京都大学防災研究所年報　第 55 号 B　平成 24 年 6 月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 55 B, 2012

Portable Ring Shear Apparatus and its Application on Croatian Landslides

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Synopsis

Kostanjek and Grohovo landslides were chosen for research as pilot areas within the Japan - Croatia joint research project ‘Risk Identification and Land-use Planning for Disaster Mitigation of Landslides and Floods in Croatia’. Laboratory soil testing is one of the activities planned for the analyses of these two landslides. A new, transportable ring shear apparatus, ICL-1, was designed to be used in Croatia. The surface samples from two Croatian landslides were tested in the ring shear apparatus. The results of these tests will be used in further research, for the planning of ring shear tests on borehole samples and as input data for landslide simulation. Since borehole samples are limited, the preliminary tests on surface samples are necessary. The results of the conducted undrained ring shear tests, both speed control and cyclic stress control tests are shown in the paper.

Keywords: ring shear test, undrained speed control test, undrained cyclic stress control test, Grohovo landslide, Kostanjek landslide

1. Introduction

The Japan - Croatia joint research project ‘Risk Identification and Land-use Planning for Disaster Mitigation of Landslides and Floods in Croatia’ was initiated as a part of UNESCO-Kyoto University-ICL UNITWIN (university twinning and networking programme of UNESCO) Cooperation Programme for landslide and water-related disaster risk management.in 2009. The five-year project involves collaborative research conducted in Japan and Croatia to evaluate hazard and mitigate landslides and flood risks in Croatia. The project aims to contribute to sustainable development through appropriate land use in Croatia (Mihalic and Arbanas, 2011). The project activities are organized in three working groups: Working Group on Landslides (WG1), Working Group on Flash Flood and Debris Flow (WG2) and Working Group on Landslide Mapping (WG3) (Arbanas and Mihalic, 2012).

Research activities of WG1 include real time monitoring of landslides, laboratory soil testing, as well as modeling of landslide behavior and early warning system. Laboratory equipment, including a newly developed ring shear apparatus, is donated by the Japanese government for analyses of landslides in Croatia. The pilot study sites are the Grohovo landslide in Rijeka and the Kostanjek landslide in the City of Zagreb (Mihalic and Arbanas, 2011). In order to install monitoring equipment and obtain soil samples for laboratory tests on the ring shear apparatus, three boreholes were drilled.

A new, transportable undrained ring shear apparatus, ICL-1, was designed for use in Croatia. The concept was to develop inexpensive and transportable undrained ring shear apparatus to be used in different counterpart organizations. It can keep undrained condition up to 1 MPa of pore water pressure (up to two times more than in previous versions of apparatus) and load normal stress up to 1 MPa.

This paper presents the results of the ring shear tests conducted on the surface samples from two Croatian landslides. The results obtained in this study, will be used in planning of further research, namely, ring shear tests on borehole samples and as input data in numerical simulation of landslides.

2. Landslides in Croatia

As previously mentioned, Kostanjek landslide in Zagreb and Grohovo landslide in Rijeka were selected as study areas within the research activities of WG1. Locations of both landslides are indicated on Figure 1.

Those study areas were selected because of their impact on local communities and the fact that they represent different conditions and triggering factors. In the following text, the main characteristics of these landslides are described.

Fig.1 Location map of two study areas in Croatia- Grohovo and Kostanjek landslide

2.1 Grohovo Landslide

The investigated landslide is situated at the northeastern slope of Rjecina river valley. Slopes in the central part of Rjecina River valley are often unstable and several larger landslides were recorded during 19th and 20th century. There are historic records of past slope movements that are closely related to rainfall and flood events in this area (Ostric et al. 2011).

The investigated landslide is a reactivate type of landslides. The landslide mass has moved several times in the past, the most recent movement occurred in December 1996. Long rainy period in autumn and early winter of 1996Triggered reactivation of this landslide mass It started by undercutting of toe of the landslide mass at the bottom of the slope that caused retrogressive development up to the top of the slope (Benac et al, 2005).

Figure 2 shows the cumulative rainfall measured in October, November, and December, 1996. at the Rijeka rain gauge. In the considered period, the monthly rainfall was from 94% (October) to 64 % (November) higher than the average monthly values in the period from 1948 to 2009 (red lines in Fig. 2) (Ostric et al. 2011).

