Residual Shear Strength Properties of the Soil from Landslide Area, Using Ring Shear Test

by
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Abstract

Landslide research, specially in Japan, is in good progress in recent years. Because of the environmental consciousness and disaster mitigation strategy, many geo-technical researchers of the world are involved in the research related to landslide. Although there are many slope stability equations developed by veteran geo-technical engineers in the past, they were very difficult to apply directly in the landslide analysis. Chandler et. al. developed the back analysis method and the stability analysis for landslide area become popular in the world. However, the residual shear strength has been adopted arbitrarily in this method since the beginning. Along with the development of soil mechanics, the concept of residual shear strength has also been developed and many geo-technical professionals have developed the machines to conduct the residual shear test. Ring shear test machine was one of the best out-come of that development. Bishop put one more step by designing new ring shear testing machine, suitable for landslide clays, in 1971. After that there have been series of developments to design the ring shear machines fitting the specific objectives. Portable machine by Bromhead and high speed machine by Sassa are few examples. Although new machines have been developed, special care has not been taken to test the real landslide sliding surface soil in un-disturbed condition. It is extremely difficult to get the undisturbed sliding surface soil, recently, as most of the drainage wells do not penetrate the sliding surface. Almost all of the geo-technical professionals agree on the dependency of residual shear strength on the clay minerals. If the dominant clay mineral in the main scarp and sliding zone soil is identical, then the residual shear strength might be similar. This concept can solve the problem of soil testing on less complicated landslides as the test can be done on main scarp soil. This will add one factor for back analysis too. The construction of drainage well is extremely difficult in these days, even in developed countries, because of its high cost. In this situation, the residual shear strength of main scarp soil can give good idea to the planners. This research is mainly focused on the relationship of residual shear strength of main scarp and sliding surface soil, the importance of clay fraction during the shearing process and dependency of residual shear strength with other strength parameters. Five landslides have been selected in Niigata Prefecture, Japan. Undisturbed soil samples have been collected from those landslides. The ring shear test result of those samples

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has been compared with that of main scarp soil of the same landslide block. The result has been found to be very close. Likewise, shearing has been found mainly on the clay fraction during multi-stage ring shear test. This shows the importance of clay minerals in residual shear strength of the soil. Very good relationship has been found between the residual shear strength and liquid limit. The residual shear strength properties in various scarps of the same landslide area have been found to be identical. This paper describes the test result and its analysis in detail.

Keywords : *landslide, residual shear strength, sheared and off-sheared zone, atterberg's limit, main scarps*

1. Introduction

Many geo-technical researchers are involved on the research for residual shear strength of the soil since some decades. Various types of new models and soil testing equipments have been developed in these few decades for the research on residual shear strength. However, the real residual shear properties as well as utilization of appropriate strength for the infrastructure design are still in the developing stage. After the development of ring shear device by Bishop in early 70's, there were many modifications regarding the structures of the machines as well as testing conditions. During the recent few years, the development of new equipments is in good progress. Bromhead designed portable type simple ring shear machine whereas Sassa designed big high speed ring shear machine. It is important to understand that whatever is the bulkiness or complexity of the machine, it should be sufficient enough to measure the residual shear strength for the analysis of existing geo-technical problems and design of possible countermeasures. The machine should be simple but sufficient enough to measure the required strength properties of the soil under study.

Estimation of real sliding zone is the main problem for recent landslide planners. Although check borings are done at many landslide areas, many of them are failed to trace real sliding zone. In this situation, the uncertainty is basically balanced by high risk factor. Conventional back analysis technique is still popularly used due to the absence of other reliable methods. Therefore, the research on the soil strength properties of the landslide area, their correlation and development of alternative approach for landslide planning play vital role. This current research is mainly focused on possible applicability of soil test data on the countermeasure planning of landslides.

