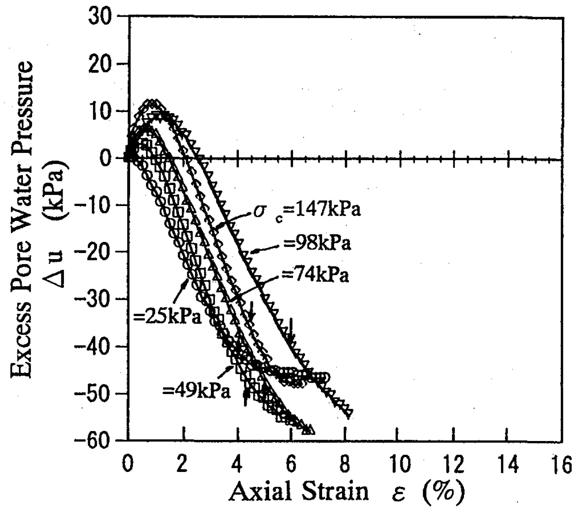
Figures 6(a) and (b) show the results of CD test for the Unzen at the in-situ density ρ_d=1.57g/cm^3. Figure 6(a) shows the relation among the principal stress difference (σ_1-σ_3), the volmetric strain ν and the axial strain ε. Considering the relationship between (σ_1-σ_3) and ε, an apparent peak of (σ_1-σ_3) is not shown for each condition of σ_c. And considering the relationship between (σ_1-σ_3) and ν, it is seen that the value of ν increases some proportionally with the progress of (σ_1-σ_3).

Table 3 Strenght parameters

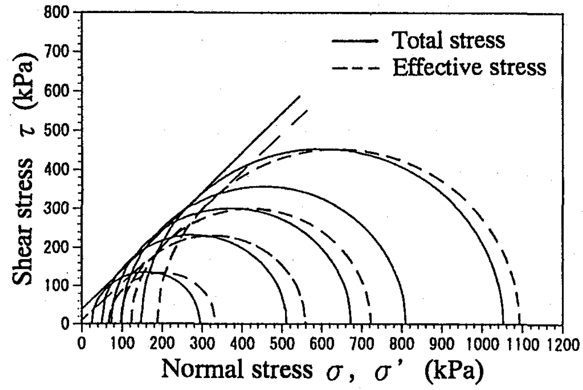
		Unzen deposits		Sakurajima deposits
Condition of tests		In-situ density ρ_d=1.57g/cm^3	Compaction density ρ_d=1.76g/cm^3	ρ_d=1.57g/cm^3
$\overline{\mathrm{CU}}$	Total stress	c_{cu}=20kPa ϕ_{cu}=40.2°	c_{cu}=40kPa ϕ_{cu}=45.6°	c_{cu}=20kPa ϕ_{cu}=32.8°
	Effective stress	c'=0 ϕ'=38.9°	c'=10kPa ϕ'=44.5°	c'=10kPa ϕ'=34.9°
CD		c_d=0 ϕ_d=40.0°	— —	— —