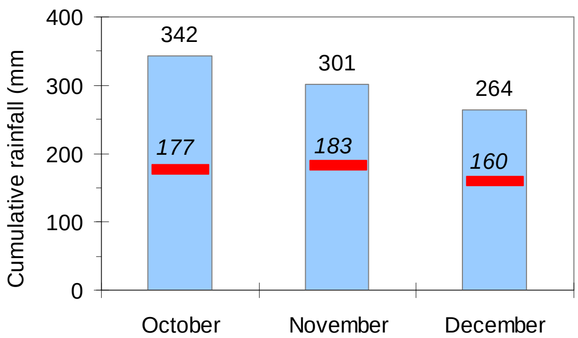

Fig. 2 Cumulative rainfall at the Rijeka rain gauge for October, November, and December 1996.
Red lines and italic numbers show long-term (1948–2009) monthly averages.

Grohovo Landslide is a reactivated landslide and a typical landslide formed on the contact between flysch and carbonate rock formations. Geological composition and groundwater dynamics of the slope were the most important landslide causes (Benac et al, 2005. and 2006). With 13 different slide bodies identified, it represents a complex composite landslide. Failure surface is assumed at the contact between slope deposits (consisting of clayey matrix from flysch weathered zone and debris material from the limestone cliffs on the top) and flysch bedrock. Estimated depth of the displaced mass varies from 6 to maximum 20 m (Benac et al. 2005). As the position of the slip surface was predisposed by the slope geology, the landslide can also be considered as dominantly translational in character (Cruden & Varnes 1996).

2.2 Kostanjek Landslide

Kostanjek landslide is located on the southwestern slope of Mt. Medvednica that belongs to the western residential area of the City of Zagreb. The area of Kostanjek landslide is a syncline dipping toward the east.

This is the largest landslide in Croatia, mainly caused by anthropogenic factors; namely, mining activities by excavation of limestone and marl at the foot of the slope. Kostanjek landslide was activated in 1963 and excavation for mining was stopped in 1988 after identification of surface excavation in the toe of landslide as the triggering factor (Stanic et al, 1996). Although excavation was stopped, surface displacement and consequently damage to the buildings and infrastructure, continued up to today.

Landslide extends over an area of approximately 1.2 km^2 with a total volume of displaced mass of $32.6x10^6$ m^3. It is a reactivated, translational type of landslide without clearly defined main scarp or landslide borders. According to Ortolan and Pleško (1992) there are three different sliding surfaces, the deepest at 90 m and two sub parallel slip surfaces at depths of 65 m and 50 m. The deepest sliding surface follows Tripoli layers (Sarmatian deposit composed of laminated marl). The shallower sliding surfaces (65 and 50 m depth) follow clayey beds within the Panonian deposits (marl and clayey marl).

Since its activation in 1963, this landslide has caused substantial damage to buildings and infrastructure and significantly limited the urban development of the City of Zagreb.

3. Test Apparatus and Test Procedures

The latest ring shear apparatus, ICL-1 as well as the testing procedure, are shortly described in this section. The details of the ring shear apparatus structure, loading and monitoring system are described in published papers (Ostric et al, 2012a, Ostric et al 2012b).

3.1 Ring Shear Apparatus

The ring shear apparatus has been widely used in the analysis of slope stability, because it provides almost unlimited shear displacement (Bishop, 1971, Tika et al, 1999, Sassa, 2004).

Sassa and colleagues have developed a series of undrained ring shear apparatus with pore pressure monitoring system since 1984 (Sassa et al. 2004). The latest, Portable Ring Shear Apparatus, ICL-1, was desinged by Sassa at the ICL as a part of Japan-Croatia joint project in 2010. Although small in dimensions, ICL-1 has high performances (Table-1). The shear box is smaller than in previous DPRI versions, and the necessary volume of sample for one test is app. 300 cm^3 which is suitable for limited amount of samples that are taken from drilled cores. Table 1 presents the major characteristics of new ring-shear apparatus in comparison to the previous versions of apparatus (DPRI-1 to 7) that were developed by Sassa and colleagues at the DPRI (Disaster Prevention Research Institute), Kyoto University.

