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<td>Gotoh, Keinosuke; Yamanaka, Minoru; Abdelhadi, Monther</td>
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Shear Strength of the Volcanic Coarse-Grained Soil

by
Keinosuke GOTOH*, Minoru YAMANAKA* and Monther ABDELHADI**

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 0.2km³. 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. 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 advance. 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
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 originat-ed at the Sakurajima Volcano. The Nojiri River is a famous place where debris flows frequently accumulated.

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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/cm³ for the Unzen deposits, and 2.65g/cm³ 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

<table>
<thead>
<tr>
<th></th>
<th>Unzen</th>
<th>Sakurajima</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of soil particle ρs</td>
<td>2.57g/cm³</td>
<td>2.65g/cm³</td>
</tr>
<tr>
<td>In-situ tests (the sand replacement method)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water content w</td>
<td>5.05%</td>
<td>5.97%</td>
</tr>
<tr>
<td>Wet density ρt</td>
<td>1.650g/cm³</td>
<td>-</td>
</tr>
<tr>
<td>Dry density ρd</td>
<td>1.569g/cm³</td>
<td>-</td>
</tr>
<tr>
<td>Relative density Dr</td>
<td>0.566</td>
<td>-</td>
</tr>
<tr>
<td>Laboratory tests (JSF T161)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum density ρmax</td>
<td>1.720g/cm³</td>
<td>1.837g/cm³</td>
</tr>
<tr>
<td>Maximum density ρmin</td>
<td>1.408g/cm³</td>
<td>1.418g/cm³</td>
</tr>
<tr>
<td>Compaction test using a rammer (JSF T711, A-b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum dry density ρmax</td>
<td>1.849g/cm³</td>
<td>-</td>
</tr>
<tr>
<td>Optimum water content wopt</td>
<td>13.0%</td>
<td>-</td>
</tr>
</tbody>
</table>

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. The Sakurajima deposits particle size is a little smaller than the Unzen ones, but classified also as SVg as the Unzen ones.

3.3 Chemical Composition

Table. 2 shows results of chemical analysis of the Unzen deposits and the Sakurajima ash instead of the Sakurajima deposits. For the Unzen deposits, SiO₂ is salient, and Al₂O₃ and Fe₂O₃ are much included. The Sakurajima ash is smaller by 6.51 mass% for amount of SiO₂ than the Unzen ones. For the amount of Al₂O₃ the Sakurajima ash is larger than the Unzen ones.

The color of each deposits are whity light-brown for the Unzen one and pale black for the Sakura-
Table 2 Chemical analysis

<table>
<thead>
<tr>
<th>Contents</th>
<th>Unzen (mass %)</th>
<th>Sakurajima (mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>64.60</td>
<td>58.09</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.50</td>
<td>17.97</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>4.10</td>
<td>7.41</td>
</tr>
<tr>
<td>CaO</td>
<td>5.00</td>
<td>6.83</td>
</tr>
<tr>
<td>MgO</td>
<td>1.90</td>
<td>2.81</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.30</td>
<td>3.23</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.18</td>
<td>1.55</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.47</td>
<td>0.76</td>
</tr>
</tbody>
</table>

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 (CU) and consolidated-drained (CD) triaxial compressive tests were carried out. For the Sakurajima deposits the 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/cm³ and 1.76g/cm³ on 95% of the maximum compaction density \( \rho_{\text{dmax}} \) 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 \( \rho_{\text{dmax}} \).

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 \( \sigma_c \) 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 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 (CU) Triaxial Test

(1) The In-situ Density Condition

Figures 3(a), (b) and (c) show the results of CU test for the Unzen deposits at the in-situ density \( \rho_d = 1.57 \text{g/cm}^3 \). In Fig. 3(a) the principal stress difference \( (\sigma_1-\sigma_3) \) is rising gradually with the progress of axial strain \( \varepsilon \). The value of \( (\sigma_1-\sigma_3) \) increases with the progress of cell pressure \( \sigma_c \), but an apparent peak of \( (\sigma_1-\sigma_3) \) is not shown for each condition of \( \sigma_c \).

In Fig. 3(b) the excess pore water pressure \( \Delta u \) increases positively at early period up to about 5% of \( \varepsilon \), after that \( \Delta u \) changes negatively. This change of \( \Delta u \) means that the specimen volume shrinks at early stage and dilates after that. The value of \( \Delta u \) increases in the direction of plus with the rising of the cell pressure \( \sigma_c \).

Figures 4(a), (b) and (c) show the results of CU test for the Sakurajima deposits on the same density as Unzen ones. The value of \( \rho_d = 1.57 \text{g/cm}^3 \) is equivalent to the relative density ratio \( \text{Dr}=42.2\% \) for the Sakurajima deposits. From the value of Dr for the Unzen deposits 56.6%, thus on comparing these two relative 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. 3(a) the principal stress difference \( (\sigma_1-\sigma_3) \) is rising gradually with the progress of the axial strain \( \varepsilon \), but the value of \( (\sigma_1-\sigma_3) \) is smaller at every \( \sigma_c \) than the one for the Sakurajima deposits shown in Fig. 3(a). The change of \( \Delta u \) in Fig. 4(b) shows the same tendency with the Unzen deposits shown in Fig. 3(b), but the change of \( \Delta u \) 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 \( \phi_{\text{cu}} \), \( \phi' \) and the cohesion \( c_{\text{cu}} \), \( c' \) are obtained respectively. The excess pore water pressure at the peak shows the value of minus by the dilatancy of plus as mentioned above, and it is seen that \( \phi' \) and \( c' \) for the effective stress condition are both lower than \( \phi_{\text{cu}} \) and \( c_{\text{cu}} \) for the total stress one. These shear strength parameters are listed in Table 3.
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Fig. 3 Results of CU test for the Unzen deposits (In-situ density condition)

Fig. 4 Results of 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 CU test for the Unzen deposits at the compaction density of $\rho_d = 1.76g/cm^3$. 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 point.

