新潟大災害研年報，第23号（2001年）
Ann. Rep. Saigai-ken, Niigata Univ., №23(2001)

# Engineering properties of the soil around Nishiyama and Kompirayama after the eruption at Mount Usu in 2000

by
Binod TIWARI*1, Hideaki MARUI*2, Osamu SATO*2, Hiromitsu YAMAGISHI*3, Naoki WATANABE*2, Gen FURUYA*2, Koji SUZUKI*2, Kazunari INABA*1
Kazuo SHIMURA*4 and Fumiaki YAMAZAKI*4

**Abstract**

**Mount Usu is erupting frequently from 18th century. Comparing the recent eruptions, the property of the eruptrd materials have been found different in various eruption periods. The major eruption in 1978 had been concentrated in Mount Koushu and Mount Oushu. However, the eruption of 2000 had been localized around Nisiyama and Kompirayama area. The soil samples collected from Nishiyama and Kompirayama had shown slight difference in strength and other soil physical properties. The mineralogical properties also show the possibility of different rocks in the vicinity of Nishiyama and Kompirayama. The strength of the soil and the mineralogical property of the volcanic ash in 1978 and 2000 eruptions show considerable difference in the soil properties. Due to the difference in nature of eruption and high clay content in Nishiyama, it exhibited less shear strength than the soil from Ousu in 1978.**

**The density of the soil near crater of Nishiyama is very low with high silt content. This clarifies the possibility of mass movement in various forms after the rainfall. Recalling the triggering of huge mass movement at mount Usu after 1978 eruption, the possible mass movement there in future can not be neglected, based on the low strength, existing land deformations and potential topography for slides.**

***Keywords*** : *Mount Usu, Volcanic eruption, Shear strength, Consistency limit, X-ray diffraction*

## 1. Introduction

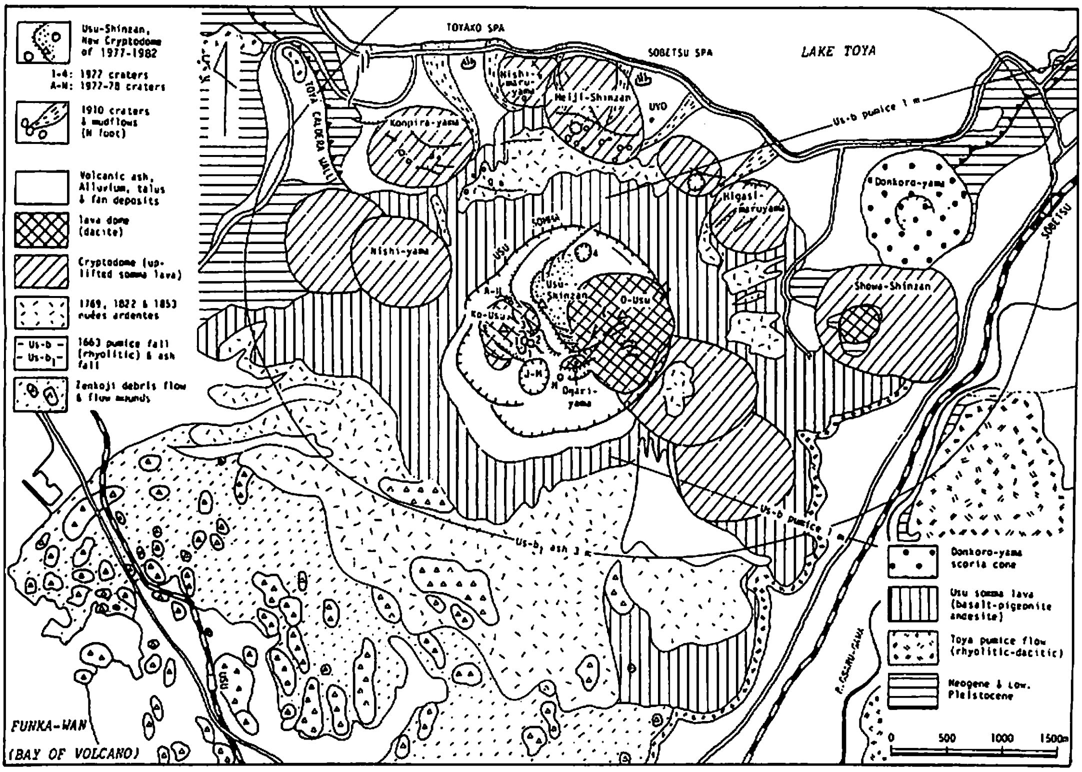
Series of eruptions in Mount Usu and the damages to the infrastructure as well as settlement had left great panic to the society in each eruptions (Hirose and Tajika, 2000). Although the volcanic eruption in March 31, 2000 was occurred after 23 years of earlier eruption, which was 10 years earlier than the experienced frequency in the past (Mimatsu Memorial hall, 1992), loss of lives could have been saved due to the efficient disaster preparedness. However, due to the evolution of shallower layer of the earth crust, mixed with the gas emitted by the solidifies magma, the materials after eruption were different than that in 1978 eruption. This fact become the matter of great interest for the researchers in order to know the differences between the soil physical properties of erupted soil between those two eruptions. Besides, the nature of erupted materials in Nishiyama and Kompirayama has been observed different. The soil physical properties of those eruptions might be helpful to know

*1 Graduate School of Science and Technology, Niigata University *2 Research Institute for Hazards in Snowy Areas, Niigata University
*3 Department of environmental Science, Niigata University *4 Shin Engineering Consultants Co. LTD.

the underneath geology of nearby area. Therefore, soil samples have been collected from the depositions of fresh eruptions as well as deposits along the stream after mass movement in Nishiyama and Kompirayama.

## 2. Previous history of soil testing

Sassa (1986) had conducted the in-situ soil test for the samples from the slope, talus and torrent deposit of Kousu torrent (Fig. 1). Shear test had been conducted with the 20 ㎝ ×20㎝ ×20㎝ direct shear box. The dry densities of the collected samples and peak shear stresses have been compiled in Table 1. The soil sampling had been done from August 2-12, 1981, about 2 years after the active eruption. Many pyroclastic flows might have occurred and huge debris flow might have affected the community after rainfall. However, the soil test data during that time can be used to compare the types of soil and their strength between the 1978 and 2000 eruptions.