In order to be transportable for use in different organizations, it was designed to be much smaller in dimensions comparing to previous versions. It can load normal stress and keep undrained condition up to 1 MPa of pore water pressure (up to two times more than in previous versions of apparatuses). This makes it suitable for investigation of large-scale and deep seated landslides.

The sample is placed in a shear box and loaded normally through an annular loading plate connected to an oil piston. It is sheared by rotating lower half of shear box (while two shear resistance cells restrain the upper half. Three shear control modes are possible in ICL-1, stress control, speed control, or displacement control mode.

The most essential part of the ring shear apparatus is the construction of the undrained shear box (SB). Design of the shear box is illustrated in

Figure 3 with enlarged diagram of the right half of the cross section of the SB and its surroundings, including the water pressure measurement system

The sample in the ring-shear box is laterally confined between pairs of upper and lower confining rings, forming the shape of two doughnuts. .During the test, the sample is loaded normally through an annular loading plate connected to an oil piston. The lower half of the shear box rotates while the upper half of the shear box is retained by two shear resistance cells that measure shear resistance.

Table 1 Features of ICL-1, compared with the previous versions of DPRI- 1 to 7.

AUTHOR	Sassa (1992) DPRI-3	Sassa (1996) DPRI-4	Sassa (1997) DPRI-5	Sassa (1997) DPRI-6	Sassa (2004) DPRI-7	Sassa (2011) ICL-1
Inner diameter (cm)	21.0	21.0	12.0	25.0	27.0	10.0
Outer diameter (cm)	31.0	29.0	18.0	35.0	35.0	14.0
Max. height of sample (cm)	9.0	9.5	11.5	15.0	11.5	5.2
Ratio max. height/width	1.8	2.38	3.83	3.0	2.88	2.6
Shear area (cm^2)	408.41	314.16	141.37	471.24	389.56	75.36
Max. normal stress (kPa)	500	3.000	2.000	3,000	500	1000
Max. shear speed (cm/sec)	30.0	18.0	10.0	224.0	300.0	5.4
Max pore water pressure (kPa)	-	490	400-600	400-600	400-600	1000
Max. data acquisition rate (readings/sec)	12	200	200	200	1000	1000

