

High-Speed High-Stress Ring Shear Tests on Granular Soils and Clayey Soils¹

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Abstract: The purposes of this study is to obtain exact knowledge of the influences on friction angle during shear by shearing speeds. Ring shear tests on sandy and clayey materials have been carried out with a newly developed High-Speed High-Stress Ring Shear Apparatus to examine if there are some changes in the frictional behaviors of these materials at high shearing speeds of 0.01cm/sec~100cm/sec and high normal stress of 0~3.8kgf/cm². Samples used for tests were glass beads, tennis court sands in the university campus, the Toyoura standard sands (uniform beach sands) and bentonite clays. All tested samples were dry.

Although result on the glass beads showed that the friction angle during shear was independent of shear speed under the normal stress up to 3.8kgf/cm², 2 ~ 5 degrees of change in friction angle were observed on the tennis court sands, the Toyoura standard sands and the bentonite clays. In the tests on the Toyoura standard sands and the bentonite clays, friction angle increased as the shear speed increased. On the contrary, friction angle during shear of the tennis court sands decreased at a shearing speed of 100cm/sec.

Change in grain size distribution implies that heavy crushing or grinding of particles occurred during shear. The grain size distribution become wider during shear by grain crushing in samples except glass beads. It could result in the increase of density and accordingly increase of the friction angle. Crushing or grinding of grains during shear can change the shape of grains. The Toyoura standard sands have round shape, because they are beach sands, it may become angular by crushing during shear. On the contrary, the tennis court sands have angular shape because they are taken from mountain slopes, it may become round by grinding during shear. Round grains have a small friction angle. It may be interpreted that the tennis court sands had a smaller friction angle during shear because of the change of angular grains to round grains by grindings. Hence, it can be said that the friction angle is affected by crushing or grinding of grains during shear, which appears in a higher normal stress and a greater shear speed (shear distance).

To measure the friction angle during shear, it is most appropriate to use ring shear apparatus because landslide motion usually causes long distance shearing of about several meters to some hundred meters. Bishop, 1961, developed a ring shear apparatus and carried out ring shear tests on samples of several kinds of clays in order to examine residual strength of clays which is a steady strength appearing after the peak strength. In reactivation of old landslides, the mobilized shear strength is not the peak strength in the virginal shear of the soil, but the residual strength which is a small steady state strength appearing after the peak strength. Bishop's ring shear apparatus had a sample box of which diameter was about 15cm (outside) and 10cm (inside). The maximum normal stress is 2.5kgf/cm². The shear speed in his experiment was 1.3×10^{-5} cm/sec and the maximum shear displacement was 132cm. But it is not enough for research of the motion of landslide, it needs a faster shear speed up to some meters per a second, and longer shear displacement up to some meters.

Sassa, 1984, developed a Low-Stress High-Speed Ring Shear Apparatus in 1984 for the research of motion of debris flow. The diameter of the sample box is 30cm (inside)—48cm (outside). The maximum normal stress is 0.4kgf/cm². The shear speed is 0.001 to 150cm/sec.

In order to know whether the shear friction during shear depends on shear speed or not, Sassa carried out ring shear tests on glass beads, the Toyoura standard sands. The results of ring shear test on glass beads of 2.0mm diameter are shown in Figure 1. Measured data on normal stress versus shear resistance which has a stress dimension are plotted. The tests were carried out under the normal stress up to 0.3kgf/cm². The normal stress was continuously increased under the constant shear speed. Such tests were repeated of same sample on different shear speeds of 0.001, 0.1, 1, 90cm/sec. Almost all data are on a straight line inclined 19° and there are little scatters among the data. So, this

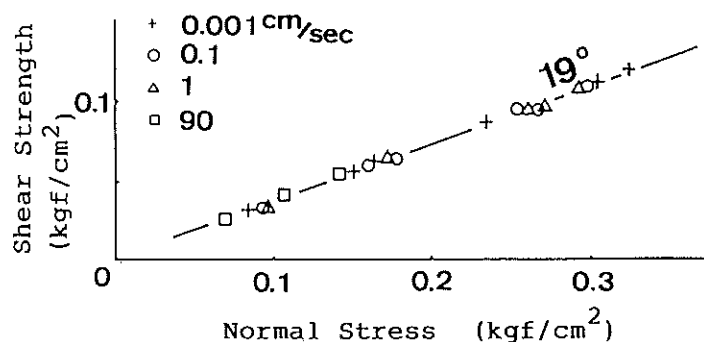


Figure 1—Result of low-stress high-speed ring shear tests on dry glass beads of 2.0mm diameter. Void ratio $e=0.65 \sim 0.67$ (Kaibori, 1986).

To know the frictional characteristics of soils during high speed shearing is very important for the research on motion of landslides.

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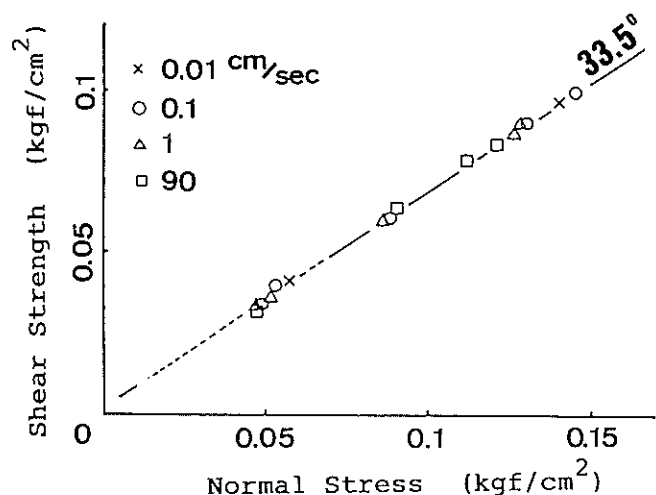


Figure 2—Result of low-stress high-speed ring shear tests on Toyoura standard sands. Void ratio $e=0.88\sim0.91$ (Kaibori, 1986).

result means that the shear friction of the glass beads is independent of shear speed in the range of shear speed and the normal stress as mentioned above.

Results of ring shear tests on Toyoura standard sands are shown in Figure 2. Procedure of the tests are almost same with the tests on the glass beads. Shear tests are carried out under the normal stress up to 0.15 kgf/cm^2 . Shear speeds of these tests are 0.01, 0.1, 1 and 90 cm/sec. The friction angle of all shear speed is 33.5° .