**(Figure copied from Showa Shinzan Volcanic Museum)**

Figure 1 : Locations of various craters within mount Usu

## 3. Soil sampling locations and methodology

Although the area was still under active explosion during the field visit (October 16 and 17, 2000), almost 6 months after the beginning of the eruption, the observation team had reached up to the main crater. The deposition of erupted material was very sticky and

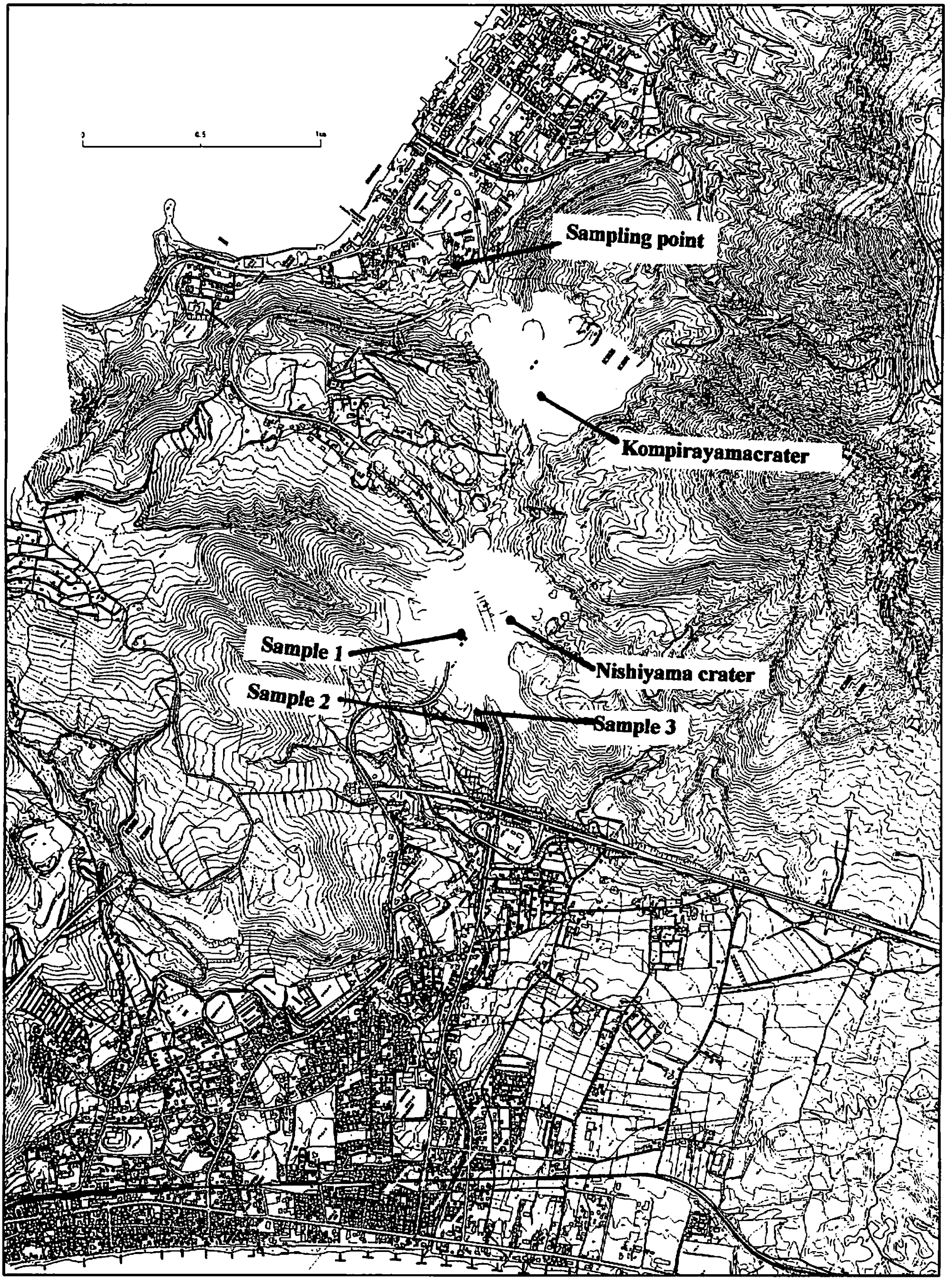



Figure 2 : Location of sampling points in Nishiyama and Kompirayama

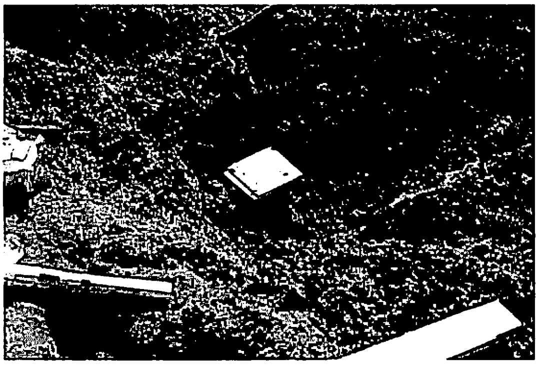


Photo 1 : Soil sampling point at Nishiyama 1, near Nishiyama crater

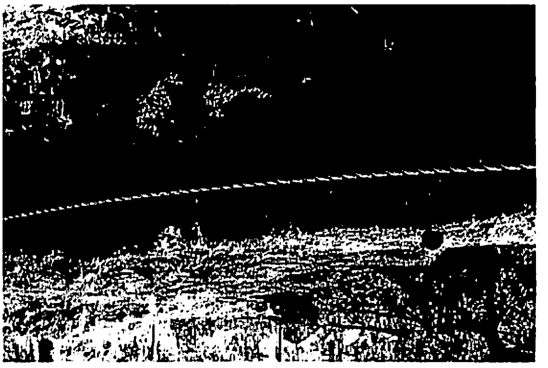


Photo 2 : Soil sampling point at the volcanic mass deposition area in Kompirayama

behaved as cushion at most of the locations near the crater. The deposited silty materials had heavily been stuck under the field boots, showing impermeability and less shear resistance. However, the deposition at several hundred meters downstream after hot mudflow and material at streambed exhibited slight difference in color and adhesion. The addition of coarser material after the flow could be clearly observed during field visit.

