INSTRUCTION AND ESSENTIAL OUTPUTS OF THE CROATIAN-JAPANESE RESEARCH PROJECT ON LANDSLIDES

prof dr **Hideaki Marui**
Research Institute for Natural Hazards and Disaster Discovery, Niigata University, Ikarashi-Ninocho 8050, Nishi-ku, Niigata, 950-2181 Japan
dr **Eisaku Hamasaki**
Advantechnology Co., Ltd., Kakyouin 1-4-8-1202, Aoba-ku, Sendai, 980-0013 Japan, Hamasaki
lect.dr.**Gen Furuya**
Engineering Department, Toyama Prefectural University, Kurokawa 5180, Imizu, 939-0398 Japan

Summary:

This paper highlights instruction and essential outputs of the Croatian-Japanese joint resarch project on landslides. The main objective of the project is to develop an appropriate landslide hazard zoning technology and a formulation technology of land-use guildelines through basic scientific study of landslide mechanism and through landslide risk identification in consideration of Croatian societal and natural conditions. The following items are essential outputs attained through in the framework of the project: (1) Individual landslide topographies in each target areas were identified based on aerial photo interpretation. Further, the danger degree of each individual landslide topography was evaluated by the analytical hierarchy process (AHP) method. (2) Characteristics of movement behavior of targeted landslides were grasped by the comprehensive monitoring systems installed in Grohovo landslide area near Rijeka City and also in Kostanjek landslide area in Zagreb City. (3) Prediction of travel distance for selected representative landslides was carried out using shear strength parameters measured by the newly developed portable ring shear apparatus. (4) prototype hazard maps and risk maps on landslide disasters were developed for selected target areas. (5) Land-use guidelines for target areas were formulated as a final output. As an important follow up output after the official termination of the project, a lumped mass system model with damper is proposed, which enables simulation of moving velocity of landslide.

Keywords:

Croatian-Japanese joint research project, Hazard zoning, Land-use guidelines, Aerial photo interpretation, Analytical hierarchy process, Potable ring shear apparatus, Lumped mass system model with damper.

1. OVERVIEW COMPOSITION of tHE JOINT RESEARCH PROJECT

The Croatian-Japanese joint research team has carried out a comprehensive research project entitled "Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia" for five years from 2009 to 2013. The project was selected for the framework of the Science and Technology Research Partnership for Sustainable Development (SATREPS), a research program under the auspices of the Japan Science Technology Agency (JST) and the Japan International Cooperation Agency (JICA). The Research Institute for Natural Hazards and Disaster Recovery of Niigata University, together with the Disaster Prevention Research Institute of Kyoto University and the International Consortium on Landslides were Japanese partner institutions in the project. Three Croatian Universities, the University of Rijeka (Faculty of Civil Engineering), the University of Zagreb (Faculty of Mining, Geology and Petroleum Engineering) and the University of Split (Faculty of Civil Engineering, Architecture and Geodesy), as well as Croatian Geological Survey, are Croatian partner institutions. The joint research team involved about 15 researchers from Japan and about 40 researchers from Croatia in order to fulfill wide range of research targets included in this project.A conceptual diagram of the project is shown in Chart 1. The project consists of three main research components, namely (1) landslide research, (2) flood research and (3) integration research. On the basis of the threecomponets, formulation of land-use guidelines for mitigation of landslide and flood disasters were targetted as final project purpose.The project aims to contribute to sustainable development through appropriate land-use in Croatia. In this report, instruction and essential outputs of the project focusing on landslides are described exclusively. The main objective of the project is to develop an appropriate landsldie hazard zoning technology and a formulation technology of land-use guidelines through basic scientific study of landslide mechanism and through landslide risk identification in consideration of Croatian societal and natural conditions. Following investigations and analyses were carried out: 1) identification and mapping of landslides, 2) comprehensive monitoring of landslides, 3) testing of physical and mechanical properties of soils and rocks, 4) modeling of landslide dynamics, 5) landslide susceptibility assessment and hazard zonation, 6) establishment of early warning systems and 7) development of risk mitigation measures through appropriate land-use.