Hung and Morgenstern, 1984, developed a high velocity ring shear apparatus in 1984. The diameter of the sample box was 15cm (outside) and 11cm (inside). The maximum normal stress is about 2 kgf/cm^2 and the maximum shear speed is 2m/sec. In use of the apparatus, they carried out ring shear tests on polystyrene beads and the Ottawa quartz sands of various grain sizes under two shear speeds of 0.025cm/sec and 98cm/sec. Results of the tests showed that the friction angle was almost independent of shear speed.

Sassa, 1988, developed a High-Stress High-Speed Ring Shear Apparatus in 1988 for the research of landslide. It attained high normal stress up to 3.8 kgf/cm^2 and it corresponds to the depth of about 19~23m of landslide mass, hence research on the motion of real landslides has become possible. The diameter of the sample box is 33cm (outside) and 21cm (inside). The maximum shear speed is 150cm/sec.

With the apparatus, Vibert, Sassa and Fukuoka, 1989, carried out the ring shear tests on torrent deposit of the Denjo river and soils of the Jizukiyama landslide in order to examine whether the shear friction depends on shear speed or not. Result of the tests on dry torrent deposits of the Denjo river showed that the friction angle during shear under the shear speed up to 10cm/sec is 35.0° but the friction angle at 100cm/sec under the normal stress up to 1.2 kgf/cm^2 is 36.5° (Figure 3).

Result of the tests on unsaturated (degree of saturation was 20%) Jizukiyama landslide soil showed that the friction angle during shear was 32.8° at 0.01cm/sec, 35.0° at 0.1cm/sec, and 38.5° at 1cm/sec and 10cm/sec (Figure 4). The magnitude of the variation is about 6° , larger than the result on the sample of the Denjo river. The friction angle during shear of both sample tended to increase as the shear

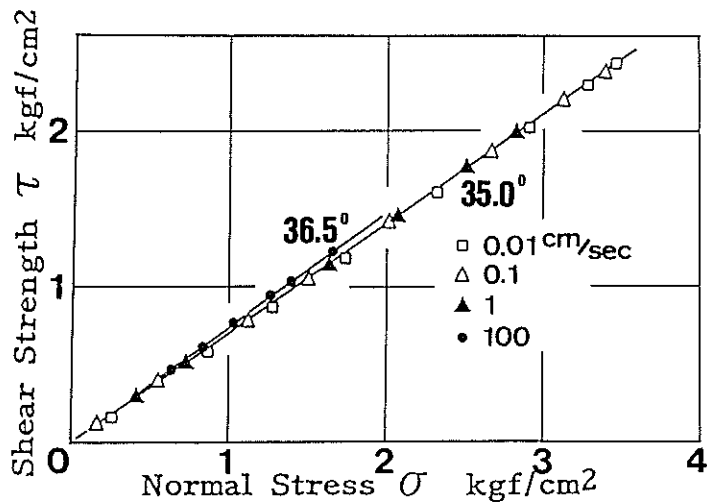


Figure 3—Result of high-stress high-speed ring shear tests on dry torrent deposit of the Denjo river. Void ratio $e=0.50\sim0.57$ (Vibert et al., 1989).

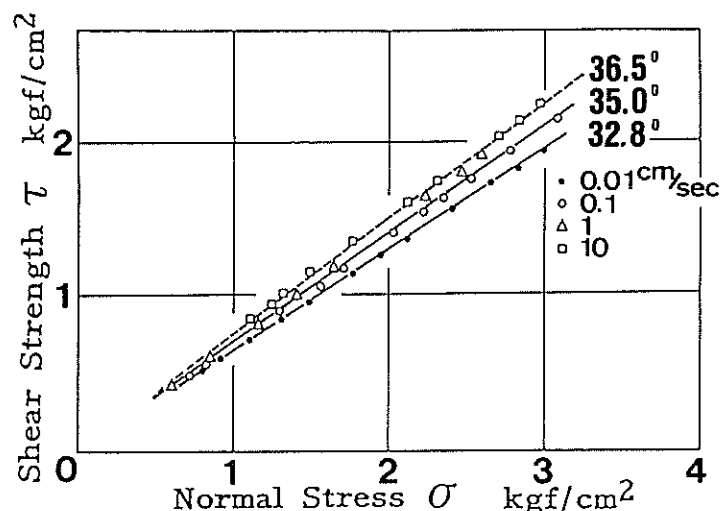


Figure 4—Result of high-stress high-speed ring shear tests on unsaturated Jizukiyama soil. Degree of saturation $S_r = 20\%$. Void ratio $e=0.50\sim0.57$ (Vibert et al., 1989).

speed increased.

Examination of both sheared samples after the tests showed that so much fine ground grains were found on the shear plane. It seemed that this grinding of soil particles relates to the variation of friction angle during shear, and the magnitude of the variation relates to the grain size.

So using the High-speed High-stress Ring Shear Apparatus, we have done ring shear tests of various samples at various shear speed to examine what causes the variation of friction angle.

SAMPLES AND APPARATUS

Samples for tests

Samples of different material and different grain size were chosen. Tested samples are glass beads of 0.2mm diameter, tennis court sands, Toyoura standard sands (uni-

beach sands) and the bentonite clay. Because pore pressure of the sample is not measured during shear test, effective stress can not be measured. So when dry or not-saturated sample were used, no excess pore water pressure would be generated and total stress would be equal to effective stress. So all of the samples tested by the apparatus were dry.

Glass Beads

Glass beads are of 0.2mm uniform diameter. The specific gravity of the glass beads is 2.50.

Tennis Court Sands

Tennis court sands are taken from the tennis court in the university campus. They are taken from mountain slope and consist of angular grains. The specific gravity is 2.60. They are dried before the tests.

Toyoura Standard Sands

Toyoura standard sands is Japanese uniform beach sands sold by a Japanese company and used as a standard sands for calibration of test apparatus for soils by Japanese soil mechanics researchers. It is a uniform, clean fine quartz sands with round grains. The grain size is 0.05 ~ 0.5mm. The specific gravity is 2.49.

Bentonite Clays

Bentonite clays used in the tests is a dry clay powder sold in Japan and usually used for civil engineering works. It is well ground and with grain size smaller than 0.3mm. The specific gravity is 2.58. Permeability of the clays is always very small and it takes so much time for dissipation of excess pore water pressure, so the sample used for shear test was completely dry to prevent generation of pore water pressure.