In the similar manner with Sassa (1986), soil samples had been collected from the deposit adjacent to the crater (Photo 1), from the place where hot mudflow was deposited on the slope and from the stream bank deposition (Fig. 2). Those samples had been collected to observe the nature of the erupted materials immediately after the eruption, after flowing some distance along the slope and after being deposited at the stream bank, after traveling along with the stream flow.

Although the color of the erupted material in Kompirayama exhibited slight difference in color to that of Nishiyama, the adhesiveness and permeability seemed similar by necked eye observation. To compare the strength of hot mudflow in Nishiyama with Kompirayama eruption, one sample had been collected from the deposited mudflow at the downstream of Kompirayama crater (Photo 2).

In all the samples i. e. sample 1 near the crater of Nishiyama, sample 2 at the stream deposit of Nishiyama and sample 3 at the hot mudflow deposits along the slope of Nishiyama eruption as well as sample from Kompirayama eruption, three undisturbed soil samples for each locations had carefully been collected to measure the densities, water content and degree of saturation. Besides, more than 10kg of each sample have been collected in the plastic bag to conduct further soil tests.

## 4. Soil testing procedure

The main objective of the soil testing was to study the characteristics of the deposited mass at various locations and to compare it with the shear strength of the deposited soil during 1978 volcanic eruption around Kousu area.

The field density ($\gamma t$), water content ($\omega$), void ratio, degree of saturation (S), dry density ($\gamma d$), specific gravity and consistency limit have been measured in the laboratory, using prevailing code of practice. Besides, the particle size analysis by sieve and hydrometer analysis had also been done.

To compare the residual shear strength of the collected soil samples, soil samples passing through 2㎜ sieve has been sheared in the ring shear machine. The peak and residual shear strengths have been measured in the modified Bishop type ring shear machine (Bishop et al. 1971). Besides, the direct shear test by the similar equipment and method, used by sassaer al. to measure the in situ shear strength of the deposited debris flow in 1981 after 1978 volcanic eruption, has been conducted for the collected samples of this year too. To compare the mineralogical composition of the soil samples, x-ray diffraction has been done for all the samples, volcanic ash and the volcanic ash of 1978 eruption.

## 5. Laboratory Test Result

Table 1 : Physical properties of the tested soil samples

| Property | N1 | N2 | N3 | K1 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|
| Water content, $\omega$, % | 42.5 | 25.6 | 25.0 | 25.5 | — | — | — |
| Field unit weight, $\gamma$, t/m3 | 1.48 | 1.85 | 1.87 | 1.93 | — | — | — |
| void ratio | 1.26 | 0.62 | 0.61 | 0.66 | — | — | — |
| Dry unit weight, $\gamma$d, t/m3 | 1.04 | 1.47 | 1.50 | 1.54 | 1.17-1.2 | 1.01-1.19 | 1.39-1.53 |
| Saturated unit weight, $\gamma$, sat, t/㎥ | 1.60 | 1.85 | 1.87 | 1.93 | — | — | — |
| Degree of saturation, S, % | 79.1 | 98.9 | 98.6 | 98.8 | — | — | — |
| Specific gravity | 2.35 | 2.38 | 2.41 | 2.55 | | | |

N : Nishiyama K : Kompirayama S : Sample by Sassa et al.

Table 2 : Particle size analysis of tested soil samples

| Property | N1 | N2 | N3 | K1 |
|---|---|---|---|---|
| % of clay | 6.2 | 8.0 | 6.1 | 6.0 |
| % of silt | 46.5 | 26.7 | 33.9 | 32.2 |
| % of fine sand | 32.3 | 20.9 | 26.3 | 13.4 |
| % of coarse sand | 7.6 | 17.6 | 20.7 | 15.5 |
| % of gravel | 7.4 | 26.8 | 13.0 | 32.9 |

N : Nishiyama K : Kompirayama

To compare the soil property at various locations, various types of laboratory tests have been conducted. The soil sample near the crater showed very high water content than other samples in Nishiyama and Kompirayama (Table 1). The water content at other locations was similar. Likewise, field density of the sample near crater of Nishiyama had been found to be very low compared to other samples (Table 1). Although the soil samples from Kompirayama deposit had highest field density, it was only slightly higher than the samples from other locations of Nishiyama. The void ratio of the sample near the crater of Nishiyama had been measured to be almost double of the other samples. The water content, field density and void ratio had been used to calculate dry unit weight, saturated unit weight and degree of saturation. Dry unit weight of the sample near Nishiyama crater was very low, slightly higher than water. The dry unit weight of other samples did not vary much. Degree of saturation of samples from hot mudflow and stream bank at Nishiyama and debris deposition at Kompirayama were almost saturated. However, the sample near crater of Nishiyama was partially saturated with 79% saturation. This had decreased the saturated unit weight of the deposition near crater to 1.6t/㎥. The saturated unit weights of other samples were almost similar. Specific gravity of the soil from hot mudflow is similar to the average of the other two samples of Nishiyama. In the other hand, Kompirayama deposit showed highesr specific gravity.