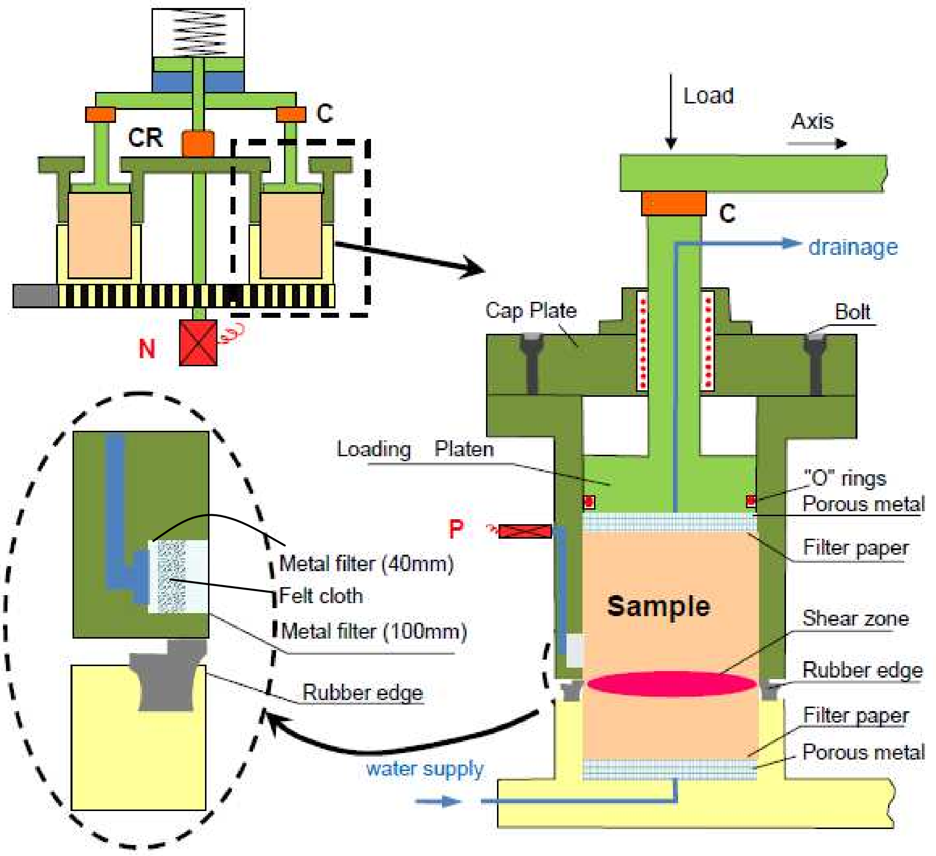

Fig. 3 A half cross-section of the shear box and the close-up diagram of the edges (CR - Connection Ring, C - Connection , N - Load cell for Normal Stress; P - Pore pressure transducer)

When shear failure occurs, the annular ring-shaped sample is sheared by relative rotary motion and the lower part starts to rotate along with the rotating table.

Pore pressure is measured by pore-pressure transducers, which are connected to a gutter along the circumference of the inner wall of the upper outer ring. The gutter is located 3 mm above the shear surface and it is covered by two metal filters. As it is shown on Figure 3, two annular metal filters with pore sizes of 100 μm and 40 μm (from inside) were placed inside the annular gutter. A felt fabric cloth was placed between these two metal filters to prevent the outside (40 μm) filter from becoming clogged with clay particles.

3.2 Testing Procedure

Testing procedure consists of the following: gap adjustment; sample setting and saturation; saturation checking by B_D measurement; sample consolidation and shearing (by shear speed control or cyclic stress control).

First, the gap value should be adjusted to avoid leakage of water and sample, by applying vertical load of 1.5 kN to both of inner and outer rubber edges. To keep rubberer edge contact pressure greater than the generated pore pressure inside the shear box. Thereafter, the gap is automatically kept constant by the servo gap control system. Then, shear box without sample was filled with CO_2 and de-aired water in order to expel entrapped air. Then, sample that was saturated by de-aired water during night is slowly placed in the de- aired water inside the shear box. The saturation of sample is then checked by measuring B_D value that should be greater than 0.95 for fully saturated samples. B_D is a pore pressure parameter in direct shear state, related to the degree of saturation that was proposed by Sassa (1988), and is formulated as:

$$B_D = \Delta u / \Delta \sigma \qquad (1)$$

Where Δu is the increment of pore water pressure increase due to a change in total normal stress Δσ in undrained conditions.

For both samples, Grohovo flysch surface sample and Kostanjek marl surface sample, we obtained B_D=0.95, which means that we succeeded to obtain fully saturated sample without water circulation.

The initial stress state of soils only due to gravity is loaded onto the fully saturated sample. So, the sample was normally consolidated under the normal and shear stress, which was calculated from the depth of soil layer, slope angle and unit weight of soil.

We used initial normal stress of 1000 kPa for Kostanjek sample and 200 kPa for Grohovo sample. After the consolidation, shearing was applied by stress control mode (cyclic test) or speed control test.

4. Test Results

In this study, we made two types of tests: speed control and cycling loading tests, both in undrained condition. Surface samples from Grohovo and Kostanjek landslide were taken from locations with outcrops of materials where sliding surfaces might be formed within the soil layer consisting of the same type of materials in the past. Kostanjek sample was taken from the marl outcrop while the Grohovo sample was taken from the flysch outcrop.

4.1 Speed Control Test

Speed control tests were conducted on a saturated marl (Kostanjek landslide) and weathered flysch (Grohovo landslide) (B_D=0.95 was obtained for both samples). After consolidation of the samples (by applying normal stress up to 1000 kPa for Kostanjek and 200 kPa for Grohovo sample) – according to estimated depth of sliding surface speed control tests were conducted under constant shear speed of 0.002 cm/sec in undrained condition. Both samples were sheared until steady state condition was obtained. The results of Speed control tests are presented in Figs. 4 and 5, showing the effective stress path (ESP) in red color and total stress path (TSP) in blue color as well as parameters obtained (mobilized and apparent friction angle, cohesion, steady state normal and shear stress).

Figure 4 shows stress path that reached the failure line and moved down along the failure line. In this test, the peak failure line was not observed. The straight line fitting the stress path gave values of the friction angle during motion as well as peak friction angle of 25.3° and apparent friction angle, ϕ_a=13.8°. We assumed cohesion is zero.

