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Study of Tertiary Creep Mechanism by Ring Shear Apparatus in Predicting Initiation Time of Rainfall–Induced Landslides

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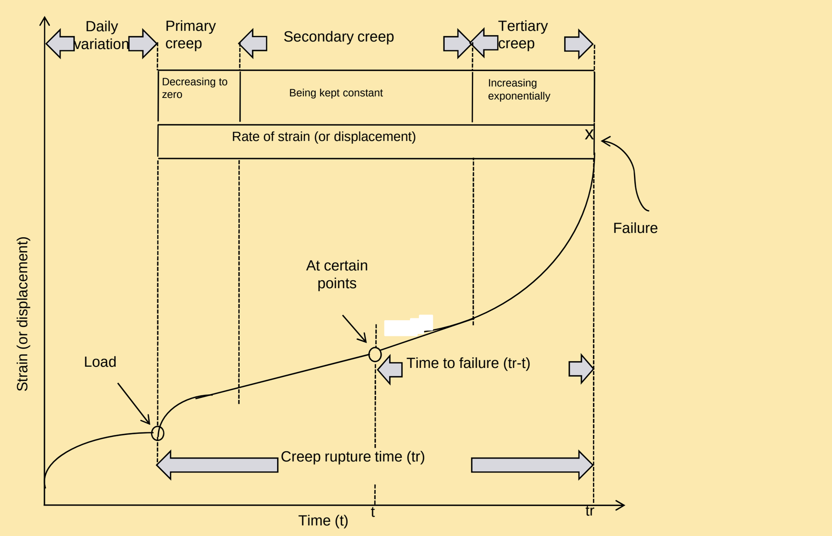
BACKGROUND

Landslides are complex geo-disasters frequently triggered by earthquake and/or intense heavy rainfall or other related natural/ anthropogenic impacts. Such catastrophic disasters have not only claimed residents' lives, but also resulted in property damages and other socio-economic consequences, which significantly interrupts the development of the communities and nations. Since the social resources for preventing those threatening potential landslides is limited in every country, the best solution is safe evacuation immediately before the final catastrophic failure of the landslide. To realize the effective evacuation, reliable prediction methodology must be established.

Accordingly, in landslide fields, failure-time prediction methods of landslide have been widely developed by many researchers. Remarkably, Fukuzono (1985) found a new method for predicting failure time of a slope based on the findings obtined from a series of large scale flume tests that logarithm of acceleration is proportional to logarithm of velocity of surface displacement immediately before the failure, $d^2x/dt^2 = A(dx/dt)^\alpha$. Fukuzono (1985, 1989) proposed a simple method for predicting the failure time by the inverse velocity of surface displacement (1/v), and it is used at many potential landslide sites in the world. However, the mechanism of this behavior is still unknown.

To investigate the mechanism of tertiary creep, a series of back-pressure control test were eventually implemented by stress-controlled ring shear apparatus. The tests were conducted under combined conditions of particular normal stress and shear stress with pore-water pressure changes to simulate the potential sliding surface condition in heavy rainfall, which no body experiences undertaking such a test series before. Mixture of sand and clay material was utilized to simulate actual landslide potential sliding surface. More, soil samples taken from actual landslide sites: El Salvador, Shobara and Tandikat cities were also tested in this test series.

CONCEPT OF CREEP IN SOILS



General relationship of strain and time of a series of creep deformation (Saito, 1960)