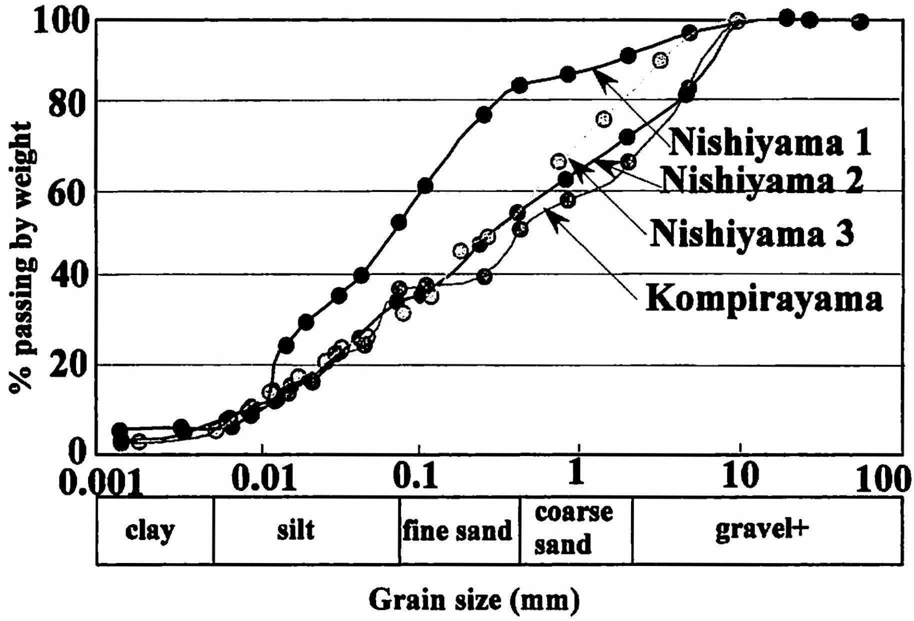



Figure 3 : Particle size distribution curve for the soil samples

The proportion of clay in the sampled soil had been measured to be almost similar in all samples of Nishiyama and Kompirayama (Table2). However, the proportion of silt in the soil sample near the crater of Nishiyama has been measured to be almost half of the total sample, considerably high compared to other samples (Fig. 3). The silt content in the sample near stream bank is lowest of the all in Nishiyama. However, the silt content in the Kompirayama deposit had been measured to be similar to the hot mudflow in Nishiyama. However, proportion of sand has not been differed in all the samples considerably although hot mudflow in Nishiyama and debris deposit in Kompirayama showed higher percentage of sand than the other samples. As expected, the percentage of gravel in stream deposit has been measured highest among all samples in Nishiyama. The proportion of gravel in Kompirayama has been found highest of all the collected samples. The textural classification shows sample 2 and 3 of Nishiyama and sample from Kompirayama as sandy loam and sample from Nishiyama 1 as silty loam (Fig. 4).

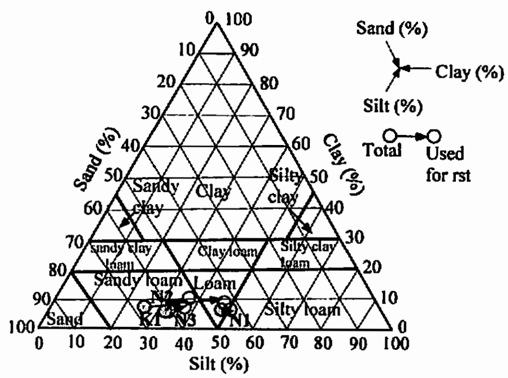



Figure 4 : Textural classification of tested soil samples

Table 3 : Consistency limit of tested soil samples

| Property | N1 | N2 | N3 | K1 |
|---|---|---|---|---|
| Plastic limit, % | 23.2 | 23.9 | 22.5 | 25.9 |
| Liquid limit, % | 65.8 | 44.6 | 37.9 | 47.8 |
| Plasticity Index, % | 42.6 | 20.7 | 15.4 | 21.9 |

N : Nishiyama K : Kompirayama

The plasticity analysis showed not so large variation in plastic limits of all samples (Table 3). However, the liquid limit of the sample near crater of Nishiyama eruption has been found to be very high compared to other samples. Deposition along the stream bank exhibited larger liquid limit than the hot mudflow. However, liquid limit of Kompirayama deposition was higher than that of stream deposition at Nishiyama. The plasticity characteristics of the sample are close to A line (Fig. 5) showing sample 2 and 3 of Nishiyama and sample from Kompirayama with low plasticity and Nishi-yama 1 with high plasticity.

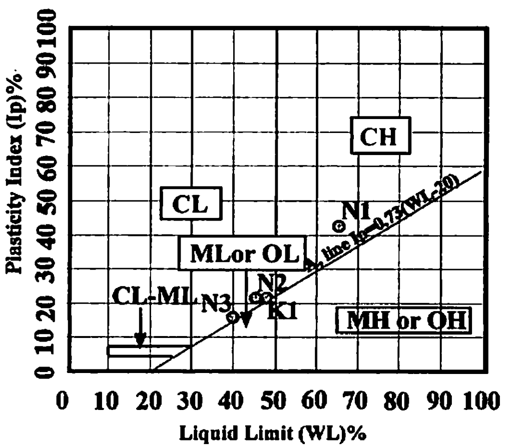



Figure 5 : Plasticity chart of the tested soil samples

The mineralogical analysis through x-ray diffraction shows similar types of minerals in all the samples (Table 4). However, the proportion of quartz in the sample near crater of Nishiyama and Kompirayama is almost half of other two samples of Nishiyama (Fig. 6). The percentage of quartz in Kompirayama is slightly less than the sample near the crater of Nishiyama. However, proportion of feldspar in Kompirayama is about 15% more than that of the sample near Nishiyama crater. The proportion of feldspar in other two samples of Nishiyama has been measured to be almost 60% of that near crater. Although the proportion of smektite in the soil sample from Nishiyama is highest among the clay minerals, proportion of kaolinite is also relatively high i.e. only about 3% less than smektite. Although proportion of smektite in the soil sample near the crater of Nishiyama is similar to that of Kompirayama, no Kaolinite had been found in the later. However, proportion of pyrite in all samples of Nishiyama and Kompirayama has been measured to be similar. The proportion of all the materials near crater of Nishiyama has been observed to be similar to that of volcanic ash during eruption in 2000, that had been collected from the roof of damaged kinner garden, although slight variation of individual minerals have been measured. Compared to the volcanic ash of the eruption in 1978, the color of the volcanic ash in 2000 was different. The former was white whereas the later was dark gray. The mineralogical composition of the volcanic ash in 1978 eruption had been measured to be almost all of volcanic glass with small proportion of feldspar as the erupted material was pumice in general.