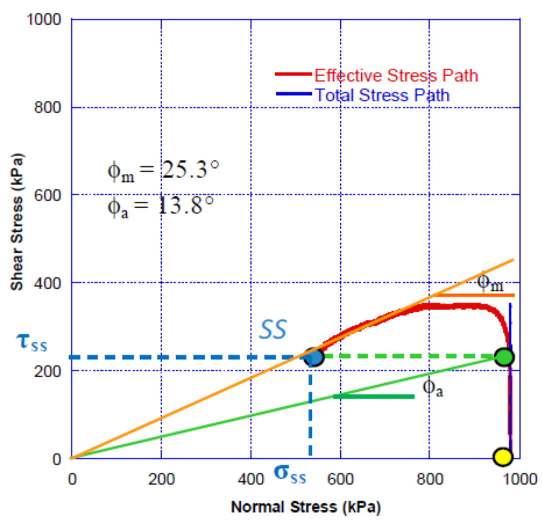

Fig.4 Stress path of Undrained Speed Control Test on saturated marl sample from Kostanjek landslide (B_D=0.95; initial dry density: 1.48 g/cm^3, specific gravity, G_S=2.70).

Figure 5 shows stress path that reached the failure line and moved down along the failure line and like in the previous test, the peak failure line was not observed. The straight line fitting the stress path gave values of the friction angle during motion and also at peak as ϕ_p= ϕ_m =31.9° and apparent friction angle, ϕ_a=20.4°. We assumed cohesion is zero.

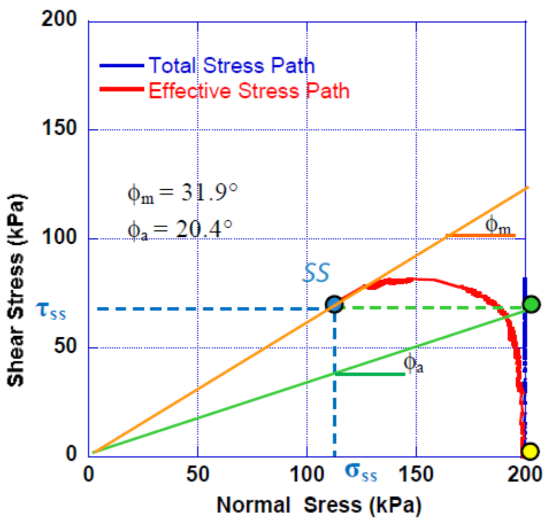

Fig. 5 Stress path of Undrained Speed Control Test on saturated clayey sample from Grohovo landslide (B_D=0.95; initial dry density: 1.51 g/cm^3, specific gravity, G_S=2.664).

4.2 Cyclic Stress Control Test

After consolidation of the sample, cyclic shear stress loading was applied in the undrained condition. The results of cyclic tests are presented in Figures 6 and 7. Figures 6a and 7a are showing time series data of cyclic tests, where the black line shows normal stress, the light blue line shows the control signal for shear stress which was given to the servo-stress control motor. The red line shows the shear resistance mobilized on the sliding surface, the dark blue line shows the monitored pore pressure and the green line shows the shear displacement. Figures 6b and 7b are showing stress path, with red line showing effective stress path and blue line showing total stress path.

Figure 6 shows time series data and the stress path of cyclic test conducted on the Kostanjek marl sample. For this sample, initial normal stress of 1000 kPa and initial shear stress of 300 kPa was applied before cyclic (sine wave) shear stress was loaded at 0.1 Hz and stepping up shear stress by 40 kPa/ cycle.

Although pore pressure must have been generated in the shear zone, it could not be well monitored as it can be estimated on Figure 6b.
During the post failure movement after 80 sec in Figure 6a, the effective stress should be on the failure line. So the horizontal difference between the failure line and the monitored effective stress (550 kPa) is excess pore water pressure value which was not monitored by the pore water pressure sensor shown in Figure 6a. This is due to the slow response resulting from the lower permeability of the material tested.

The accelerated motion was produced after failure, as it is shown on Figure 6a. Although, initially both lines of the control signal for shear stress and the mobilized shear resistance are the same, they differ after failure. Shear resistance decreased from the maximum value of 490 kPa to the steady state although control signal is continued to be increased. The difference of stress is used for acceleration of shear motion.
Figure 7 shows the time series data and stress path of cyclic test conducted on the Grohovo clayey flysch surface sample. Due to the low permeability of this sample, we chose much slower cycle shearing of 2 cycles/ hour.