Structure of the Apparatus

Figure 5 is the schematic diagram of High-Speed High-Stress Ring Shear Apparatus. The sample box is shaped circular channel. The diameter of the sample box is 33cm (outside) and 21cm (inside). It is made of transparent acrylic resin, retained by metal frame and the outside of the sample can be observed during test. Section of the sample box is 6cm wide and about 6~8cm high. The width of the section is constant. The loading plate can move vertically, so only the height of the sample can change. The sample box is separated horizontally at about midheight (Figure 6). The lower one is rotated by servo-control motor for shear. Several non-skid needle assemblies are fixed on the base and the ceiling (loading plate) of the sample box and they prevent the sample from slipping on either side. So, rotation of the lower sample box causes shear of sample. After the shear test, horizontal shear plane is usually formed between the upper and the lower part of the sample box. There is a rubber edges at the inside and outside gaps between the upper and the lower part of the sample box and they are bound on the upper part of the sample box to seal the gap, and preventing leak of sample from the sample box.

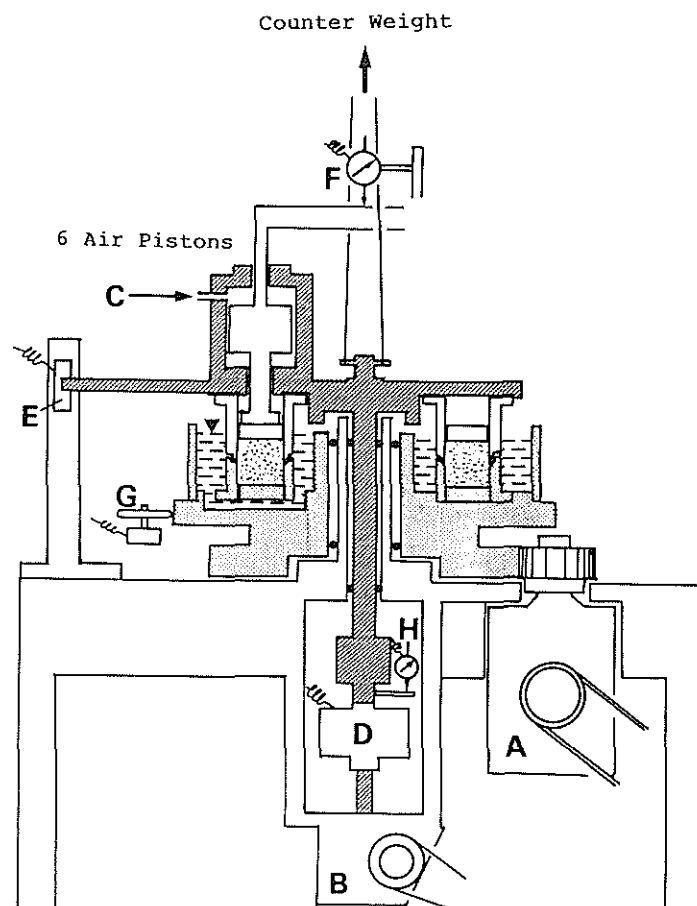


Figure 5—Schematic diagram of the High-Speed High-Stress Ring Shear Apparatus. A: servo-control motor for shear, B: servo-control motor for gap control, C: servo-control air regulator, D: load cell for normal stress, E: load cell for shear stress, F: dial gauge for volume change, G: shear displacement detector, H: dial gauge for gap.

The electric servo-control motor (marked as A in the Figure 5) can rotate the lower part of the sample box at constant speed, so it enables constant shear speed shear test. Available shear speed is from 0.001cm/sec to 150 cm/sec with use of four different gears in the gear box (also in A in the Figure 5).

The normal stress to the sample is given by an air compressor. The compressed air is put into six air pistons through an servo-control air regulator. The air pistons push down the loading plate (ceiling of the sample box) and the normal stress is loaded on the sample uniformly. The maximum normal stress is 3.8kgf/cm².

The gap distance between the upper and the lower part of the sample box should be constant throughout the test procedures, because too much narrowing of gap distance or contact of the upper and the lower part of the sample box may increase the measured value of the normal stress. While, too much widening of gap distance may lead to leak of sample from the sample box during shear test.

So, the apparatus has a servo-control motor for gap control (marked as B in Figure 5) and a electric distance meter for gap distance measurement on the order of 1/1000 mm. With them, gap distance is kept constant during a test as the same value at which shearing of the sample starts.

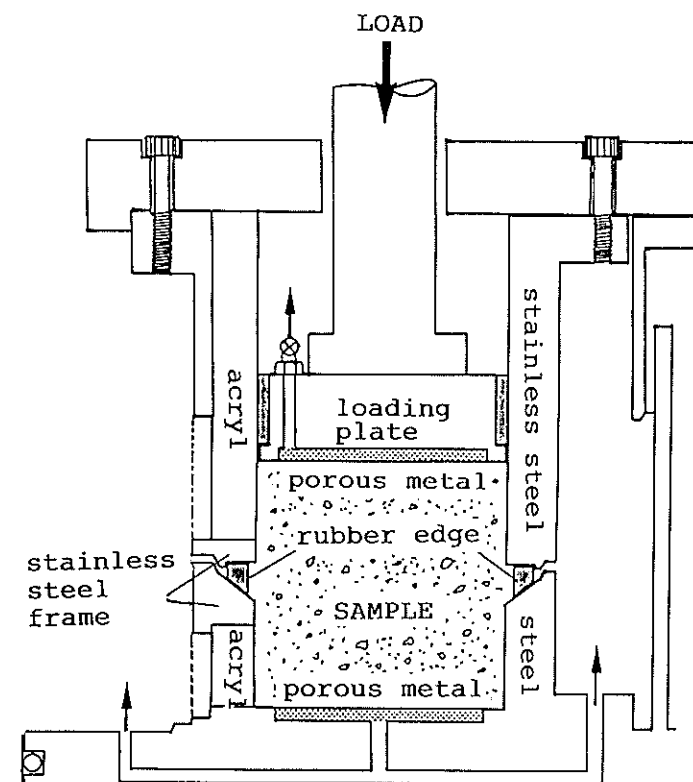


Figure 6—Section of sample box of the High-Speed High-Stress Ring Shear Apparatus.