The peak shear strength of the soil samples has been measured by both ring shear apparatus and the direct shear box that had been used by Sassa et al. in 1981. Due to the lack of sample volume for stream bank and hot mud flow in Nishiyama, direct shear test could not be conducted for them. Direct shear test for the similar field density in Nishiyama 1 and

Table 4 : Mineralogical constitution of tested soil samples

| Mineral | N1 | N2 | N3 | K1 | VA, 2000 | VA, 1978 |
|---|---|---|---|---|---|---|
| quartz | 21 | 40 | 43 | 20 | 23 | 0 |
| feldspar | 43 | 25 | 27 | 59 | 47 | 100 |
| smektite | 17 | 15 | 16 | 18 | 19 | 0 |
| kaolinite | 15 | 12 | 11 | 0 | 6 | 0 |
| pyrite | 4 | 4 | 3 | 4 | 5 | 0 |

N : Nishiyama K : Kompirayama VA : Volcanic ash

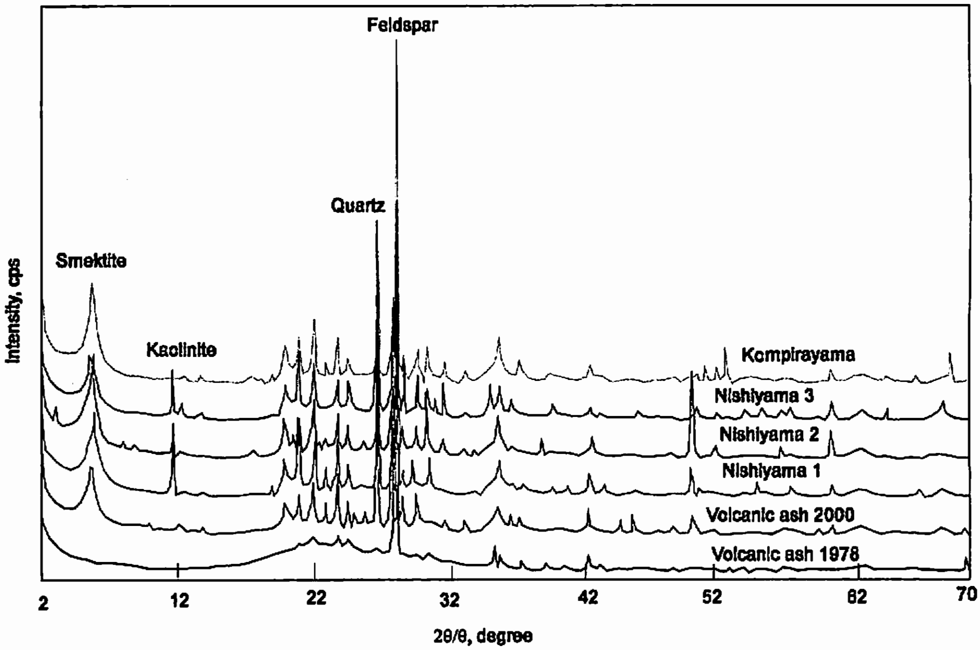



Figure 6 : X-ray diffraction result of the soil samples from mount Usu volcanic area

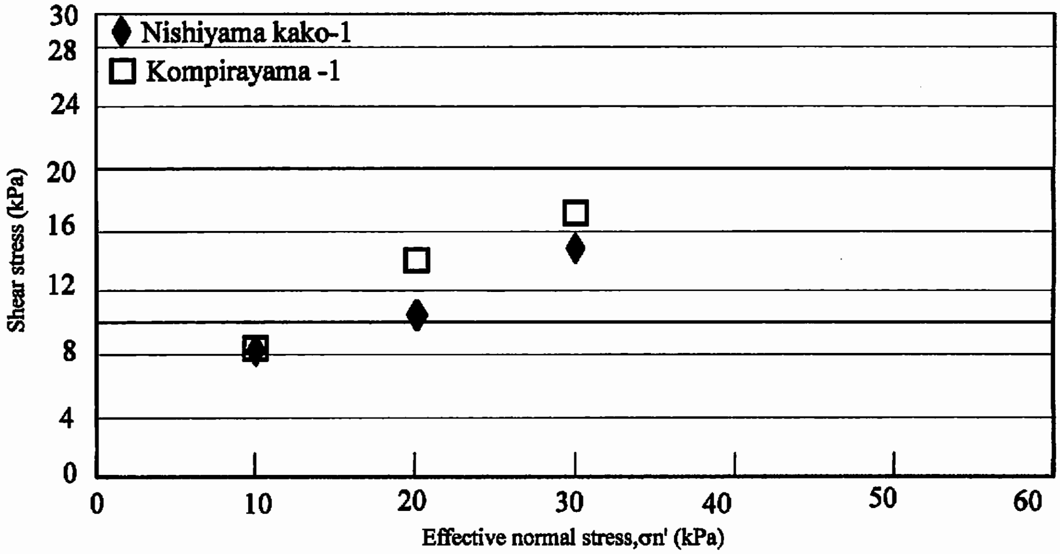



Figure 7 : Peak shear envelope of soil samples by direct shear test

Table 5 : Peak shear strength of the tested soil samples

| Property | N1 | N2 | N3 | K1 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|
| Peak c, direct shear test, kPa | 6.0 | — | — | 5.0 | 30 | 14 | 6 |
| Peak $\phi$, direct shear test, degree | 20 | — | — | 23 | 33 | 28 | 32 |
| Peak c, ring shear test, kPa | 11.0 | 6.0 | 5.2 | 13.8 | — | — | — |
| Peak $\phi$, ring shear test, degree | 23 | 24 | 26 | 21 | — | — | — |

N : Nishiyama K : Kompirayama S : Sample by Sassa et al.