2. Study Area

Five different landslide areas were selected in Niigata Prefecture, Japan (figure 1). It is rare, even in Japan, to collect the soil sample from the sliding zone of landslide area. However, undisturbed sliding surface soil samples have been collected from almost all landslide areas

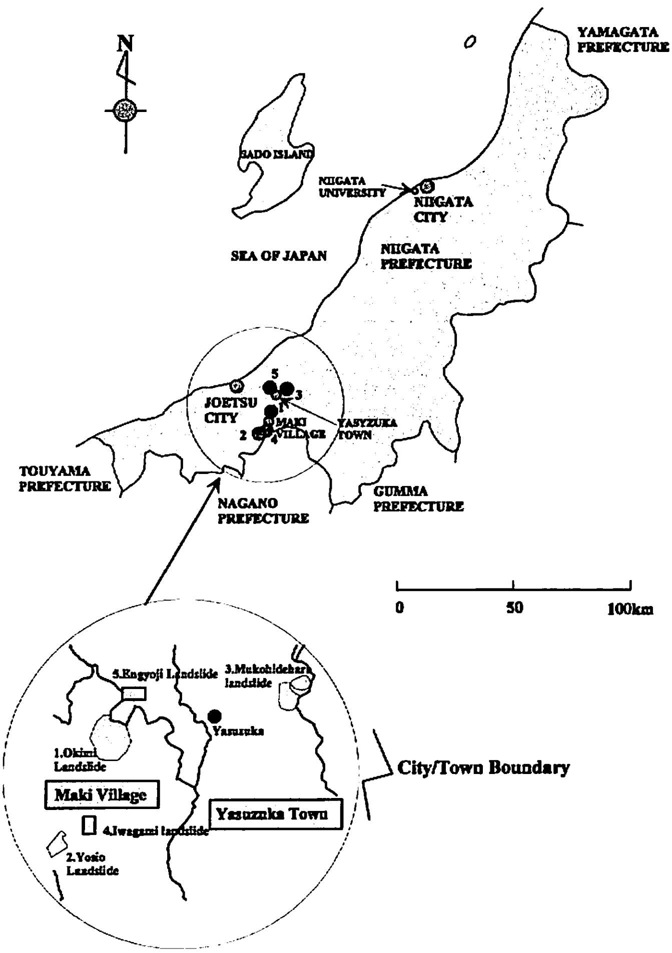


Fig. 1 Location map of studied landslide area

under study. Likewise, soil samples have been collected from the main scarps of the same landslides. Main purpose of main scarp soil sample collection is to compare the soil strength properties of main scarp and sliding surface soil. Okimi landslide has mainly been focused whereas data of other landslides are collected to verify Okimi landslide's data with other similar or different landslides. Okimi landslide is one of the large landslides in Niigata prefecture (Tiwari and Marui, 1999). It has five distinct blocks. As A block is less complicated and covers major part of the affected area, it was mainly focused, after analyzing some soil samples from C block. Soil sample from the sliding surface at A-block (11 m deep), revealed during check boring has been compared with the soil samples from the main and side scarps. Total 18 samples have been collected from Okimi landslide among which 14 samples have been collected from A-block associated scarps (figure 2). To compare the soil test result of Okimi landslide with the soil strength characteristics of other area, which are similar and different in nature and geological condition, soil samples have been collected from four other landslide areas.