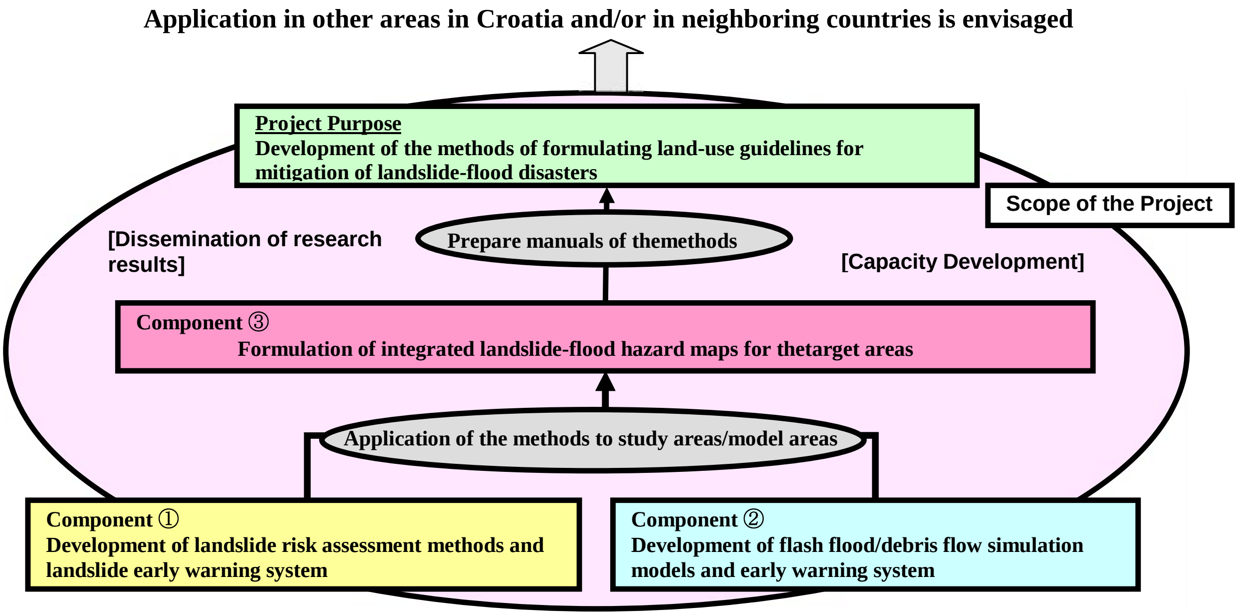


Chart 1. Conceptual diagram of the Croatian-Japanese joint research project

Individual research components and performance steps described above are shown in Chart 2. In early stage of the project, comprehensive real time monitoring of landslides, laboratory soil testing and numerical modeling of static and dynamic landslide behavior were carried out. Newly developed dynamic ring shear apparatus, software for landslide stability analyses and equipment for comprehensive landslide monitoring systems were donated by the Japanese government for analyses of two most important targeted landslides in

Croatia: the Grohovo landslide near Rijeka City and the Kostanjek landslide in Zagreb City. The monitoring systems should be used not only for research purposes but also for practical applications of early warning systems for possible hazards related to future dangerous landslide movements. The early warning system will be used for crisis management in communities where the dangereous landslides were located. The monitoring systems and the data on landslide behavior should be used to design appropriate interventions to mitigate the hazards and design steps for the evacuation of the population and the protection of infrastructures and facilities.

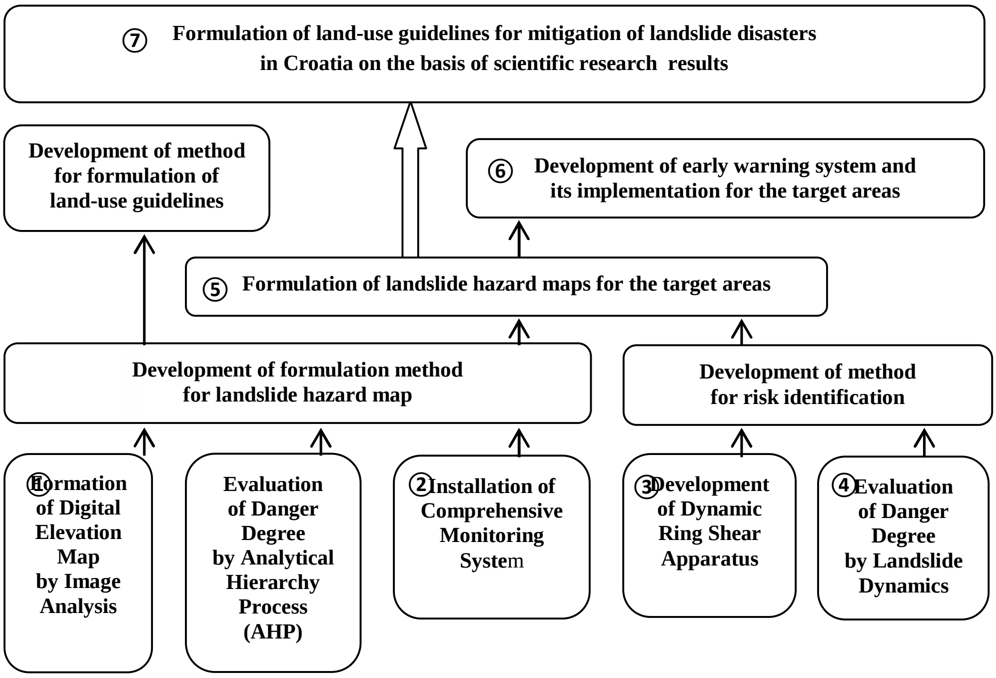


Chart 2. Individual research componets and performance steps

2. COMPREHENSIVE MONITORING SYSTEMs

Several analytical results obtained by the both monitoring systems mentioned in the previous chapter will be described. Comprehensive monitoring systems are composed of various types and categories of techniques and equipment in order to clarify the relationship between landslide movements and triggering factors. A desirable monitoring system depends on the characteristics of movement types and also local geomorphological and geological conditions of the target landslide area. Therefore, different systems were installed in the Grohovo landslide area and in the Kostanjek landslide area respectibly.