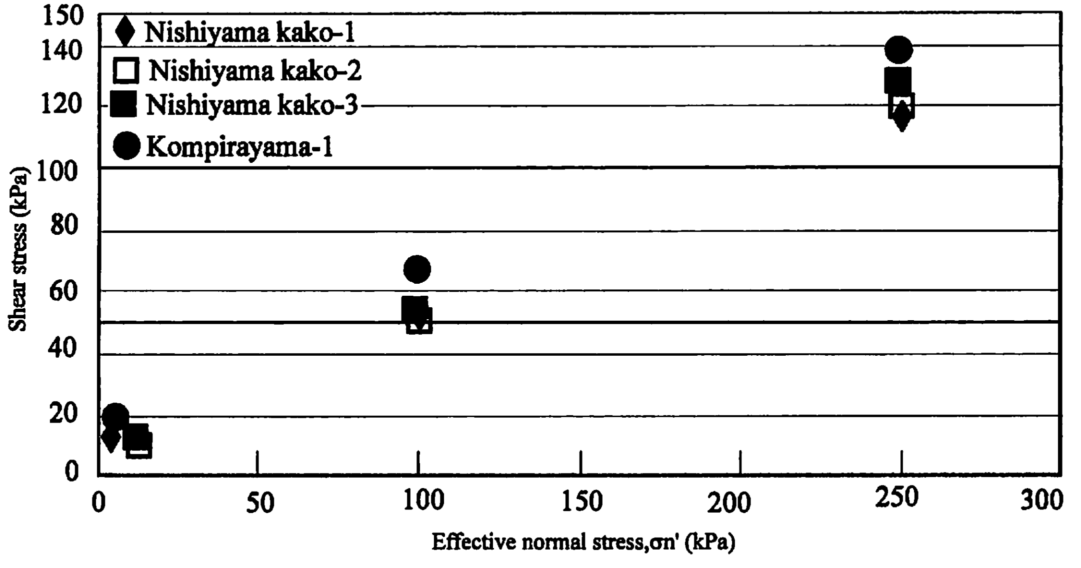



Figure 8 : Peak shear envelope of the soil samples by ring shear test

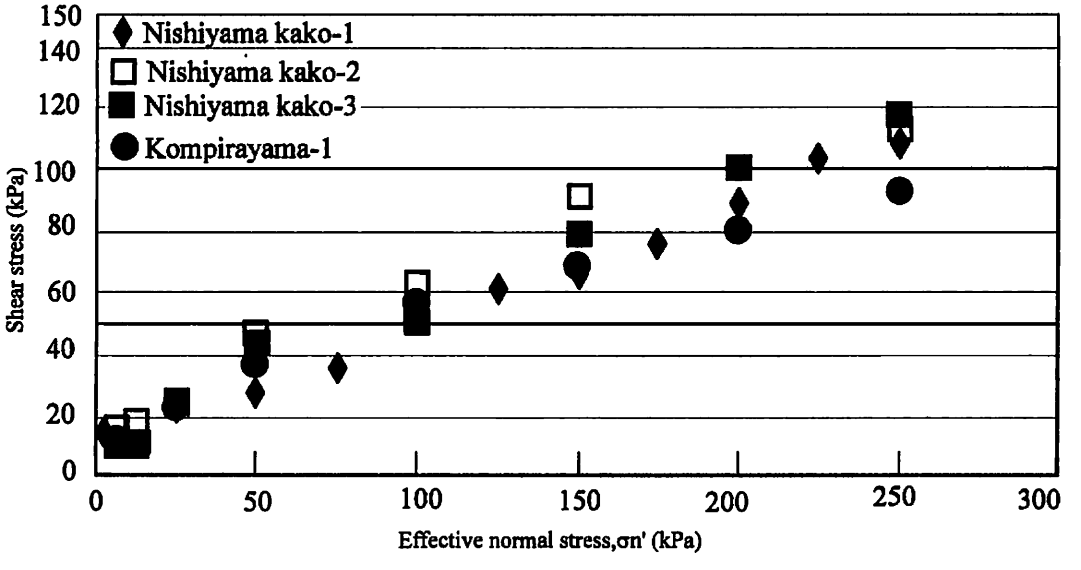



Figure 9 : Residual shear envelope of the soil samples by ring shear test

Kompirayama have shown the similar peak shear intercept (c) (Table 5). However, the peak $\phi$ of Kompirayama sample had been measured to be about $3^0$ higher than that of Nishiyama 1 (Fig. 7). Peak c by ring shear test had also been found to be similar in both the sample (Fig. 8). However, the peak $\phi$ in Kompirayama was found to be $3^0$ lower than that in Nishiyama 1 by ring shear test. The peak c in other samples of Nishiyama had been found to be almost half of the sample near the crater of Nishiyama. However, peak $\phi$ by ring shear apparatus in the sample near the stream bank of Nishiyama have been measured to be slightly higher than that of the sample near crater. Likewise, peak $\phi$ of hot mudflow in Nishiyama has been found to be slightly higher than that of the samples from stream deposition.

Table 6 : Residual shear strength of tested soil samples

| Property | N1 | N2 | N3 | K1 |
|---|---|---|---|---|
| Residual c, kPa | 10.0 | 5.0 | 3.4 | 8.0 |
| Residual $\phi$, degree | 21 | 23 | 24 | 18 |

Table 7 : Settlement, water content and densities after ring shear test

| Property | N1 | N2 | N3 | K1 |
|---|---|---|---|---|
| Maximum settlement,mm | 7.4 | 8.4 | 6.8 | 11.0 |
| Saturated density after test, $t/m^3$ | 1.95 | 1.96 | 1.98 | 2.16 |
| maximum dry density, $t/m^3$ | 1.41 | 1.54 | 1.56 | 1.64 |
| Water content, upper part, % | 40.1 | 23.9 | 28.4 | 34.5 |
| Water content, shear zone, % | 68.1 | 29.6 | 31.3 | 45.5 |
| Water content, lower part, % | 35.1 | 25.2 | 25.9 | 28.6 |

N : Nishiyama K : Kompirayama

The residual c of soil sample near crater of Nishiyama and Kompirayama has been measured almost similar (Fig. 9). However, the value of residual $\phi$ in Kompirayama has been measured about $3^0$ ess than the former. In Nishiyama, there was slightly higher residual $\phi$ in stream deposition, which itself has slightly lower residual $\phi$ than that in hot mudflow (Table 6). However, residual c in other samples has been found almost half of that near crater.