Monitoring System

Normal load on the sample is measured with a load cell set beneath the axis (marked as D in Figure 5). The compressed air which produces the normal load on the sample push up the air pistons and axis, then normal load is measured as tension force.

Shear resistance of the sample is measured with a load cell (marked as E on Figure 5). The upper part of the sample box and the upper unit (including air pistons) are fixed and restricted not to rotate with the lower part of the sample box, (marked E in Figure 5) with load cell for shear resistance. So, shear resistance is measured as tension force. As the shear resistance is supposed to originate uniformly on the shear plane, the shear resistance is easily calculated from the equation of shear torque. Above mentioned two load cells are electrically connected to dynamic strain meters with cables, and tension forces are measured with them.

Vertical displacement of the sample is measured with the dial gauge (marked as F on Figure 5). As the sample box cannot deform sideways, the measured vertical displacement multiplied by the area of loading plate is variation of volume of the sample.

Shear displacement is measured with rotary encoder which contact with the lower part of the sample box which rotates during test. The shear speed is calculated from the rate of rotation and it is displayed at each result of the tests shown below as the shear speed at the center of the sample.

All these measured parameters (normal load, shear resistance, sample height and shear displacement) are output as electric voltage through the amplifier unit. All values are recorded on the sheet of a pen-recorder and also put

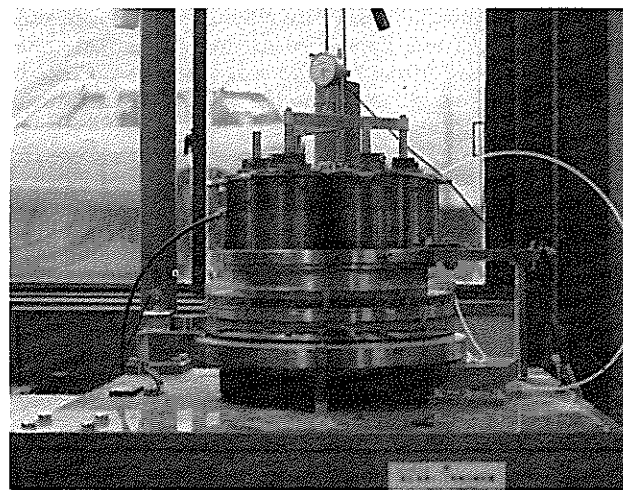


Figure 7—The High-Speed High-Stress Ring Shear Apparatus.

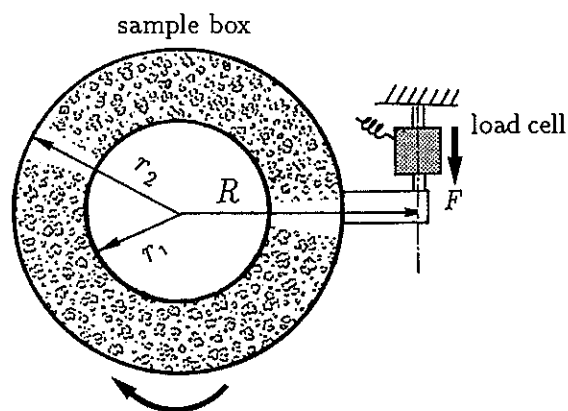


Figure 8—Calculation of shear resistance and shear torque of the High-Speed High-Stress Ring Shear Apparatus.

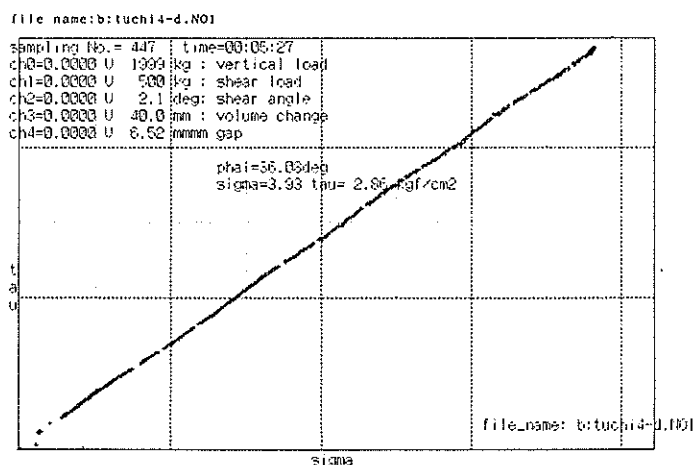


Figure 9—Screen copy of real-time monitoring system of the apparatus, assisted by personal computer. Displaying normal stress and shear resistance relation.

into personal computer through A/D converter board in it, then the data are saved on magnetic floppy disk and the normal stress (σ)—shear resistance (τ_f) relation are plotted on the computer display at real time. Figure 9 is the screen copy of the computer display of the real-time monitoring system plotting stress conditions (normal stress and shear resistance).

Pore pressure is not measured because it is difficult to measure pore pressure at the shear plane. Only total stress on the sample can be measured. Therefore, tests were carried out under dry conditions.

Calculation

Normal stress σ (kgf/cm²) is calculated from:

$$\sigma = \frac{W}{\pi(r_2^2 - r_1^2)} + \gamma_t \cdot h_{up}$$

Here, W: Normal load acting on the sample through loading plate measured by the load cell, r_1 : diameter of the sample box (inside), r_2 : diameter of the sample box (outside), γ_t : total unit weight of the sample, h_{up} : sample height above shear plane (about 3~4cm). $\gamma_t \cdot h_{up}$ is at most 0.008kgf/cm². The normal stress loaded on the sample during the ring shear tests are between 0.5~3.8kgf/cm², so this term is almost negligible. So, this term was not calculated during the ring shear tests.

Shear resistance τ (kgf/cm²) is calculated from the equation of rotational torque (Figure 8):

$$\int_0^{2\pi} r d\theta \int_{r_1}^{r_2} r \tau dr = RF$$

$$\tau = \frac{3}{2} \pi \frac{RF}{r_2^3 - r_1^3}$$

Here, R: distance from the axis to the load cell for shear resistance, F: shear load measured at load cell which retains the upper part of the sample box from rotation.

PROCEDURE OF TESTS

Sample Preparation

The soils for the sample was compacted inside the sample box up to about 6cm high with steel bar. Compaction is carefully executed to make homogeneous sample.

Then set the upper unit including loading plate and air pistons, connect electric cables of measuring device to amplifiers and strain meters and connect air tubes of air pistons to the air regulator. The air compressor starts to run and supply pressure to air regulator.