2.1. Monitoring system in the Grohovo landslide area

The Grohovo landslide, one of the largest active landslides along theAdriatic coast, is located on the north-eastern slope of the Rjecina River Valley. The comprehensive monitoring system in the Grohovo landslide area consists of geodetic and geotechnical monitoring [1]. Geodetic monitoring includes geodetic surveys using a robotic total station that measures positions of 23 prisms and displacement measurements of GPS receivers (9 rovers and 1 master unit). The robotic total station and the GPS master unit are located on the top of the opposite slope. Equipment for the geotechnical monitoring includes2 vertical inclinometers, 11 long-span and 3 short-span wire extensometers, 4 pore pressure gauges and weather station.

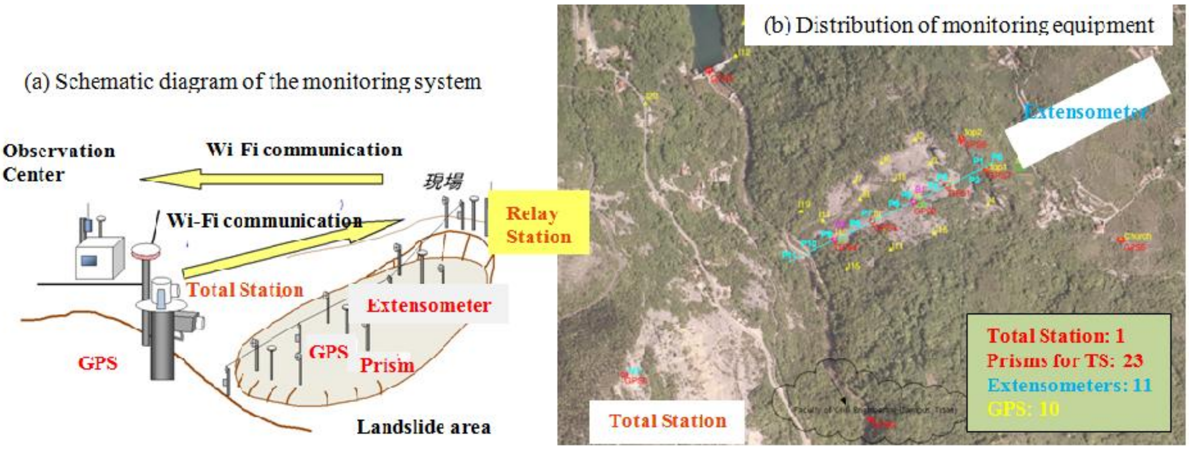
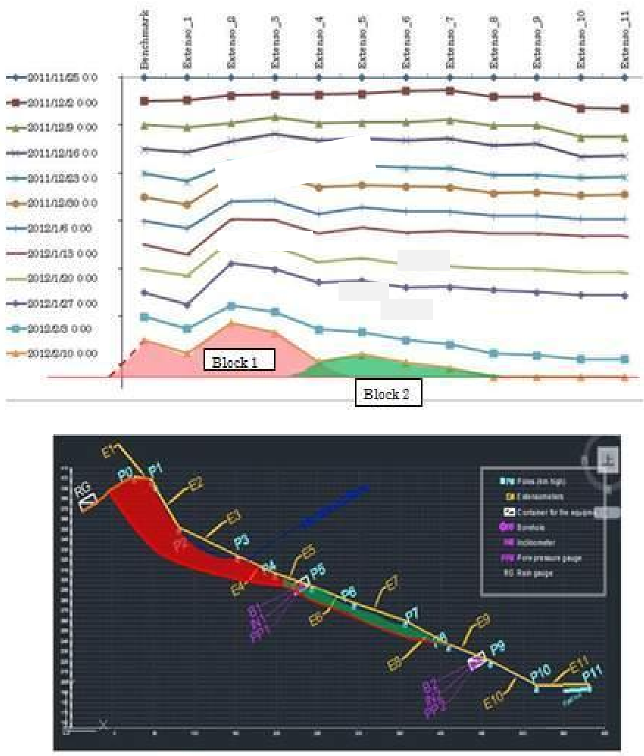


Chart 3.Comprehensive monitoring system installed in the Grohovo landslide area



Interpretation of the Grohovo landslide based on the extensometer monitoring from 25 November 2011 to 10 February 2012. (Sassa & Nagai 2012.2.19)

Chart 4. Monitoring results by extensometers

All monitoring equipment is connected in one system with continuous monitoring and transfer availability of the data to a central computerunit located at the Faculty of Civil Engineering, University of Rijeka. Overview of the monitoring system is shown in Chart 3.