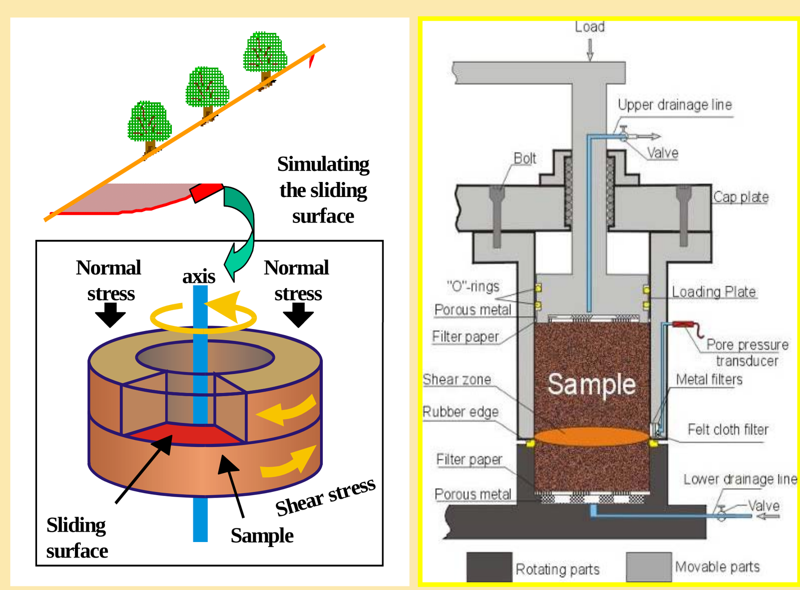
TEST DESCRIPTIONS

26 back-pressure control tests were performed to study the mechanism of tertiary creep deformation by paying attention to the inverse velocity curves, α value and relationship between A and α values. Such test series were undertaken under drained condition that the sample can changes its volume with BD value varies 0.95-0.99 and slope inclination θ= 30 .

Test no.	Samples	OCR	Pore pressure increase rate (du/dt, kPa/hr.)
1	SS8	1.0	150
2	SS8	1.0	150
3	SS8	1.0	150
4	SS8	1.0	100
5	SS8	1.0	100
6	SS8	1.0	100
7	SS8	2.0	150
8	SS8	2.0	150
9	SS8	2.0	150
10	SS8	2.0	100
11	SS8	2.0	100
12	SS8	2.0	100
13	SS8	4.0	150
14	SS8	4.0	150
15	SS8	4.0	150
16	SS8+Ben10%	1.0	150
17	SS8+Ben10%	1.0	150
18	SS8+Ben10%	1.0	150
19	SS8+Ben10%	5.0	150
20	SS8+Ben20%	1.0	75
21	El Salvador	1.0	25
22	Shobara	1.0	150
23	Tandikat 1	1.0	150
24	Tandikat 1	1.0	100
25	Tandikat 2	1.0	150
26	Tandikat 2	1.0	100

All test conditions

RING SHEAR APPARATUS

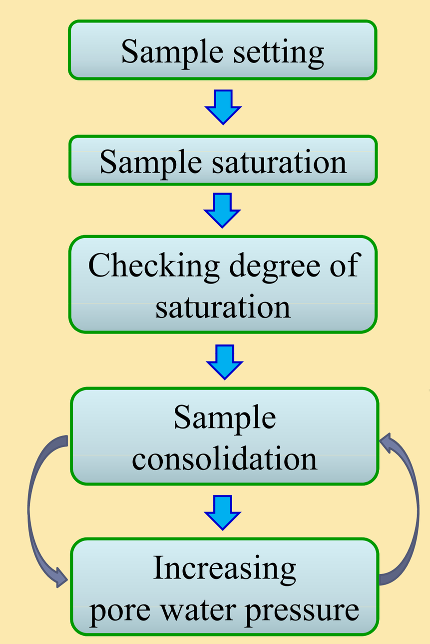


Design concept of the ring shear apparatus (Sassa, Fukuoka, et al., 2004)

View of the ring shear apparatus DPRI-7 *(by Sassa, Fukuoka & their colleagues at DPRI, Kyoto University to simulate the potential landslide sliding surface under earthquakes and rainstorm condition)*

- Shear box: inner and outer diameters: 27cm and 35cm.
- Unlimited shearing
- Undrained/ partially drained testing under rapid shearing and pore pressure monitoring.
- Shear speed: 33–300cm/sec.
- Rapid loading and high-speed data acquisition 12–1000 readings/sec.
- Transparent shear box made of acrylic basin enables observation of shear zone during the initiation and post-failure motions of landslide.
- Cyclic shear-displacement control, torque control, and shear speed control tests are possible.