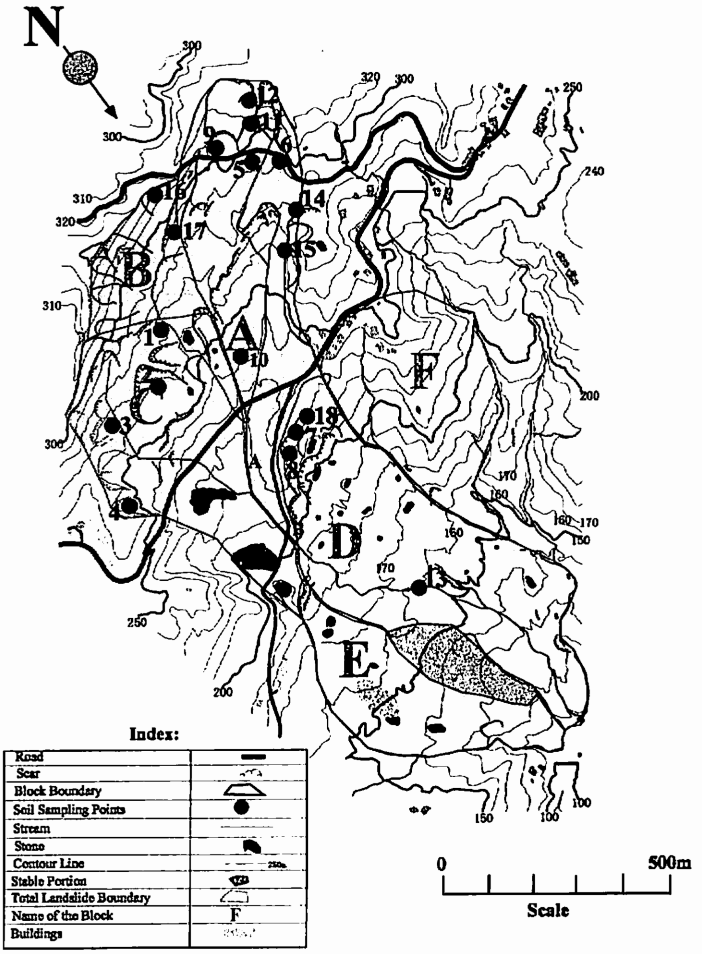


Fig. 2 Soil sampling points in Okimi landslide

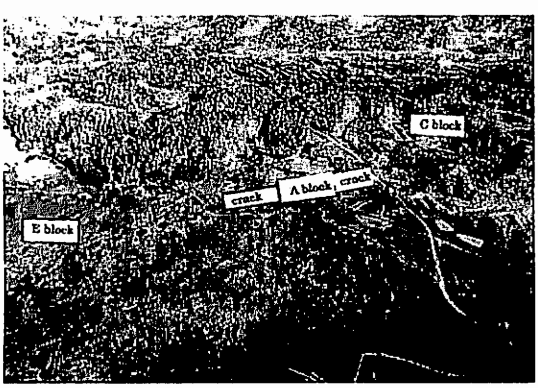


Photo 1 Overall view of block A, B and C from air

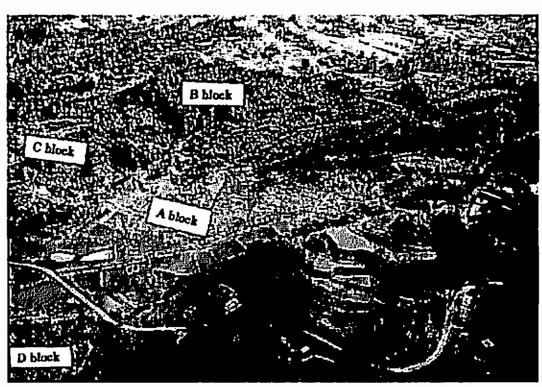


Photo 2 Overall view of block A, B, C and D from air

Those landslides are Yosio landslide, Mukohidehara landslide, Engyoji landslide and Iwagami landslide. Undisturbed sliding surface soils have been collected and ring shear test has been conducted in undisturbed condition. To see the variation in residual shear strength, main scarp soils of all these landslides have also been collected and tested. Special sampler was designed to collect the undisturbed soil sample from landslide area and test it in the ring shear apparatus.

3. Sampling Methodology

Special care was taken to sample the undisturbed sliding surface soil. In all cases, the real sliding zones have been identified first. The sample box has been dropped down and undisturbed soil sample has been picked up with the help of showel. The samples have been cut well by the core cutter to shape it into testing size. Then, it has been directly tested in ring shear testing machine. However, the main scarp soil samples have been sieved by 2mm or 425μ sieves after complete drying. The required weight of the sample fitting the unit weight of sliding surface soil has been taken. As there was no variation in the strength properties by 2mm and 425m sized samples (Tiwari and Marui, 1999), sample passing from 2mm sieve has been considered for most of the samples. During the field sampling of main scarp soil, finer possible sizes have been collected to reduce the sample volume. The general soil property tests like sieve analysis, hydrometer analysis, specific gravity test, atterberg's limit test have been done for all the samples before the ring shear test.