Consolidation

Before shear test begins, sample is consolidated with normal stress of 3.8kgf/cm². Progress of consolidation is monitored by the dial gauge for measurement of sample height on pen-recorder. All soils for sample except bentonite were sandy soil and dry, consolidation completed quickly within about several seconds. Bentonite clay sam-

ple, which was dry powder, also completed consolidation quickly.

Ring shear test

After the sample is consolidated, normal stress is decreased to 0.5kgf/cm². Then slowest gear is connected to the servo-control motor, corresponding signal voltage for 0.01cm/sec is set on servo-control unit, and then servo-control motor starts. Confirming that the sample reaches residual condition, increase normal stress gradually up to 3.8kgf/cm² at constant rate and decrease to 0.5kgf/cm² again, then stop the servo-control motor. During shear test, stress path (relation between normal stress and shear resistance) is drawn continuously on computer display at real time.

Ring shear tests at shear speed of 0.1, 1, 10, 100 cm/sec follow after the test at 0.01cm/sec step by step. At each test, appropriate gear is selected and test is executed in same way except test at 100cm/sec. As it takes about some minutes to complete one cycle of a test, during which servo-control air regulator increases and decrease the normal stress, at the test of 100cm/sec sample sometimes leaks outside through the gap between the upper and the lower part of the sample box. It is difficult to keep running for long time at 100cm/sec. Then the test at 100cm/sec is done in different way, that for about only three or ten seconds the sample box is rotated for the discrete normal stresses of 0.5, 1.5, 2.5 and 3.5kgf/cm².

After shear test on each sample is completed, the upper unit, the upper part of the sample box and also the sample above the shear plane is removed and shearing plane of the sample is closely examined.

RESULT OF TESTS

Glass beads

Dry glass beads were tested under the normal stress up to 3.8kgf/cm². Figure 10 is the result of uniform dry glass beads of 0.2mm diameter. Ring shear test was executed at constant shear speed of 0.01cm/sec as the normal stress was increased gradually. Then, another test at faster shear speed (0.1, 1, 10, 100cm/sec, step by step) followed it in

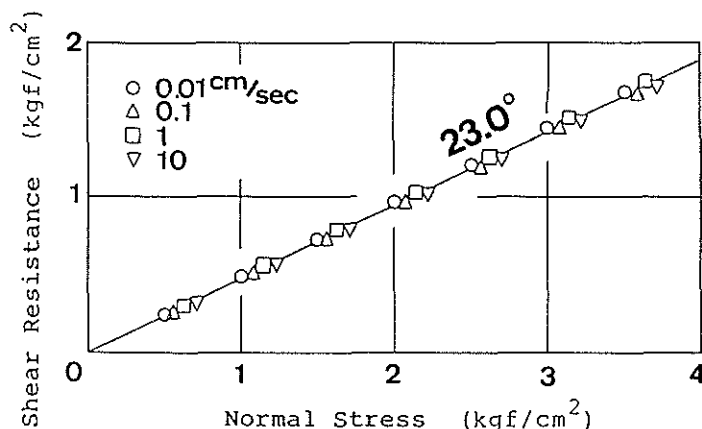


Figure 10—Result of high-stress high-speed ring shear tests on the 0.2mm glass beads. Void ratio during shear test: $e=0.87\sim0.88$.

the same procedure. So continuous normal stress-shear resistance relation was gained at each test. Plotted points in the figures of normal stress v.s. shear resistance in this paper are picked up from the recorded data at the normal stresses of every 0.5 kgf/cm^2 between 0.5 and 3.5 kgf/cm^2 .

The friction angle scattered little, mean friction angle is 23.0° , being independent of shear speed of 0.01 cm/sec to 10 cm/sec . Test at 100 cm/sec was carried out, but some sample leaked out of the sample box and the test was terminated. From the examination of sample after shear test, no grinding or crushing of the glass beads occurred.

Tennis court sands

Results of high stress ring shear test on dry tennis court sands are shown on Figure 11. It displays the relation between normal stress and shear resistance. The friction angle at the shear speed slower than 10 cm/sec is 35.1° , but it decreases to 31.9° at 100 cm/sec . After the test, removing the upper unit and the upper part of the sample box and cross section of the sample was closely examined. So much fine ground grains were observed on and near the shearing plane (Figure 13 (a) and (b)). Variation of grain size distribution between before and after the shear test are shown in Figure 12. Curve of after the test is that of

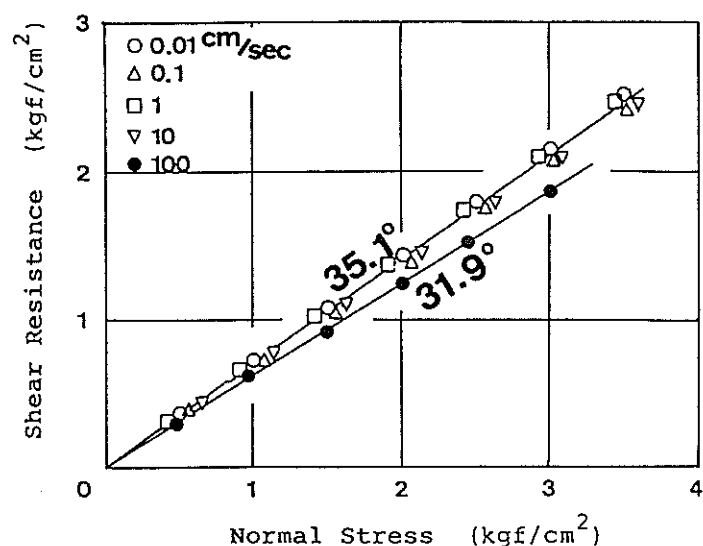


Figure 11—Result of high-stress high-speed ring shear tests on the dry tennis court sands in the university campus. Void ratio during shear test: $e=0.51\sim0.68$.