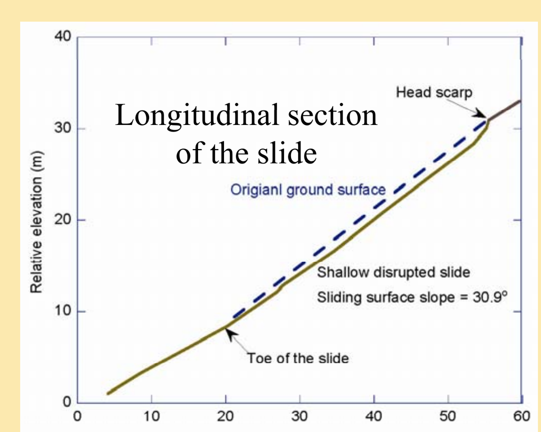
TEST PROCEDURES



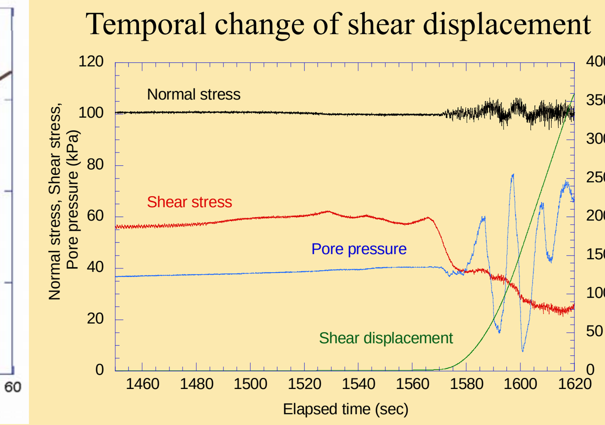
1. Samples were freely placed with filter paper insertion at the top and bottom.
2. CO_2 and de-aired water circulation for 1 or 2hr.(s) and 1 overnight respectively.
3. $B_D = \Delta u/\Delta\sigma$ ($B_D \geq 0.95$) (σ = 50–100 kPa in undrained condition)
4. Slowly load σ and τ (natural condition simulation) OCR = 1.0-5.0 with θ=30°.
5. Progressively increase pore water pressure to a targeted value (95kPa) with the particular σ and τ applied till failure occurs.

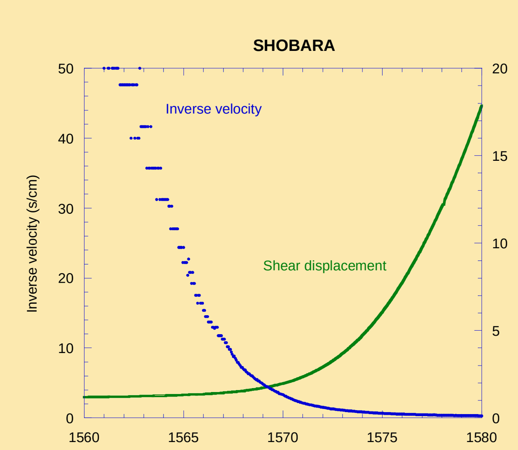
LANDSLIDE IN SHOBARA CITY

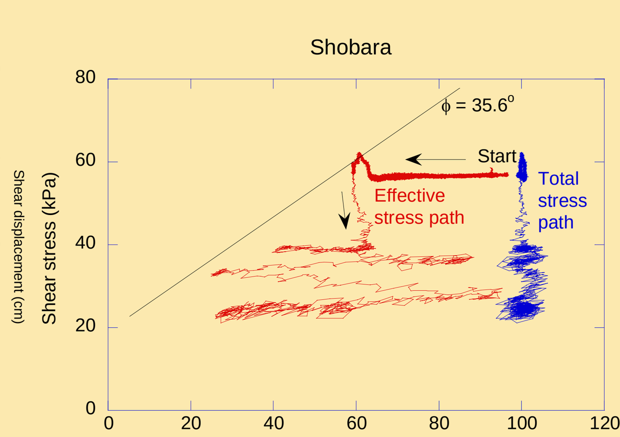
Sampling of the soils from the head scarp of the slide (less plastic silty soils)