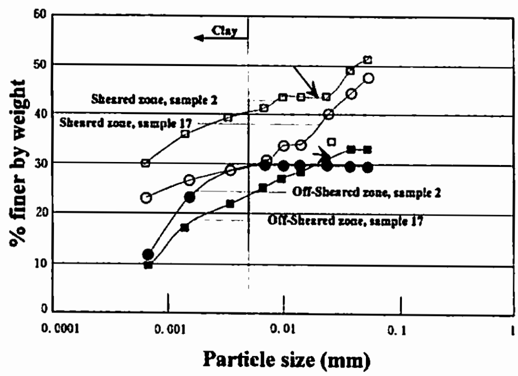
4. Soil Testing Procedure

In all the cases, natural water content has been measured immediately after the sample reaches the laboratory. The samples have been dried. Specific gravity has been measures using pycnometer analysis. Likewise, the unit weight of sliding surface soil has also been measured. Sieve and hydrometer analyses have been done to confirm the particle size distribution, amount of clay and to fix the speed of rotation. For undisturbed landslide sliding surface soil, the samples were cut into the required shape, using the specially designed cutter and directly loaded to the ring shear machine. Except the samples from C block of Okimi landslide, 2mm down soil has been tested in all samples. As multi-stage ring shear test was found to be more appropriate (Tiwari and Marui, 1999), it was used in most of the soil samples. Due to the limitations of the machine, speed of rotation of 1mm/min has been applied. After the ring shear test, clay portion in sheared zone and off-shear location has been compared.

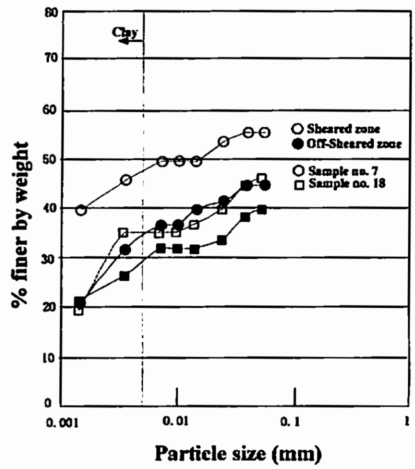
5. Test Results

5－1. Particle size analysis result

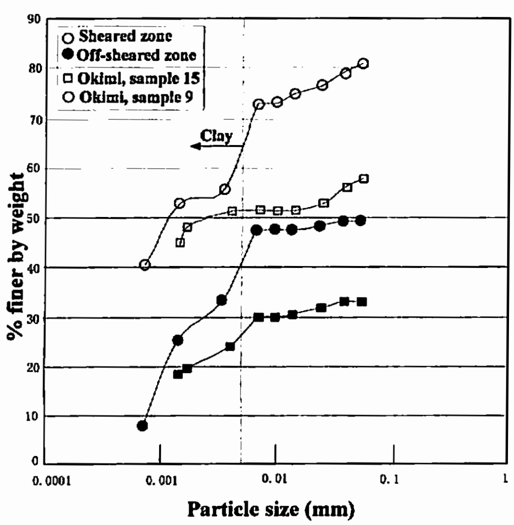
Sieve and hydrometer analysis have been done for most of the samples. The purpose of this analysis was to identify the proportion of finer particles like clay and silt in the tested soil sample before the ring shear test. Hydrometric analysis has been done again to check the variation of fine particles between the shearing and off-shear locations (figure 3 a, b, c, d). Location between the upper porous stones (8mm above the shear zone) has been chosen for



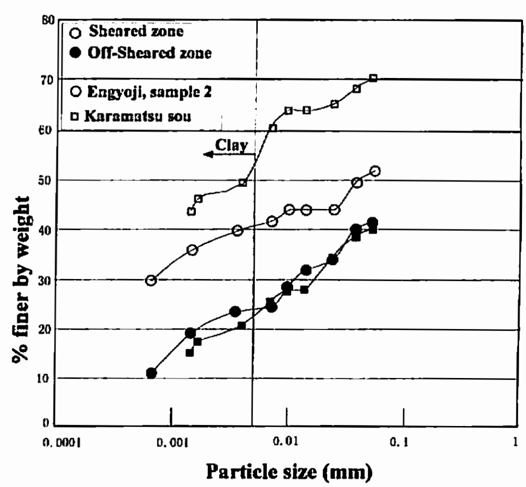
a. Sample no. 2 and 17, Okimi landslide



b. Sample no. 7 and 18, Okimi landslide



c. Sample no. 9 and 15, Okimi landslide



d. Sample no. 2 of Engyoji landslide and Karamatsu sou ura (foundation soil)