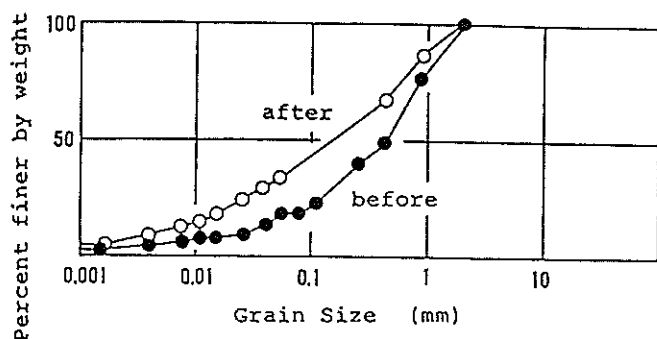
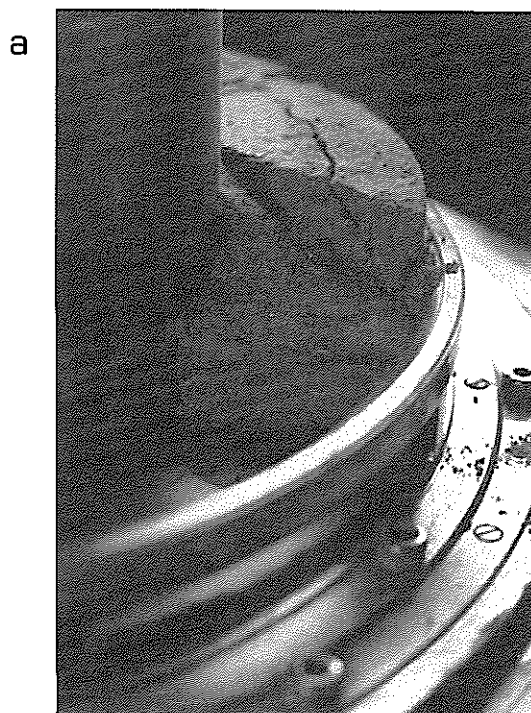


Figure 12—Grain size distribution of the tennis court sands. ●—● : before the test, ○—○ : after the test



b



Figure 13 (a) The campus soils after test. (b) Well ground soil particles of the shear zone on the fingers.

the sample taken from fine ground grains around the shear plane. It shows clearly that shearing causes grinding of grains.

Toyoura Standard Sands

Figure 14 is the test results of the dry Toyoura standard sands at shear speed of $0.01\sim100 \text{ cm/sec}$. The test was done from the slowest speed of 0.01 cm/sec to the highest speed of 100 cm/sec step by step. The friction angle during shear increased from 31.7° to 33.8° under the respective shear speed. Thereafter, tests were continued at slower speeds; 1 cm/sec , 0.1 cm/sec , 0.01 cm/sec step by step. These tests at reducing shear speeds were carried in

order to examine whether shear friction depends only on the shear speed or not. Results of the tests were shown on Figure 15. Change of the sample height which means change of the sample volume and friction coefficient which is $\tan \phi_m$ (tangent of friction angle) versus shear speed is plotted. Plots with number of 1~5 are the same data of Figure 14. Plots with number of 6~8 are the results of successive tests following Figure 14. Sample height increased until the test of No. 3 and then continued to decrease during tests of No. 4~7. Increasing process was maybe dilatancy of the sample. The decreasing process seemed to be owing to crushing of the sample. It is proved by the comparison of grain size distribution between before and after the test, shown in Figure 16. Smaller grains finer than 0.05mm which was not included in the sample before

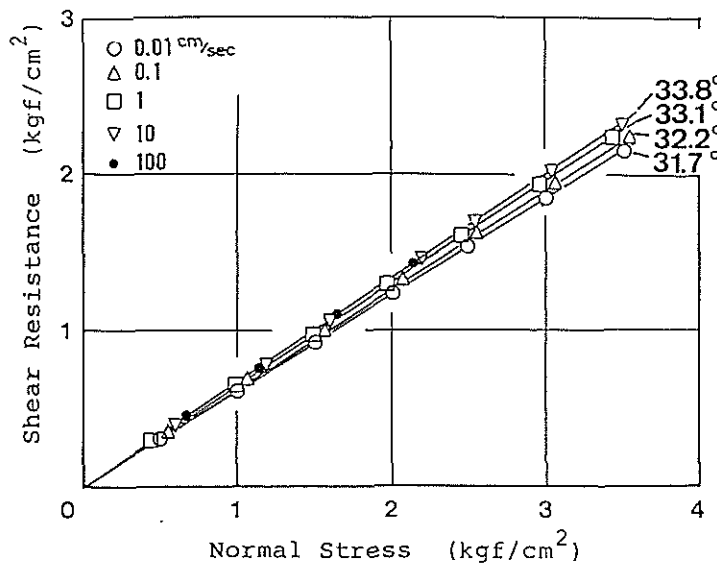


Figure 14—Result of high-stress high-speed ring shear tests on the dry Toyoura standard sands. Void ratio during shear test: $e=0.65\sim0.83$.

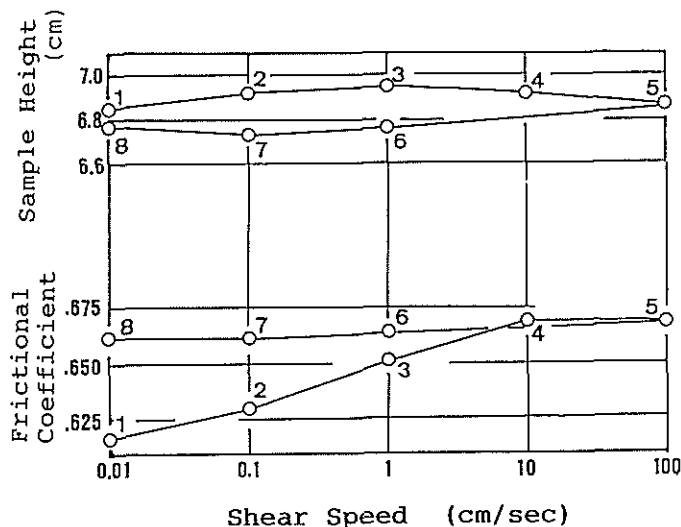


Figure 15—Shear speed v.s. sample height and frictional coefficient relationship for the dry Toyoura standard sands.