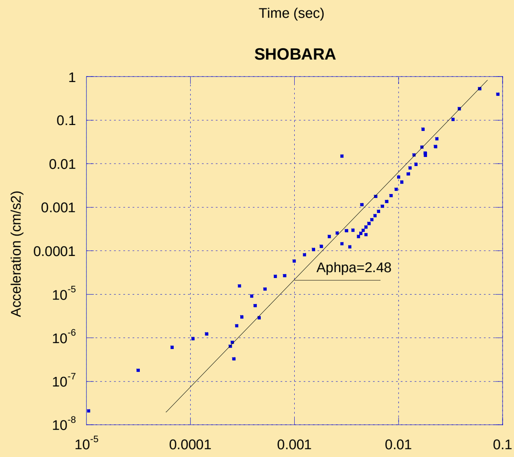


Temporal change of shear displacement

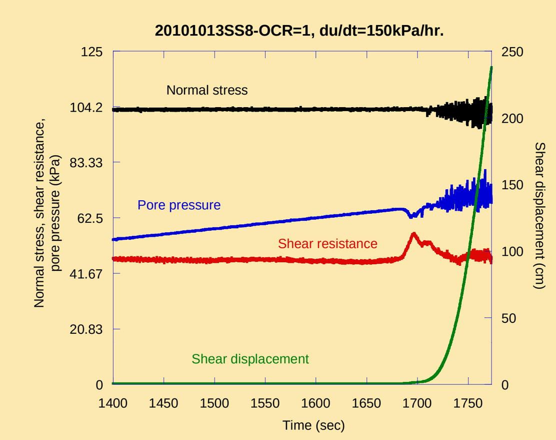


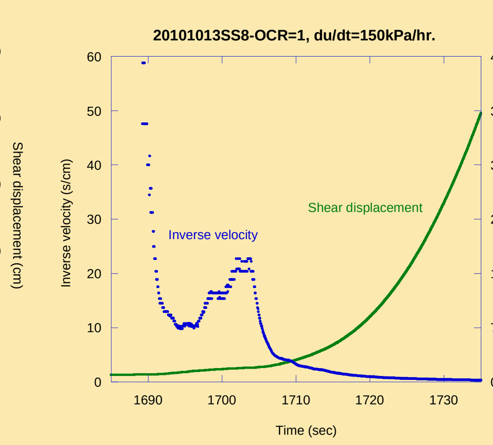


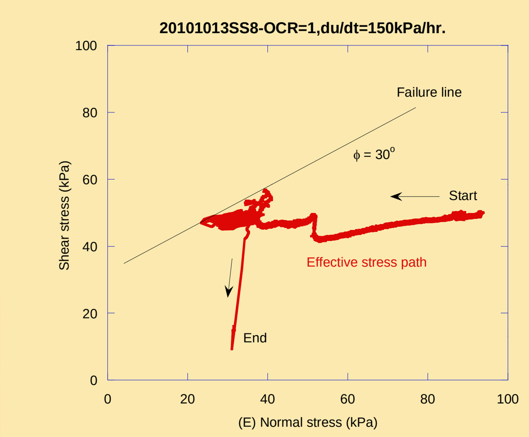


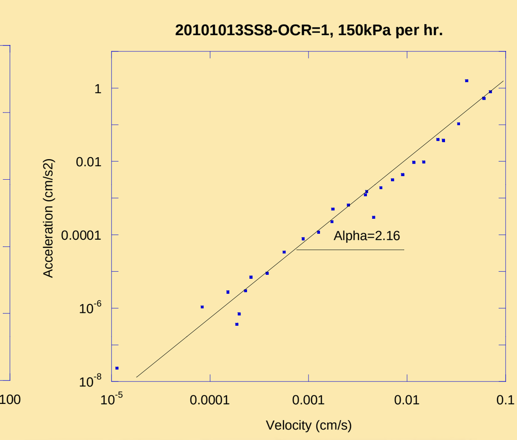


A PREFERABLE TEST RESULT









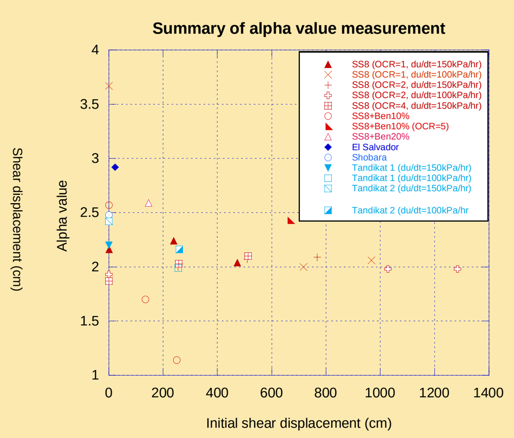
RESULTS AND DISCUSSION

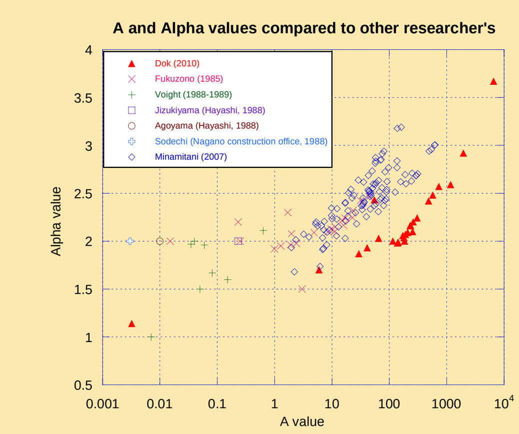
The investigation is principally focused on the curve of inverse velocity and shear displacement in several seconds immediately before failure, and the increment of acceleration and velocity observed about a few thousand seconds before failure to quantify tertiary creep deformation analysis. *Failure point is the point at which shear resistance is reaching its peak and after which shear displacement starts to increase cumulatively through constant time interval.*

Test no.	Samples	Initial shear displacement (cm)	α value	A value
1	SS8	1	2.16	234.94
2	SS8	239	2.24	305.73
3	SS8	473	2.04	180.87
4	SS8	717	2	185.2
5	SS8	967	2.06	173.43
6	SS8	0	3.67	6573.02
7	SS8	255	2	115.23
8	SS8	510	2.07	190.38
9	SS8	767	2.09	208.57
10	SS8	1028	1.98	139.73
11	SS8	1285	1.98	139.73
12	SS8	0	1.93	41.22
13	SS8	513	2.1	254.83
14	SS8	0	1.87	29.44
15	SS8	258	2.03	65.04
16	SS8+Ben10%	0.122	2.57	729.45
17	SS8+Ben10%	135	1.7	5.92
18	SS8+Ben10%	250	1.14	0.0032
19	SS8+Ben10%	668	2.43	55.14
20	SS8+Ben20%	146	2.59	1165.34