Fig. 3 Distribution of clay and silt particles in sheared and off-sheared samples

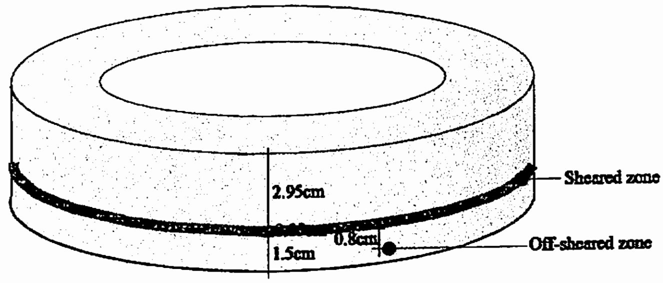


Fig. 4 Sampling location in the sheared sample for the hydrometric analysis to check the clay proportion

Table 1 Proportion of clay before the soil test and after the ring shear test

Sample	Ring shear (shear zone)		Ring shear(off- shear zone)		Before shear test		
	% of clay	% of silt	% of clay	% of silt	% of clay	% of silt	% of sand
Okimi 2	75	20	24	15	15.3	26.4	58.3
Okimi 7	49	17	34.3	23.7	18	30	52
Okimi 9	63.6	24.4	40.3	14.7	20	25	55
Okimi 15	51.2	12.8	26.4	11.6	21	20	59
Okimi 17	29.8	27.2	29.4	11.6	22.6	13.2	64.2
Okimi 18	35	26	29	21	21	16	63
Engyoji 2	40.6	25.4	23.8	34.2	14	48	38
Karamatsu sou 2	52	21	21.9	28.1	18.4	40	41.6

the off-shear zone sample where exact shearing zone soil has been analyzed to measure the clay fraction in shearing zone (figure 4). The result has been tabulated in Table 1.

5－2. Atterberg's limit

Tests for the Atterberg's limit have been done for entire samples (figure 5). The main objective of this test was to find plastic limit (Wp), liquid limit (Wl) and plasticity index (Ip). Atterberg's limits of various samples have been compared with the residual ϕ of soil samples (figure 6). The test results have been presented in Table 2.