A series of wire extensometers (11 long-span) are installed from riverbed of the Rjecina River to the limestone mega-block at the top of the slope. Monitoring results using extensometers are shown in Chart 4. Left up figure shows accumulation value of movements. Point (P1) is treated as a stable point. Compression is indicated by (+), extension by (-). Lower convex shapes showapparent movement blocks, namely Block 1 and 2. Distance from basement line shows amount of movement. Left down figure shows the estimated two landslide blocks on the target slope. Upper block is colored by red. Middle Block is colored by green. It is necessary to check the margin of the upper Block. Margin of the Block can be at Point P0 at the top of the slope, or it can be a little bit downward the slope over the ridge. Two additional short-span extensometers are installed to check the location of the margin.

Wire extensometers provide reliable data on surface movement of landslide mass because of its simple design and structure. It is useful to compare observed data by total station surveying and by GPS to data measured by extensometers.

2.2. Monitoring system in the Kostanjek landslide

Kostanjek landslide is the largest landslide in Croatia with a total volume of 32x106m3. It is located in the western part of Zagreb City, in residential area at the margin of the southwestern slope of the Mt. Medvednica. A comprehensive, real time monitoring system was installed. The monitoring system consists of geodetic, geotechnical, seismological and hydrological equipment [4]. Geodetic equipment includes 15 GNSS (Global Navigation Satellite System) stations, geotechnical equipment includes 9 extensometers at five different locations and one 100m borehole with inclinometer casing. Pore pressure gauges were installed in borehole at the central part of the landslide area, at three different levels. Landslide movement was measured by GNSS-receivers distributed at various points of the landslide area as shown in Chart 6. All GNSS-receivers show continuously a certain extent oflarge displacement to the southwest direction.

(a) Overview of Kostanjek landslide area (b) Extensometer installed in tunnel (c) Distribution of equipment