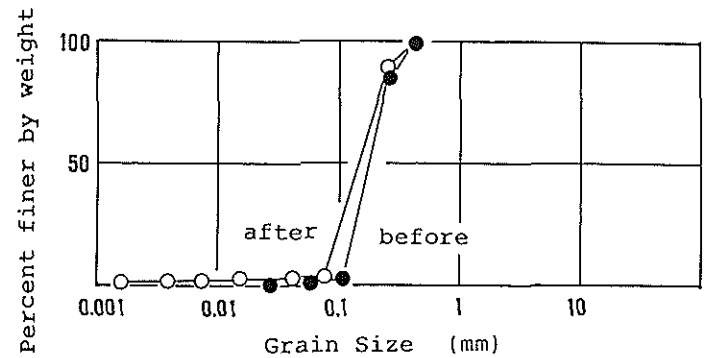


Figure 16. Grain size distribution of the Toyoura standard sands. ●—● : before the test, ○—○ : after the test

the ring shear test appear in the distribution curve of the sample after the test. Although Figure 16 is not comparison of the sample of shear plane, but of total sample, it is obvious that grain crushing occurred in the sample. Friction coefficient tends to increase during the tests of No. 1~5 and almost keep constant (or slightly decreased) during the tests of No. 6~8.

Bentonite Clay

Test result of ring shear tests on the bentonite clays is shown in Figure 17. It showed the greatest difference of friction angle with the change of shear speed. The friction angle was 28.6° at the first test with shear speed of 0.01cm/sec. And then it varied as 34.1° at 0.1cm/sec, and 34.8° at 1 and 10cm/sec. In this test, test at the speed of 0.01cm/sec was executed again after the test at 10cm/sec. But the friction angle remained almost same with that at 10cm/sec speed.

Figure 18 shows the entire process of shear test at shear speed of 0.1cm/sec. The normal stress increased up to 3.5kgf/cm^2 and decreased again. Shear resistance also changed in proportion with the normal stress. The most important is the behavior of the friction coefficient, namely tangent of friction angle ($\tan \phi_m$). It increased with increase of normal stress (during the shear displacement of 0~20cm)

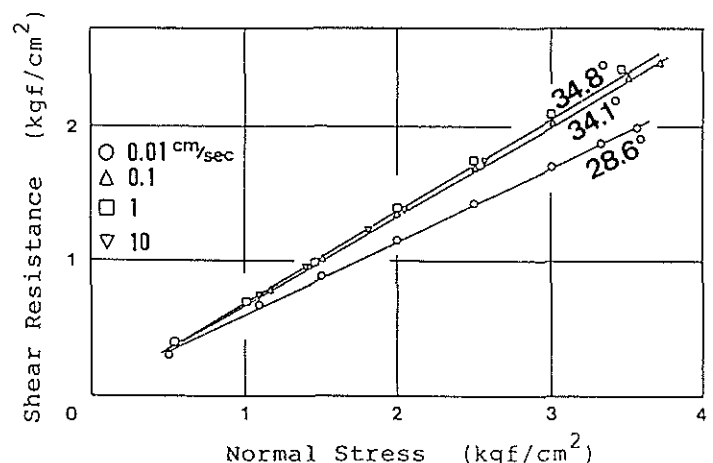


Figure 17—Result of high-stress high-speed ring shear tests on the dry bentonite. Void ratio during shear test: $e=1.74\sim2.04$.

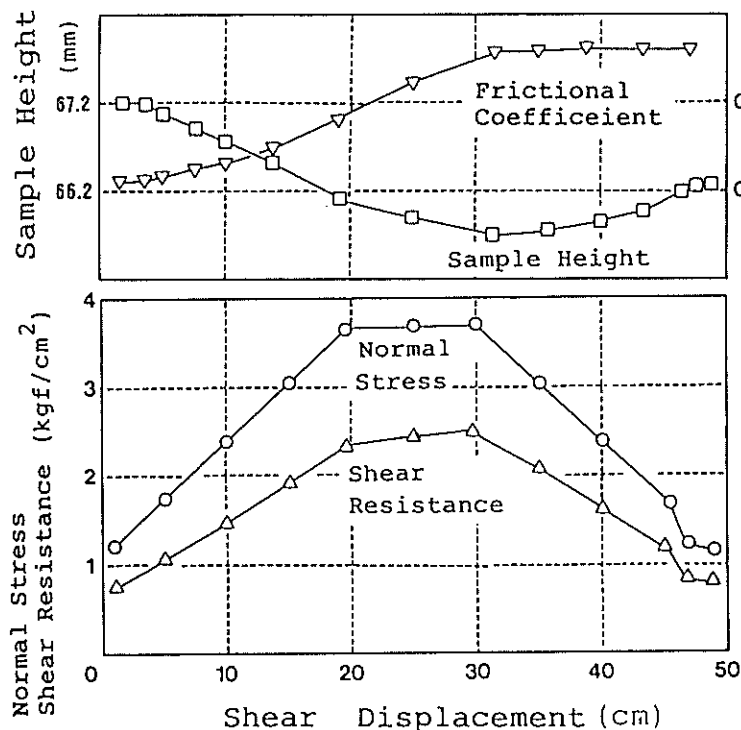


Figure 18—Variation of frictional coefficient, sample height, shear resistance during a cycle of test. (shear velocity: 0.1 cm/sec)

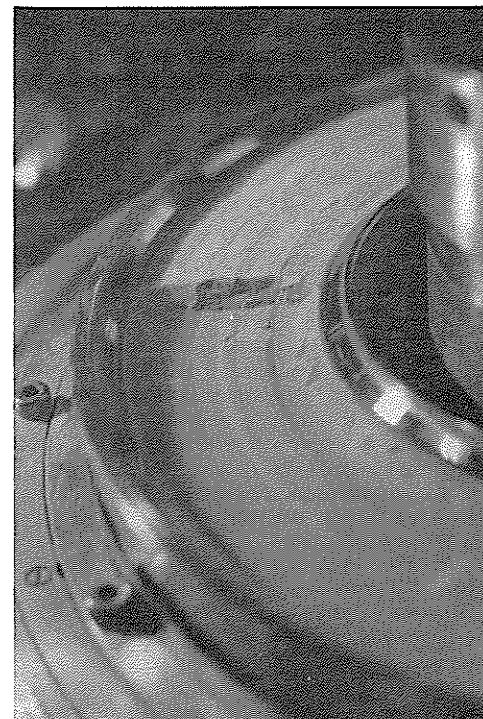


Figure 20—Bentonite sample after ring shear tests, showing polished and striated slip surface (upper portion of the sample is removed).