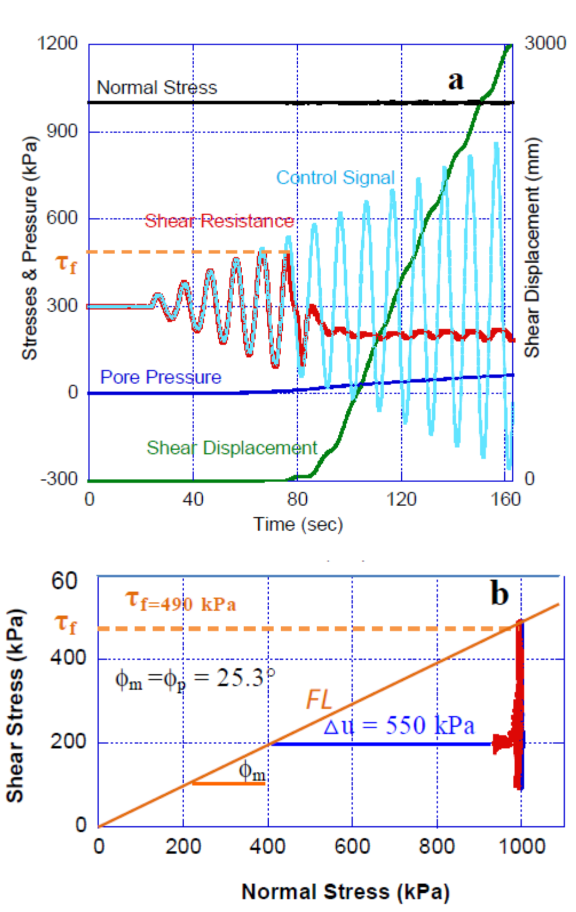

Fig. 6 Undrained cyclic loading test on saturated marl sample from Kostanjek landslide (B_D=0.96; initial dry density: 1.48 g/cm^3, specific gravity, G_S=2.70). a) Time series data for stress, pressure and shear displacement and b) Stress Path.

For Grohovo sample, initial normal stress of 200 kPa and initial shear stress of 80 kPa was applied before cyclic shear stress was loaded with the amplification increment of 10 kPa/ cycle at 0.1 Hz. The sample failed, but without rapid failure motion. Figure 7a shows that displacement of 700 mm occurred after 6, 000 sec and pore pressure of app. 20 kPa was generated. Unlike the previous case (Kostanjek sample), both lines of the control signal for shear stress and the mobilized shear resistance are the same during the test.

Shear displacement occurred in a different mode then for Kostanjek sample. Each time shear stress given by control signal reached value of shear resistance, shear displacement occurred.