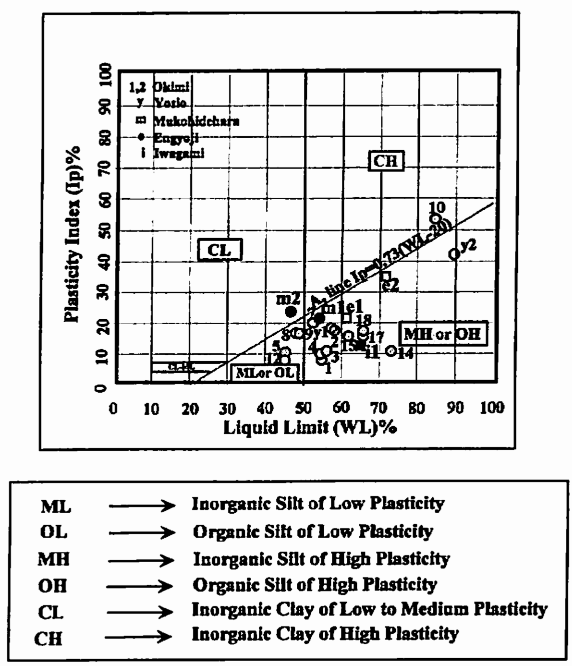


Fig. 5 Plasticity chart for various soil samples

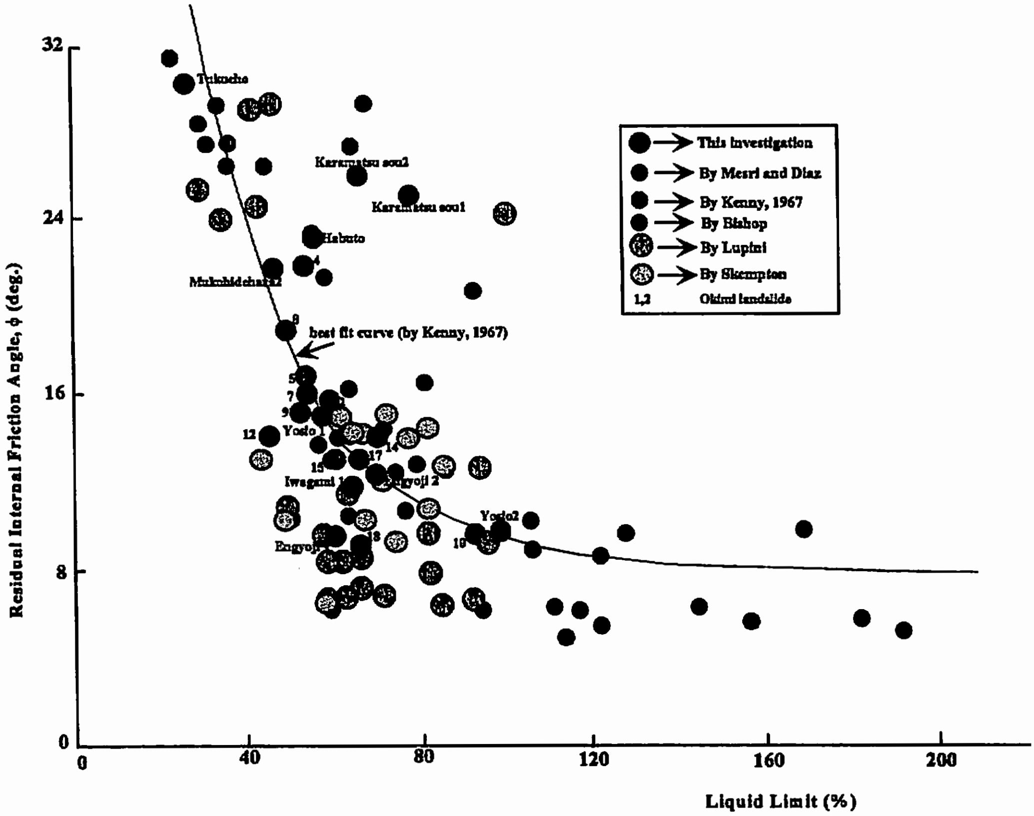


Fig. 6 Relationship between residual ϕ and liquid limit, fitted in the graph given by Kenny

Table 2 Atterberg's limit and residual shear strength of various samples

Soil sample		Wp(%)	Wl(%)	Ip(%)	c, kPa	ϕ, deg.
1. Okimi landslide	2	40	58	18	6.6	16
	4	44	54	10	5.6	22
	5	34	45	11	5	12
	7	33	53	20	3	15
	8	32	48	16	7	19
	9	33	49	16	6	15
	10	30	84	54	6	10
	12	37	45	8	5	14
	15	45	61	16	7	13
	17	50	66	16	7	13
	18	48	66	18	4	9
2. Yosio Landslide	1	39	58	19	9	13
	2	46	89	43	12	10
3. Mukohidehara landslide	1	33	54	21	3	18
	2	22	46	24	0	21
2. Engyoji landslide	1	40	61	21	7	11
	2	36	71	35	4.9	9.5
3. Iwagami	1	52	65	13	5	11.6