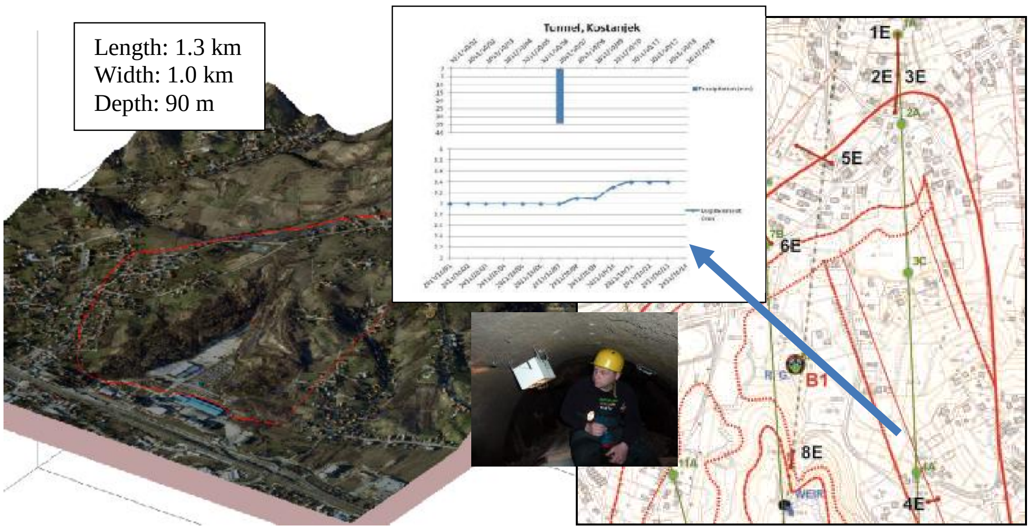


Chart 5.Comprehensive monitoring system installed in Kostanjek landslide

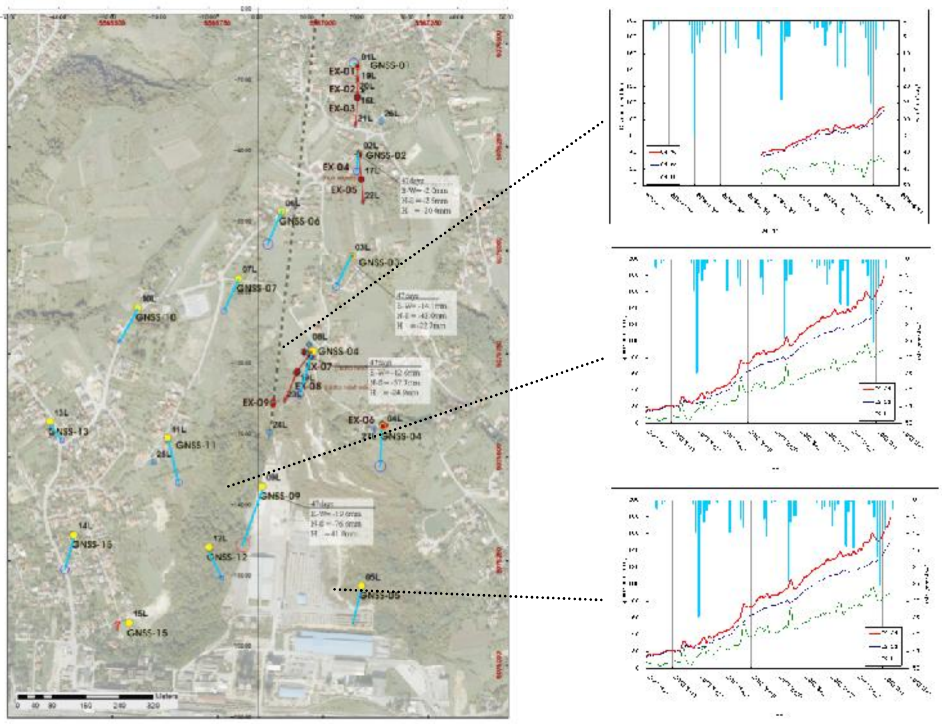
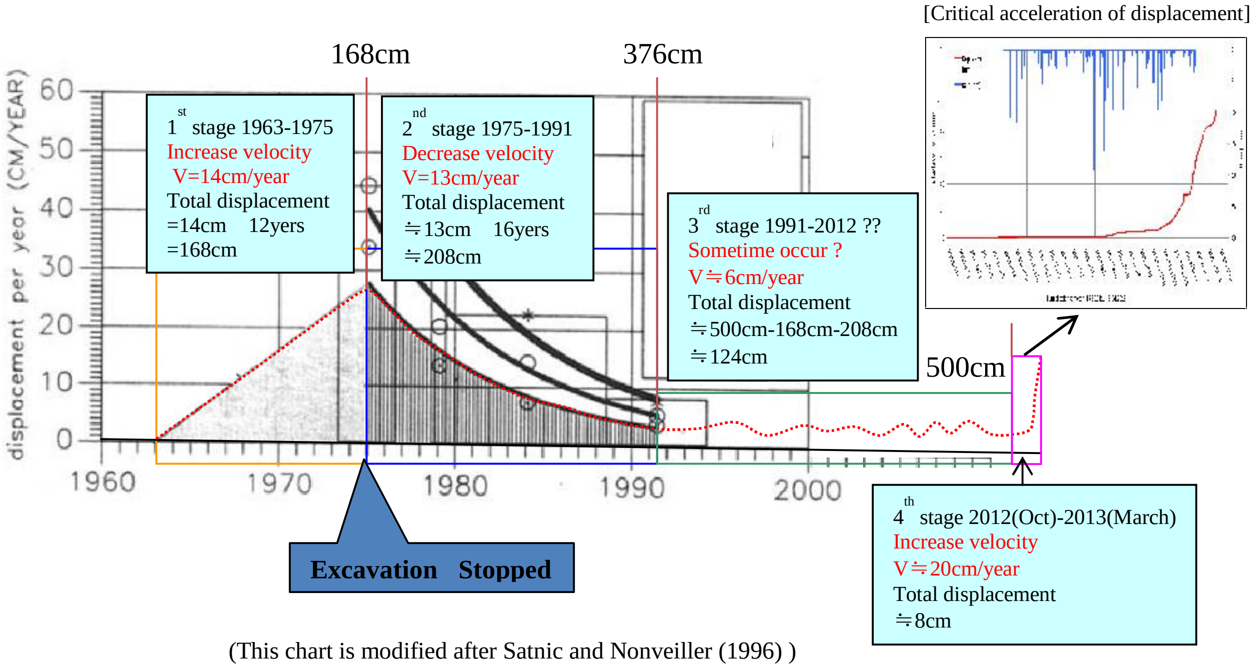


Chart 6. Landslide movement measured by GPS-receivers

2.3. Application of monitoring data for early warning

Cumulative horizontal displacements were interpreted from aerial photos and from measurements of geodetic points. The Kostanjek landslide was activated in 1963 after 2.1x106 m3 of marl was excavated at the foot part of the slope [7]. Temporal variation of the displacement of the landslide mass since 1963 to 2013 is shown in Chart 7. The velocity of displacement was increased till 1975 when excavation was stopped (1st stage) and decreased till 1991 (2nd stage). Annual displacement amount between 1991 and 2012 were reduced to around 6 cm per year (3rd stage). However, the velocity of displacement was significantly increased to around 20 cm per year (4th stage). Especially, a certain critical acceleration of displacement was observed by an extensometer installed in tunnel from the begging of February to middle of April. The authors have discussed with responsible persons of the Emergency Management Office of Zagreb City about appropriate warning criteria in order to arrange practical early warning and necessary evacuation.