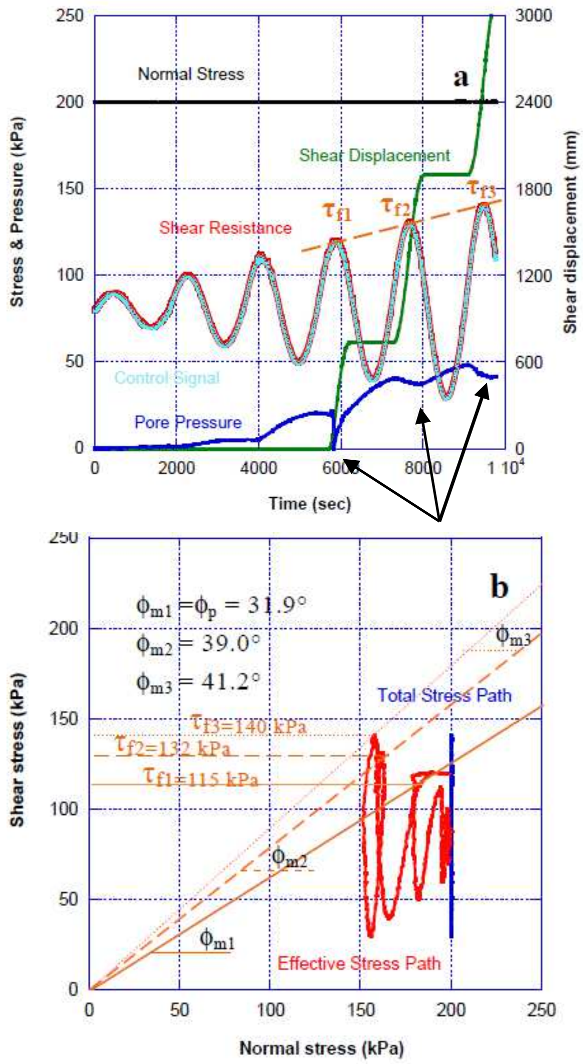

Fig. 7 undrained cyclic loading test on saturated clayey flysch sample from Grohovo landslide (B_D=0.96; initial dry density: 1.51 g/cm^3, specific gravity, G_S=2.66). a) Time series data for stress, pressure and shear displacement and b) Stress Path.

When shear stress decreased, displacement stopped and shear resistance moved down with loaded shear stress lower than failure line. Sample showed dilative behavior, which is indicated by black arrows on the graph, showing negative pore pressure generation at each displacement step. Consequently, the peak friction angle increased as well, from the initial value of 31.9° to 39.0° and 41.2°. The sample showed strength-hardening behavior.

5. Summary and Conclusions

Laboratory soil testing are planned to support monitoring and modeling of landslides for the analyses of two Croatian landslides. A new, transportable ring shear apparatus, ICL-1, was applied for these two landslides. The purpose of this apparatus was to design a new transportable and inexpensive apparatus used in different counterparts in Croatia.

By performing undrained ring shear tests on surface samples from two Croatian landslides, experimental procedure is established and preliminary results are obtained. Since the amount of borehole samples is very limited, it is necessary to establish a successful testing procedure for these landslides. Besides planning of further ring shear tests, the results obtained by this study could be used as input parameters in numerical analysis of both landslides.

The undrained cyclic test results showed different behavior for the two samples. Kostanjek sample failure was followed by a rapid motion, while Grohovo sample had an increase of friction angle and shear resistance, showing soil hardening behavior. From this we could conclude that soil from Kostanjek landslide is weak, while the Grohovo sample showed to be hard to seismic loading.

Acknowledgements

The authors are grateful for the help of Dr. Zeljko Arbanas and Dr. Snjezana Mihalic. The help of Master student, Hendy Setiawan is also highly appreciated. The design and construction of the ring shear apparatus ICL-1, was conducted under the support of SATREPS Programme (Science and Technology Research Partnership for Sustainable Development) and Internatioal Programme on Landslides (IPL-161 "Risk identification and land-use planning for disaster mitigation of landslides and floods in Croatia"). The tested soils were imported from Croatia with permission from the Japanese Minister of Agriculture, Forestry,and Fisheries based on the Plant Protection Law of the Government of Japan and tested at the UNESCO-KU-ICL UNITWIN laboratory in the Yoshida main campus of Kyoto University

Thanks go to Mr. Takaaki Hirano and other engineers of Marui & Co., Ltd.. Osaka, Japan for numerous improvement and modification for the practical use of the apparatus abroad based on the Japan-Croatia joint experinents in 2010 and 2011.

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(Received June 8, 2012)

ポータブルリングせん断試験機とクロアチア国での地すべりへの応用

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要　旨

コスタニック(Kostanjek)とグロホボ(Grohovo)地すべり地域を，JICA-JST共同研究「クロアチア土砂・洪水災害軽減基本計画構築プロジェクト」におけるパイロット研究地域として選んだ。これらの二つのパイロット地域の地すべりのせん断特性を解明するために実験室における土質試験を計画し，日本ークロアチア共同研究のために開発された新型のポータブルリングせん断試験機ICL-1を用いて両地域の表土サンプルのせん断試験を実施したので報告する。本試験結果は，今後、ボーリングにより採取した分量の限られたサンプルのせん断試験の立案に用いるとともに，両地すべりの発生・運動予測のための地すべり数値シミュレーションに必要な入力数値の決定に利用する。本研究では，せん断速度制御と繰返し載荷せん断応力制御試験の双方における非排水リングせん断試験の結果について述べる。

キーワード: リングせん断試験，非排水速度制御試験，非排水繰返し応力制御試験，グロホボ地すべり，コスタニック地すべり