5－3. Residual shear strength

All the samples were sheared in ring shear apparatus to get the residual shear strength. As already mentioned, sliding surface soils have directly been tested in undisturbed condition whereas 2mm down soil particles have been tested for most of the main scarp soil samples. The residual shear strength variation by individual and multi-stage ring shear test method has already been observed in sample 2 and 4 of Okimi landslide (Tiwari and Marui, 1999). Following the results, most of samples have been tested by multi-stage ring shear testing. However, cross checks have been done for many normal stresses. In most of the cases, clear shearing zone of about 0.5mm thickness has been formed after multi-stage ring shear test (figure 7). However, many oblique shear zones have been detected in between the lower porous stone and shearing zone. As the minimum possible speed of rotation for the available ring shear machine is 1mm/min., special care was taken to let full drainage during the shearing and minimize dilatency. This has been clearly marked by the settlement of the sample during shearing. In most of the cases, shear stress has been increased even after being stable for about an hour. Due to this, at least three local peaks have been observed in stress-displacement curves. The final value, which has been constant for more than three hours have been considered as residual shear stress for that normal stress.

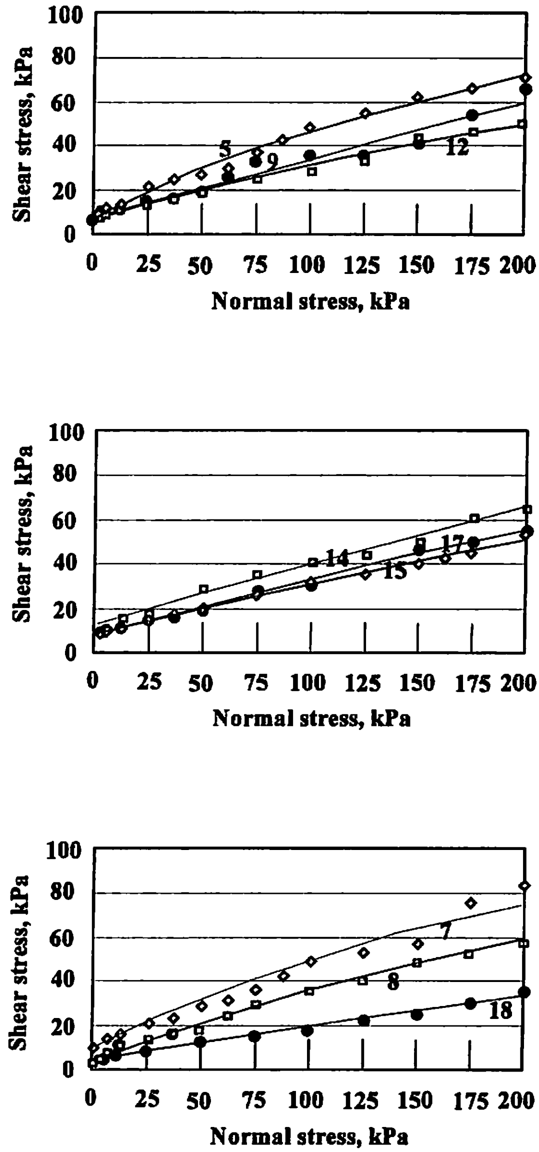
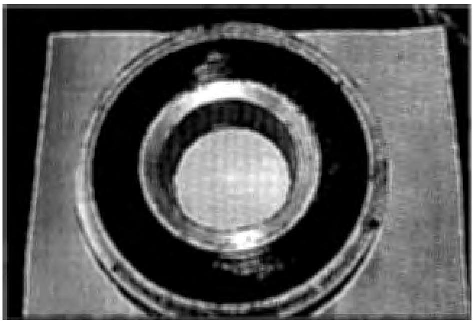
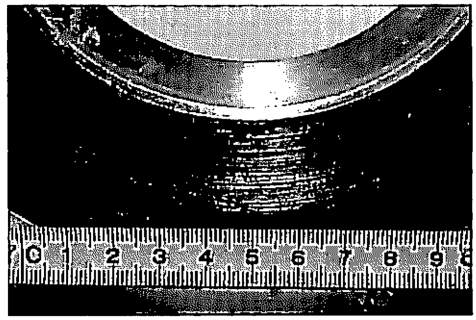