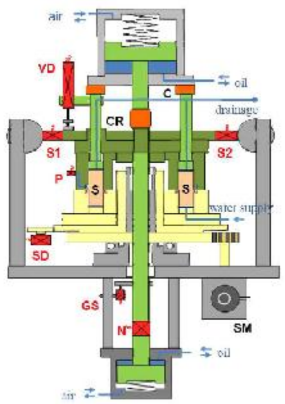


(This chart is modified after Satnic and Nonveiller (1996))

Chart 7. Temporal varitaion of the displacement of the landslide mass

3. LANDSLIDE DYNAMICS

A new transportable undrained dynamic loading ring shear apparatuswas developed in the framework of the joint research project. The structure of the apparatus is shown in Chart 8 [5]. (S:Specimen, CR:Connecting ring, C:connection, N:Load cell for normal stress; S1,S2:Load cell for shear resistance; P:Pore pressure transducer; GS:Gap sensor; VD:Vertical displacement; SD:Shear displacement). This ring shear apparatus can reproduce the stress and pore pressure acting on a potential sliding surface. It can keep undrained condition up to 1 MPa of pore pressure and load normal stress up to 1 MPa. This is suitable for investigation of large scale and deep seated landslides. Some examples of test results by this apparatus are shwon in Chart 9. Left Chart shows test results using soil sample (Flysh) from Grohovo landslide area under undrained condition. Right Chart shows test results using soil sample (Marl) from Kostanjek landslide area under undrained condition. Soil sample of Grohovo lanslide shows higher friction angle of 20.4 degree. Soil sample of Kostanjek landslide shows lower friction angle of 13.8 degree.



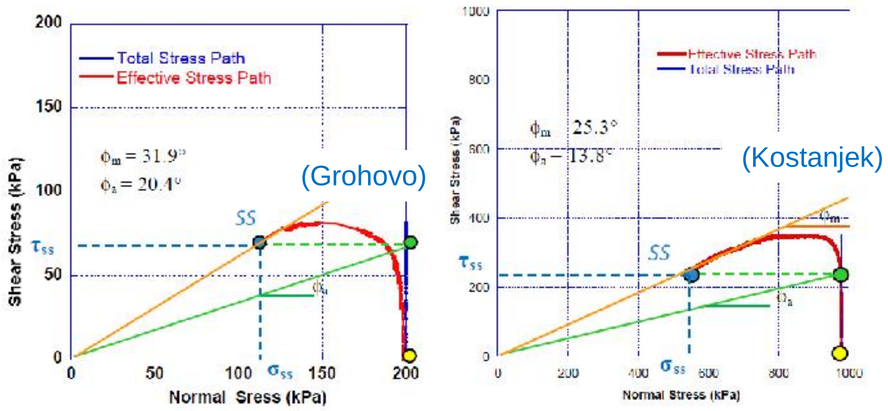
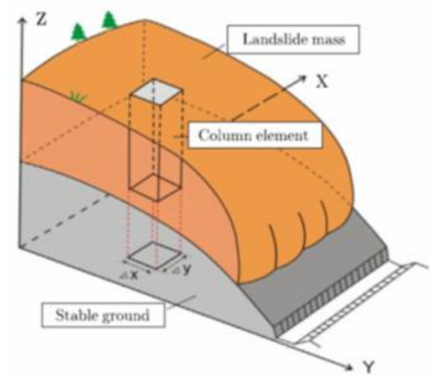


Chart 8.Structure of ring shear apparatus. *Chart 9. Test results by the ring shear apparatus*

An Integrated Landslide Simulation Model (LS-RAPID) produced by Sassa can assess the initiation and motion of rapid landslides triggered by earthquakes, rainfall or their combined effects. In this model, a vertical imaginary column is considered within a landslide mass as shown in Chart 10. The model calculates the discharge and the height of soil mass by assuming that the balance of all forces acting to this column (Self-weight, Seismic forces, Lateral pressure, Shear resistance including the effect of pore water pressure) will accelerate the soil mass by acceleration on the horizontal plane and the discharge flowing into the column is the same with the change of the height of soil [3], [6].Soil testing should be conducted on representative samples using portable ring shear apparatus designed for testing the residual shear resistance mobilized along the sliding surface at large displacements under static and dynamic loading conditions. The results of the ring shear tests are necessary to be inputted for analyses of the development and propagation of the sliding soil mass by LS-RAPID. An example of simulation results on the behavior of the sliding soil mass is shown in Chart 11 for the case of Grohovo landslide caused by increase of pore water pressure.