The excess pore water pressure $\Delta u$ and the axial strain $\epsilon$ are related as shown in Fig. 5(b). This relation 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 $\Delta u$ 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 $\rho_d = 1.57g/cm^3$. Figure 6(a) shows the relation among the principal stress difference $(\sigma_1 - \sigma_3)$, the volumetric strain $\nu$ and the axial strain $\epsilon$. Considering the relationship between $(\sigma_1 - \sigma_3)$ and $\epsilon$, an apparent peak of $(\sigma_1 - \sigma_3)$ is not shown for each condition of $\sigma_0$. And considering the relationship between $(\sigma_1 - \sigma_3)$ and $\nu$, it is seen that the value of $\nu$ increases some proportionally with the progress of $(\sigma_1 - \sigma_3)$.

![Stress-strain curve](image)

(a) Stress-strain curve

![Excess pore water pressure](image)

(b) Excess pore water pressure

![Mohr's circle](image)

(c) Mohr's circle

Table 3 Strenght parameters

<table>
<thead>
<tr>
<th>Condition of tests</th>
<th>Unzen deposits $\rho_d = 1.57g/cm^3$</th>
<th>Sakurajima deposits $\rho_d = 1.76g/cm^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total stress</td>
<td>$c_{ua} = 20kPa$ $\phi_{ua} = 40.2^\circ$</td>
<td>$c_{ua} = 40kPa$ $\phi_{ua} = 45.6^\circ$</td>
</tr>
<tr>
<td>Effective stress</td>
<td>$c' = 10kPa$ $\phi' = 38.9^\circ$</td>
<td>$c' = 10kPa$ $\phi' = 44.5^\circ$</td>
</tr>
<tr>
<td>CD</td>
<td>$c_d = 0$ $\phi_d = 40.0^\circ$</td>
<td>$-$</td>
</tr>
</tbody>
</table>
Axial Strain $\varepsilon$ (%)

(a) Relation between stress and volmetric strain

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

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 $\phi'$ of the $C\bar{U}$ and the $\phi_d$ of the CD test, it is seen that the $\phi_d$ is bigger by about 1° than the $\phi'$ as same as a general tendency. The valve of $\phi_d=40.0°$ agrees with that obtained by Taira et al.

5. Conclusions

As a result of this research, 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 $C\bar{U}$ tests at the in-situ density condition, the value of the principal stress difference $(\sigma_1-\sigma_3)$ increases with the progress of cell pressure $\sigma_c$ but an apparent peak of $(\sigma_1-\sigma_3)$ is not shown for each condition of $\sigma_c$. And the dilatancy is positive at early shear regardless its medium density. Although the relative density $Dr$ is medium (56.6%) for the Unzen deposits on the in-situ density condition, the angle of shear resistance $\phi_{cu}$ for the $C\bar{U}$ test shows the high value as compared with the general sand. For the Sakurajima deposits on the same density condition, $\phi_{cu}$ 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 $\phi_{cu}$ of the compaction density condition is bigger by 5.4° than the one of the in-situ density, thus the $\phi_{cu}$ of the compaction density condition shows very big value.

Table 3 shows the strength parameters obtained by the $C\bar{U}$ tests and the CD test as mentioned above. Although the relative density $Dr$ is medium (56.6%) for the Unzen deposits on the in-situ density condition, the angle of shear resistance $\phi_{cu}$ for the $C\bar{U}$ test shows the high value as compared with the general sand. For the Sakurajima deposits on the same density condition, $\phi_{cu}$ 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 $\phi_{cu}$ of the compaction density condition is bigger by 5.4° than the one of the in-situ density, thus the $\phi_{cu}$ of the compaction density condition shows very big value.

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(4) From the results of $C\bar{U}$ tests on the condition of the compaction density $\rho_v=1.76g/cm^3$ for the Unzen deposits, comparing with the result for the in-situ density condition, which is seen that peaks of the $(\sigma_1-\sigma_3)$ are one and half times or twice relatively and slopes of the curve are growing at early point for the compaction density condition. The cohesion is some produced by rising the density for
the specimen, this is considered that the apparent cohesion occurs by an 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 \( (\sigma - \sigma_d) \) is not shown for each condition of \( \sigma_c \). As compared with the \( \phi' \) of the CU and the \( \phi_d \) of the CD test, it is seen that the \( \phi_d \) is bigger by about 1° than the \( \phi' \) as same as a general tendency of \( \phi_d = 40.0° \).

Acknowledgment
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References