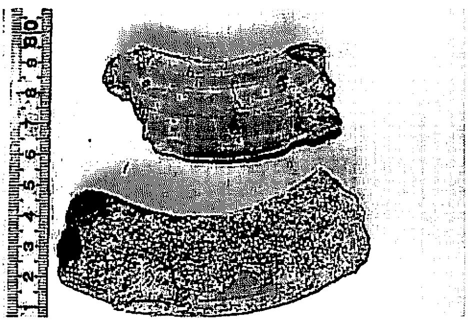
Fig. 7 Residual shear envelope for various soil samples of Okimi landslide



a. Sample no. 14, Okimi landslide



b. Sample no. 14, Okimi landslide, enlarged view



c. Sample no. 15, Okimi landslide

d. Sample no. 17, Okimi landslide

e. Sample no. 18, Okimi landslide

f. Sample no. 18, Okimi landslide, Enlarged view

Photo 3 Sheared portion and un-sheared portion after multi-stage ring shear test

6. Analysis of the tested data

The plasticity index for the main scarp soil samples of A-block in Okimi landslide were almost same, except in few samples. It ranges from 16% to 20% in most of the cases. Smektite and Kaolinite are dominant clay minerals in those samples (Tiwari and Marui, 1999). This is very good outcome to understand the plasticity behaviour of the soil in identical geological condition. The plasticity index of main scarp soil of Yosio, Mukohidehara and Engyoji landslide are also similar to Okimi landslide although they are 4-6% higher than Okimi landslide whereas that of Iwagami landslide is lower than Okimi landslide. Plasticity index of sliding surface soil from Okimi and Yosio landslide are very high in comparison to main scarp soil samples although that does not differ much in Mukohidehara landslide. The relationship between residual ϕ and liquid limit has been plotted in the same graph presented by Mesri and Diaz (1978). Very good relationship has been observed between Wl and residual ϕ. The results from the landslide area follow the similar pattern.

Higher variation in clay fraction has been found between sheared, off-sheared zones and original samples. Except few samples, almost 15% to 25% increase in clay fraction has been found from off-shear to sheared zone. Likewise, 5 to 8% increase in clay fraction has been found between off-shear to original soil sample. It clearly shows the gradual increase in clay fraction from outer zone towards shearing zone. If it would only be increased in sheared zone, it might have been due to grain crushing. However, the gradual increase in clay fraction shows the movement of clay fraction from outside towards shearing zone either due to suction or any other causes. Besides, there might have been crushing effect to convert sand into silt. However, crushing effect can not be thought in very large extent as it is very difficult to have crushing in clay particle itself.

The residual shear envelopes in most of the cases are curved. It was difficult to define exact function for each envelopes. From the graph, it can be understood that there are some normal stress ranges from which the function of shear envelope changes. This gives very good hint for stability analysis. Residual c in Okimi landslide varies from 4kPa to 7kPa and did not become zero. This clearly shows the existence of small residual c in many soil samples. Residual c of Yosio landslide is slightly higher than Okimi landslide whereas it is almost similar in other landslides. However, it is to be noted that residual c of main scarp and sliding surface soils of same blocks are closer.

Residual ϕ of Okimi landslide varies from 12 to 16°, except few samples. The sliding surface soil has residual ϕ of 10°, slightly lesser than the average ϕ of main scarp soil samples. There is 3° difference between the residual ϕ of main scarp and sliding surface soil of Yosio and Mukohidehara landslide whereas it is 1.5° in Engyoji landslide. This clearly shows that there is not so high variation in residual ϕ between main scarp and sliding surface soil.

7. Conclusion

From the aforesaid test results and their analyses, following conclusions can be made.

1) In the similar geological condition with less complicated landslide movement, clay minerals in main scarp and sliding surface soil are more or less identical. In this situation, the residual shear strength (c and ϕ) of the soil samples from these locations seems to be closer.
2) There seems to be considerable movement of clay fraction from outer portion towards

the shearing zone during ring shear test. This will increase the amount of clay in shearing zone. This amount will further be increased by particle crushing. This indicates that ultimate shearing takes place among the fine particles, specially the clay particles, irrespective of the size of the particle composing the sample.

3) The above two points clearly show that the residual ϕ of the soil is dominated by clay particles of the whole sample irrespective of the proportion of coarse grained materials consisting in the sample.

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