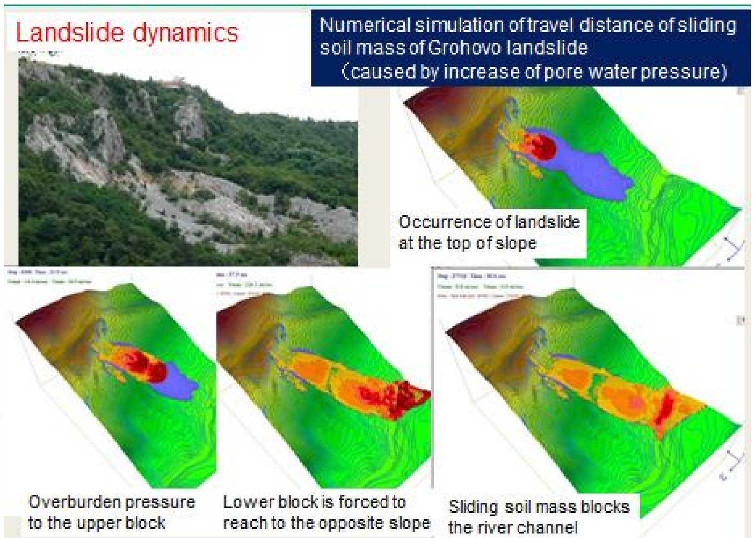
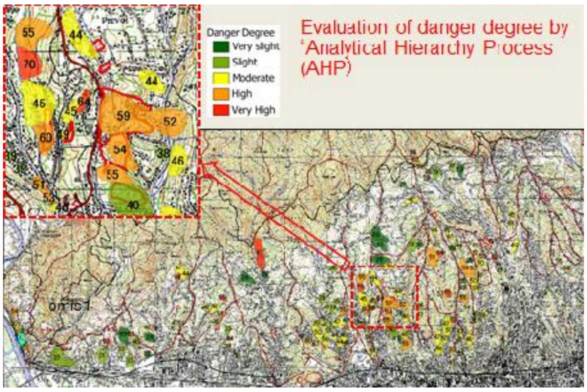


Chart 10. Vertical column elemnt *Chart 11. Numerical simulation of travel distance of sliding soil mass*

4. HAZARD ZONATION AND LAND-USE GUIDELINE

Hazard zonation of landslide disaster has significant importance. The process of landslide risk identification can be described as follows. As a first step, 'Recognition of individual landslide' shoudld be carried out by aerial photo interpretation. As a next step, 'Evaluation of landslide susceptibility' should be carried out using method of 'Analytical Hierarchy Process'. An example of this step concerning Kostanjek landslide is shown in Chart 12.Based on such evaluation of danger degree of individual landslide area so-called 'Landsldie

Hazard Map' is formulated at this stage. Subsequently, it is necessary to consider situation of current land-use and importance of objects to be protected. After the interpretation of current land-use, 'Landslide risk map' should be formulated as a final output in process of hazard zoning. A prototype of landslide risk map for northwestern part of Zagreb City is shown in Chart 13. On the basis of this landslide risk map, a guideline is formulated as a key output of the joint research project. It provides the following items: Definition and Terminology, Description of the types and levels of landslide zoning, Definition of levels of mapping and suggested scales for maps taking into account the needs and objectives of land-use planners and the purpose of the mapping and finally Guidance on formation process of hazard map and risk map.



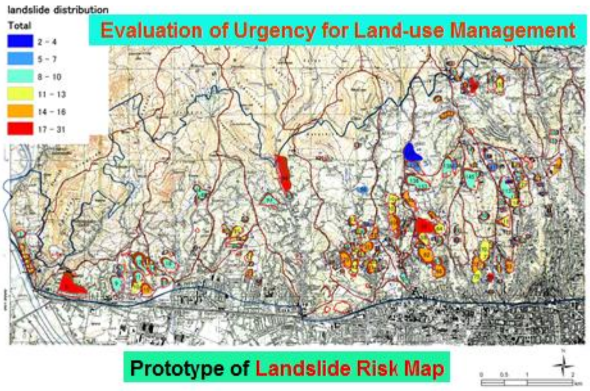


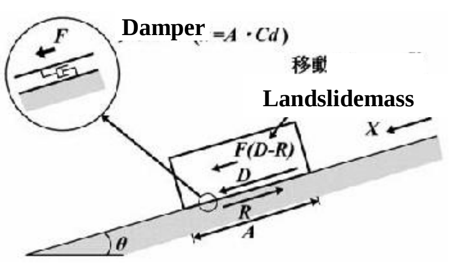
Chart 12. Evaluation of danger degree by AHP method