Initial dry density has been adjusted according to the field condition, while ring shear testing. Then the sample had been sheared for more than 30,000㎜ for all the samples (Fig. 10). The final settlement of the soil sample in Nishiyama except sample 1 (Fig. 11) had been found to be similar (about 6 to 8㎜), whereas that in Kompirayama and Nishiyama 1 has been found to be more than 11㎜ (Table 7). That had yielded similar saturated density in all samples of Nishiyama although it has been found to be 10% higher in Kompirayama. As the water content after ring shear fesr in the sample near crater of Nishiyama has been found to be almost 10% higher than the other samples, it yielded less dry density than other samples. Although the water content of the shearing zone has been measured to be

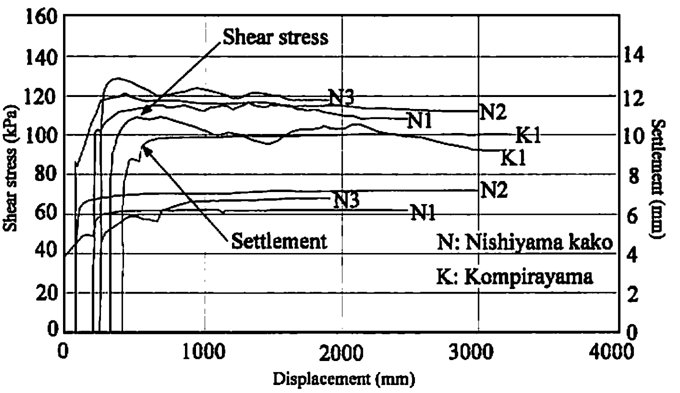


Figure 10 : Stress displacement curve for various samples for the normal stress of 250 kPa

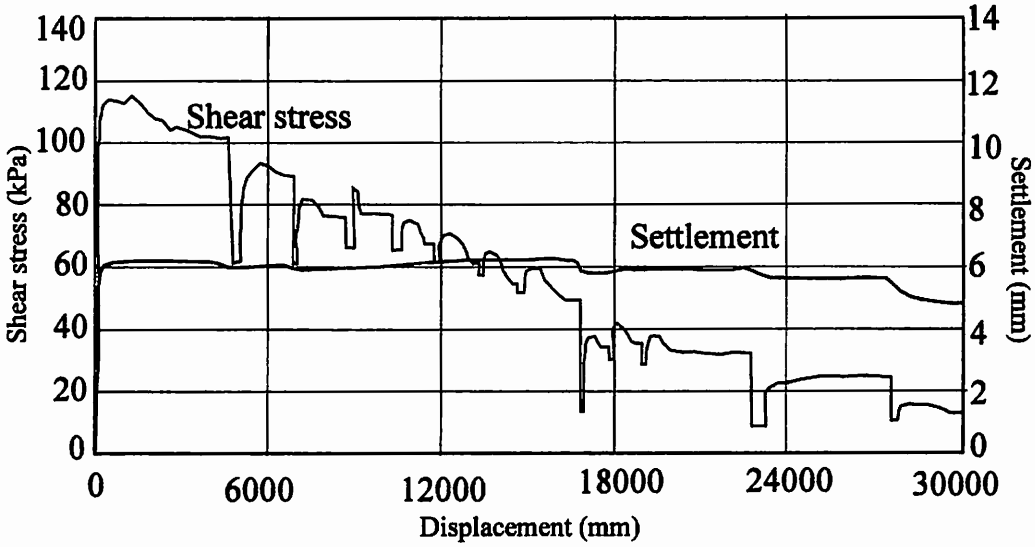



Figure 11 : Stress displacement curve for sample 1 of Nishiyama for whole stress range

5 to 10% higher than upper and lower part in most of the samples, it was almost double in case of sample 1 of Nishiyama.

### 6. Comparison of the soil strength with that of the previous eruption

The dry density and peak shear strength of the talus material, material at the slope and shear deposition at Kousu area had been measured by Sassa (1986). The dry density of the slope deposition in 1981 has been measured to be similar to that of the deposition near crater of Nishiyama (Table 1). Likewise, the dry density of stream deposition in 1981 has been found to be similar to the stream deposition in Nishiyama. However, the dry density of talus deposition is considerably less than the hot mudflow.

The mineralogical composition of volcanic ash in 2000 eruption has been measured to contain similar types of minerals as the deposition near crater, which includes all minerals from quartz to smektite. However, the volcanic ash in 1978 contained only volcanic glass with small quantity of feldspar (Fig. 6).

The peak c in the slope material by direct shear test in 1981 has been measured to be almost double of that of the erupted material in Nishiyama. Likewise, the peak $\phi$ of the material in the slope in Koushu had been measured to be almost 40% higher than that of the sample near Nishiyama crater (Table 5). The peak $\phi$ of other samples from Koushu had been measured to be slightly higher than the material from the slope. Similar variation has been measured in the shear strength of hot mudflow and stream deposition in Nishiyama. The increase in peak $\phi$ in Kompirayama from the sample near the crater of Nishiyama has been observed to be similar to the increase in peak $\phi$ in slope and stream deposition in Kousu during 1978 eruption.

### 7. Discussion on the test findings

As the fine material after eruption had been deposited near the crater and could not be consolidated, the void ratio and water content of the sample has been measured to be very high. The other samples in Nishiyama and Kompirayama showed similar nature during deposition and showed similar water content. However, due to the slight variation in soil property, the specific gravity of the soil from Kompirayama had been measured to be slightly higher than other samples. Due to greater void ratio and existence of large proportion of fine materials, the field unit weight of the sample near the crater of Nishiyama has been measured to be considerably low than other samples. Due to the higher specific gravity, the field density of the sample from Kompirayama has been measured to be slightly higher than the other samples. That has also resulted in higher saturated density as the sample 2 and 3 of Nishiyama and sample of Kompirayama had been found to be in almost saturated condition in the field. Observing the dry density of the samples measured by Sassa et al. , the sample near slope had similar dry density as the sample near the crater of Nishiyama. This is obvious, as the deposition might have been still remained in the slope even after the frequent slope failures along the slope. Likewise, the dry density of the sample from stream bank deposition in 1981 had been measured similar to the stream bank deposition in Nishiyama in 2000. However, the dry density of the slopes for sample 2 and 3 of Nishiyama and Kompirayama had not been differed much. It is to be noted that after ring shear test, the sample near the crater of Nishiyama had been settled considerably to give about 40% higher dry density than the natural condition. The settlement of other samples in Nishiyama after ring shear test had been less than half of that in sample 1. The dry density of other samples after ring shear test has been increased by 5 to 7% only. That has yielded similar saturated density after the ring shear test although sample from Kompirayama had shown about 10% higher saturated density as the final settlement amount after ring shear test for it had been measured more than sample 2 and 3 of Nishiyama. This clearly shows that the saturated density of sample near the crater of Nishiyama may be increased after consolidation, which will increase the potentiality for sliding. Due to the existence of fine particles, the water content of the sample near the crater of Nishiyama has been measured considerably high than the other samples. Besides, due to its fineness, the difference between the water content in the shearing zone has been measured to be almost double of that in upper and lower part in the same testing. Due to the high silt content, shearing zone of Kompirayama has exhibited almost 50% higher water content than the upper and lower portions. Even in sample 2 and 3 of Nishiyama, the water content at shearing zone had been measured about 25% higher than upper and lower portions. This clarifies the increase in the fine materials around the shearing zone during ring shear test although the exact increment quantity depends on the proportion and type of material composing the soil.