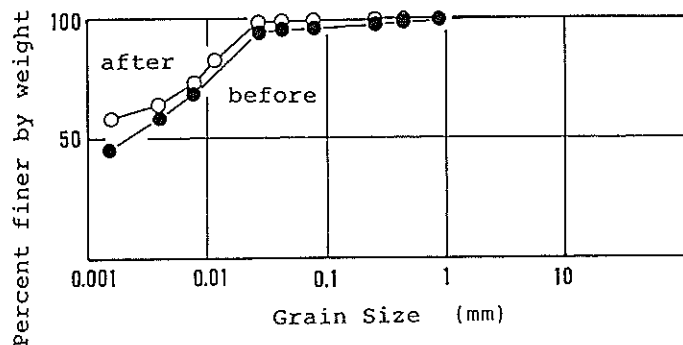


Figure 19—Grain size distribution of the dry bentonite. ●—● : before the test, ○—○ : after the test

and also while the normal stress kept constant peak (shear displacement of 20~30 cm). While the normal stress is decreasing, the friction coefficient remained constant (shear displacement of 30~45 cm). The sample height decreased during shear and didn't recover the initial height at the end of the test.

Figure 19 is the comparison of grain size distribution of bentonite sample between before and after the test. This is from the sample of shear zone. It still clearly exhibited the effects of grain crushing through shearing.

Influence of Grain-crushing on the Friction Angle during Shear

The results shown above by the High-Speed High-Stress Ring Shear Apparatus suggest that friction coefficient may be affected by crushing (grinding) of grains at increasing

process of normal stress. And high speed shearing may have worked for a rapid crushing. We observed heavily crushed grains in shear zones after the tests of each sample except the glass beads. Glass beads are enough strong not to be crushed under the normal stress of the apparatus and the friction angle does not change with shear speed.

Here, we suppose two factors influencing the variation of friction angle during shear caused by grain crushing. One is the variation of grain size distribution and another is the variation of grain shape, i.e. round or angular.

As for the variation of grain size distribution, crushing of grains during shear, especially in the material of uniform grains makes a lot of finer grains and the sample becomes wider in grain size distribution. It should increase the density of the sample and the interlocking between grain particles. Increase of density of soils usually causes increase of internal friction angle. This seems to be the reason why the friction angle increased in the test of Toyoura standard sands and bentonite clays.

However, in the test on the tennis court sands, the friction angle at a high speed shearing decreased in spite of occurring of grain crushing. What can be the cause of this is not clear at present, but one possibility is the shape of grains. The initial shape of Toyoura sands which were from beach was round, so crushing can make them angular. So the variation of grain shape in the Toyoura standard sands didn't act for decreasing of the friction angle and so the factor of variation of density had to be dominant. We could not observe the initial and sheared grain shape of bentonite clays by eyes, then the influence of the variation of grain shape on the friction angle of bentonite clays was unknown.

On the contrary, the tennis court sands were mountain sands, the initial shape was rather angular, so crushing

could increase the roundness of grains. Because sample of round grains usually have smaller friction angle than that of angular grains, crushing of grains during shear can reduce the friction angle. It can be one interpretation.

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Morphological Study on the Prediction of the Site of Surface Slides¹

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Abstract: The annual continual occurrence of surface slides in the basin was estimated by modifying the estimation formula of Yoshimatsu. The Weibull Distribution Function revealed to be usefull for presenting the state and the transition of surface slides in the basin. Three parameters of the Weibull Function are recognized to be the linear function of the area ratio a/A . The mapping of the hazardous zones could be successfully done using the stream line distribution map and the relief map.

Sediment yield produced by frequent surface slides on the mountain slopes of granitic rocks become as dangerous as those produced by gigantic landslides or large scale slope failures, because of the high frequency of occerrence in a basin in spite of the dimension.

It is recognized that surface slides will occur on the mountain slopes of every geology. As for the investigations on surface slides, almost all papers in Japan deal with surface slides which occur on the mountain of granitic rocks which are often severely weathered and distribute widely in the south-western district of Japan and disasters due to this geology occur frequently on the occasion of heavy rain which will be brought about by the typhoon or the frontal storm.

ESTIMATION FORMULA OF SURFACE SLIDES

In order to express the condition of the occurrence of surface slides in a basin, usually the parameter a/A ; the ratio of the total area of surface slides to the area of a basin (the terminology "area ratio" is used hereafter) is used. In most of the studies concerning the occurrence of surface slides, efforts were made to express the area ratio as the function of the precipitation and formulas by Uchiogi(1) and Yoshimatsu(2) are the presentative ones. Here, the formula below by Yoshimatsu is taken to be discussed.

$$a/A = K \times R_r \times (R-r)^{1.5} \quad \text{----- (1)}$$

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where, "R" is the amount of precipitation of one continual rain which has led to the disaster occurrence of surface slides, "r" is the invalid limited precipitation being of no effect on the occurrence of surface slides, R_r is the relief ratio and K is the coefficient.

In Table 1, values concerning the above formula by Yoshimatsu are indicated; area of the basin, total area of surface slides in the basin, area ratio and relief ratio and Figure 1 shows the relation between the area ratio and the amounts of continual precipitation both for measured and calculated are shown, and both values show good conformity.

Table 1--States of the occurrence of surface slides due to heavy rain (by Yoshimatsu(2))
(i) R. Kamanashi basin

Precipitation(mm)	Area of basin	Total area of slides	Area ratio	Relief ratio
275	4.58	0.0120	0.0026	0.38
300	3.46	0.0510	0.0147	0.51
325	7.67	0.1795	0.0234	0.51
350	13.98	0.5595	0.0400	0.47
375	16.65	0.7693	0.0462	0.57
400	13.27	1.1986	0.0903	0.67
425	6.11	0.9829	0.1609	0.76
450	5.68	0.9632	0.1696	0.80

(ii) R. Tenryuu basin

Precipitation(mm)	Area of basin	Total area of slides	Area ratio	Relief ratio
350	2.00	0.0140	0.0070	0.24
375	5.66	0.0907	0.0160	0.27
400	5.26	0.1230	0.0234	0.24
425	7.72	0.4284	0.0555	0.36
450	12.87	0.7627	0.0593	0.38
475	15.84	1.2451	0.0786	0.36
500	10.05	1.0213	0.1016	0.34
525	7.99	0.8741	0.1094	0.30
550	14.17	1.8614	0.1314	0.30

(iii) R. Kizu basin

Precipitation(mm)	Area of basin	Total area of slides	Area ratio	Relief ratio
425	3.41	0.0446	0.0131	0.18
475	25.28	0.3257	0.0129	0.20
525	22.59	0.5110	0.0226	0.18
575	12.07	0.4371	0.0362	0.18