21	El Salvador	23	2.92	1955.48
22	Shobara	0	2.48	569.95
23	Tandikat 1	0	2.2	260.05
24	Tandikat 1	256	1.99	143.03
25	Tandikat 2	0	2.42	482.92
26	Tandikat 2	260	2.16	231.33

Results of back-pressure control tests by DPRI-7

PLOTS OF ALL TEST RESULTS





Left: variation of alpha value v.s. initial shear displacement, including repeated creep tests of same specimens. When longer shear displacement, less variation was observed.
Right: Relationship between A and alpha values of this test series and previous studies.

CONCLUSION

❖ Successful reproduction of tertiary creep behaviour similar to previous flume tests with artificial rainfall and previous progressive failure tests under shear stress increment conditions in ring shear apparatuses by pore-water pressure control ring shear test.

❖ Values of A and α obtained in this test series are in range of 0.003–6573 and 1.17–3.67, which agree with those found by previous researchers in spite of variation s of A value.

❖ The reason could be attributed by:
(1) portion of finer grains,
(2) slightly higher rubber edge friction of the shear box compared with previous ring shear tests,
(3) Increase rate of pore water generation due to time.

❖ Additionally repeated 1–15 time shear test for a specimen to produce reactivated motion landslide indicated less variation of alpha value.

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