Although sample from the stream bank in Nishiyama exhibited slightly higher proportion of clay, the clay contents in all the samples did not vary considerably. However, proportion of silt near the crater is almost the half of the total sample. The sample from hot mudflow of Nishiyama and Komirayama had also shown about one third of silt content of the total soil. This shows that excluding the gravel, the constituent in the sample from Kompirayama and sample near stream of Nishiyama have been found similar (Table 8). The soil sample with less than 2㎜ size had been used for ring shear test. The proportion of clay in sample 2 of Nishiyama contained more than 10% clay whereas other samples contained about 7 to 9% clay. The proportion of clay and silt in Nishiyama 1 and Kompirayama were almost similar. Sample 2 of Nishiyama has higher proportion of clay and silt than sample 3. This might be the main reason for the slightly less residual shear strength and higher liquid

Table 8 : Particle size used for the ring shear testing

| Property | N1 | N2 | N3 | K1 |
|---|---|---|---|---|
| % of clay | 6.7 | 10.9 | 7.0 | 8.9 |
| % of silt | 50.2 | 36.5 | 39.0 | 48.0 |
| % of fine sand | 34.9 | 28.6 | 30.2 | 20.0 |
| % of coarse sand | 8.2 | 24.0 | 23.8 | 23.1 |

N : Nishiyama K : Kompirayama

limit in sample 3 than in sample 2. Similar reason can be thought for the higher liquid limit and less residual shear strength of sample 1. The higher proportion of silt and clay in sample 1 might have caused higher liquid limit.

As there is not so big variation in the mineral constituents of volcanic ash from 2000 eruption and the sample near crater, it is clear that the material underneath had been exploded out along with the steam during that eruption. However, no minerals except feldspar in the volcanic glass during 1978 volcanic eruption shows that the origin of the eruption might be very deep and was different than the 2000 eruption. The higher proportion of kaolinite in sample 1 might be due to the surrounding rocks as the volcanic ash contained less than half the quantity of kaolinite than the deposits near crater. Due to its nature of eruption and quality of magma, the quantity of feldspar in the volcanic ash is higher than that near crater. Due to their nature, the proportion of quartz in the sample from Nishiyama 1 and Kompirayama is very less than other two samples. However, percentage of feldspar in those samples has been found to be very high than other samples, although proportion of smektite and pyrite has not been differed considerably. However, no kaolinite had been found in the sample from Kompirayama. Besides, feldspar content in those samples had also been measured relatively high. The proportion of smektite is also in decreasing order from Nishiyama 1 to Nishiyama 3. The variation in quartz, feldspar and kaolinite might be one of the main reasons to have least residual shear strength of the sample from Kompirayama. Besides, aforesatd factors and proportion of clay and silt might be the reason to have the shear strength in decreasing order from sample 1 to 3 of Nishiyama.

The peak shear strength of soil sample tested by Sassa et al. has shown almost 40% higher shear strength than that in 2000. The main reason for it is the nonexistence of clay but higher existence of volcanic glass and feldspar in sample after 1978 eruption.

The measured soil physical properties and strength analysis shows that the soil along the mass flow route in Nishiyama and the parent rocks inside the crater may be different to that of Kompirayama. Besides, the mineral composition and peak shear strength of the soil sample tested in 1981 has shown similar dry density but different shear strength. This clarifies that the characteristics of erupted materials and their origin during those consecutive eruptions were different.

## 8. Conclusion

From the soil test result and its analysis, following conclusions have been made.

- The soil types in the route of the mass movement in Nishiyama and Kompirayama are different. The result of shear strength shows that the Kompirayama side is more vulnerable than Nishiyama. The fact of small shear strength of the soil from both locations should be considered well while designing the countermeasures for the debris flow in that area.

- The engineering properties of the hot mud flow and stream bank deposit is quite similar. However, both of them have higher strength than the soil from craters. This shows the increase in the shear strength after the mixing of the eruption mass with the original soil of the area.
- The shear strength of the soil near the crater of Nishiyama is relatively low. It is loose in nature. This shows the possible mass movement disaster in future after rainfall. Timely care should be taken to stop the possible disaster by the movement of that mass.
- The origin of the soil as well as properties of the erupted material during 1978 and 2000 eruptions are different. As the strength of the soil after 2000 eruption is smaller than that in 1978 and 1978 eruption has done considerable damage due to mass movement, special precaution should be taken to reduce mass movement in future.

## References

Bishop, A. W., Green, G. E., Garga, V. K., Anderson, A. and Brown, J. D. (1971): New ring shear apparatus and its application to the measurement of residual strength, *Geotechnique* **21**-4, 273-328.

Hirose, H. and Tajika, J. (2000): The 2000 eruption of Usu volcano and related damages, *Journal of Japan Society of Engineering Geology*, **41**-3, 150-154.

Mimatsu Memorial hall (1992): *Guidebook of Showa Shizan of Usu volcano*, 1-28.

Sassa K. (1986): The mechanism of debris flows and the forest effect on their prevention, *Proceedings of IUFRO, 18th world congress*, **1**, 227-238.

Tiwari, B., Marui, H., Sato, O., Yamagishi, H., Watanabe, N., Furuya, G., Suzuki, K., Inaba, K., Shimura, K. and Yamazaki, F., (2001): Engineering properties of the soil around Nishiyama and Kompirayama after the eruption of Mount Usu in 2000, *Proceedings of 40th Annual Conference of Japan Landslide Society*, 479-482.