(a) Stress-strain curve

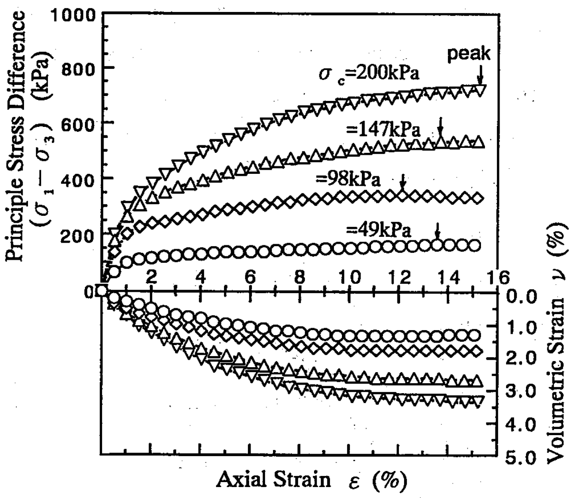


(b) Excess pore water pressure

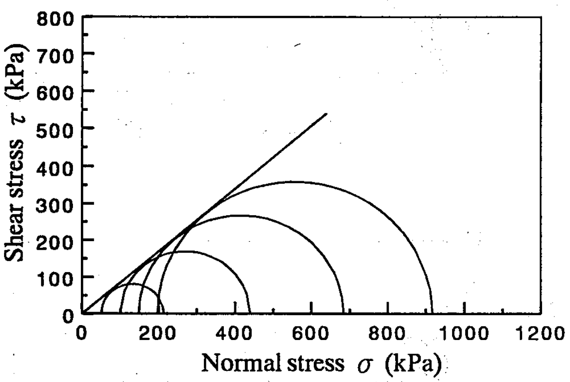


(c) Mohr's circle

Fig. 5 Results of $\overline{\mathrm{CU}}$ test for the Unzen deposits (Compaction density condition)



(a) Relation between stress and volmetric strain



(b) Mohr's circle

Fig. 6 Results of CD test for the Unzen deposits (In-situ density condition)

Figure 6(b) shows the Mohr's stress circle for the CD test, and the obtained strength paremeters are listed in Table 3.

4. 4 Strength Parameters

Table 3 shows the strength parameters obtained by the $\overline{\text{CU}}$ tests and the CD test as mentioned above. Althouth the relative density Dr is medium (56.6%) for the Unzen deposits on the in-situ density condition, the angle of shear resistance ϕ_{cu} for the $\overline{\text{CU}}$ test shows the high value as compared with the general sand. For the Sakurajima deposits on the same density condition, ϕ_{cu} is 32.8°. This value is smaller than one of the Unzen deposits, and it is considered that this reason is associated with the difference of the relative density. The ϕ_{cu} of the compaction density condition is bigger by 5.4° than the one of the in-situ density, thus the ϕ_{cu} of the compaction density condition shows very big value. The cohesion is produced by rising the density for the specimen, which is considered that the apparent cohesion occurs by the interlocking effect among soil particles.

And more as compared with the ϕ' of the $\overline{\text{CU}}$ and the ϕ_d of the CD test, it is seen that the ϕ_d is bigger by about 1° than the ϕ' as same as a general tendency. The valve of ϕ_d=40.0° agrees with that obtained by Taira et al[5].

5. Conclusions

As a result of this reseach, we can provide some useful knowledges in the following:

(1) The particle size of the Unzen volcanic deposits is a little bigger compared with those of the Sakurajima ones, but they are classified as SVg (Volcanic Sand including Gravel), which is considered as a well graded sand, by Japanese Unified Soil Classification System in either case.

(2) From the results of the chemical analysis, the SiO_2 content of the Unzen deposits is 6.51% bigger than the Sakurajima deposits, that the Al_2O_3 content of the Sakurajima ash is bigger than that of the Unzen deposits.

(3) From the results of $\overline{\text{CU}}$ tests at the in-situ density ρ_d=1.57g/cm^3 for the Unzen and the Sakurajima deposits, the value of the principal stress difference (σ_1-σ_3) increases with the progress of cell pressure σ_c but an apparent peak of (σ_1-σ_3) is not shown for each condition of σ_c. And the dilatancy is positive at early shear regardless its medium density. Althouth the relative density Dr is medium of 56.6% for the Unzen deposits, the angle of shear resistance ϕ_{cu} for the $\overline{\text{CU}}$ test shows high value 40.2° as compared with the general sand. For the Sakurajima deposits at the same density condition, ϕ_{cu} is 32.8°.

(4) From the results of $\overline{\text{CU}}$ tests on the condition of the compaction density ρ_d=1.76g/cm^3 for the Unzen deposits, comparing with the result for the in- situ density condition, which is seen that peaks of the (σ_1-σ_3) are one and half times or twice relatively and slopes of the curve are growing at early piont for the compaction density condition. The cohesion is some produced by rising the density for

the specimen, this is considered that the apparent cohesion occures by a interlocking effect among soil particles.

(5) From the results of CD test for the Unzen deposits on the condition of the in-situ density, an apparent peak of (σ_1-σ_3) is not shown for each condition of σ_c. As compared with the ϕ' of the $\overline{\text{CU}}$ and the ϕ_d of the CD test, it is seen that the ϕ_d is bigger by about 1° than the ϕ' as same as a general tendency of ϕ_d=40.0°.

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