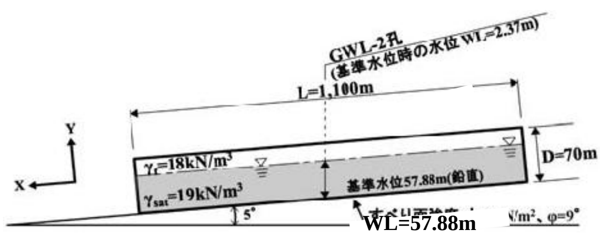
Chart 13. Landslide risk map for northwestern Zagreb

5. LUMPED MASS SYSTEM MODEL WITH DUMPER

The authors propsed a lumped mass system model with damper in order to predict moving velocity of landslide mass before reaching the strain limit [2]. This model can be incorporated into simple slope stability analysis such as Fellenius method. In slope stability analysis, resistant force (***R***) and driving force (***D***) are calculated in each individual slice and summed up for all slices. Downward force is defined as difference between driving force and resistant force namely (***D*** - ***R***). Damper (***k***) is introduced to express damping force which effects along the sliding surface to the opposite direction to downward force (***F***) as shown in Chart 14. Damping force is proportional to the velocity (***v***). Damper (***k***) is defined as product of coefficient of viscous resistance (***Cd***) and area of sliding surface of landslide mass (***A***). Namely $k = A\cdot Cd$.Safty factor (***Fs***) is indicated as $Fs=R/D$.Then, equation of motion is derived as $m\alpha=F - k\cdot v$ or $m\alpha=F-A\cdot Cd\cdot v$. In the equation ***m*** is mass and ***α*** is acceleration of the landslide. After solving this equation of motion, finally the formula to express the velocity of landslide '$v \approx F/A\cdot Cd$' is obtained.

Using this lumped mass system model with damper, the variation of landslide velocity in response to the variation of the groundwater level concerning Kostanjek landslide is analyzed. In consideration of available data values, a simplified lumped mass system model as shown in Chart 15 is used for two dimensional slope stability analysis. The moving velocity (***v***) and displacement (X) of theKostanjek landslide are calculated using daily observation results of groundwater level concerning target period. The safety factor (***Fs***) of the landslide is also calculated as $Fs=R/D$.





Strength Parameters

Chart 14. Kinematic diagram of landslide mass

Chart 15. Schematic diagram of simplified landslide mass

ISSN 2303-8403 Broj 2, 2016

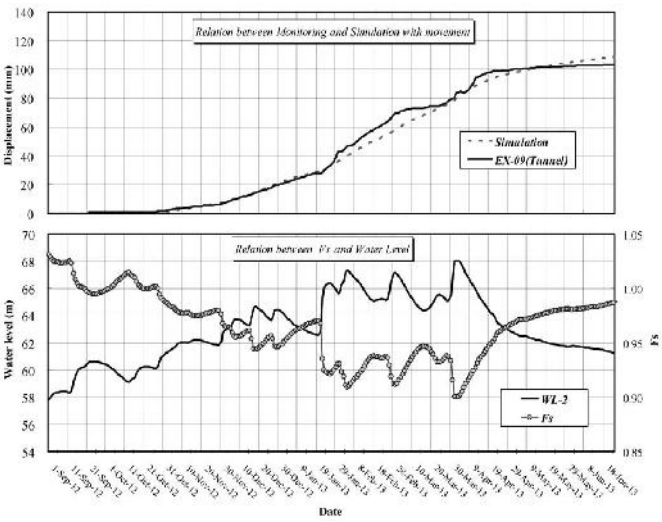


Chart 16. Simulation results using lumped mass system model

Calculation results are shown in Chart 16. Upperfigureshows relationship between actually monitored value by the extensometer in tunnel and calculated value of displacement. Both values show basically good coincidence, although there is still slight difference. Lower figure shows relationship between safety factor (***Fs***) and groundwater level. Variation of safety factor shows very clear inverse correlation with the groundwater level. Furthermore, correlation between monitored value and calculated value of displacement velocity evaluated by 10 days moving average is examined. The correlation coefficient shows high value of 0.88. It is clarified that this lumped mass system model with damper is effective to reproduce the variation of landslide velocity in response to the variation of the groundwater level.

6. CONCLUDUNG REMARKS

An overview information of essential research results of the Croatian-Japanese joint rsearch project on landslides isdescribed in this paper. Croatia is located in a region with a specifically complex topographical and geological structure which tends to cause frequently landslide disasters. This project has been focussing on disaseter mitigation in developing regions and places with significant societal value in Croatia. The most important initial stage is fundamental study to grasp actual behavior of landslide, to know charactersitics of landsldie and to clarify the mechanism of landslide. Only based on such fundamental study results, planning and design of effective and useful mitigation measure can be feasible. On the basis of such idea, comprehensive monitoring systems were installed in two representative target landslide areas. Abundant interesting and important data on characteristics and mechanism of landslides have been provided by such monitoring system. It enables to dvelop some new model to explain landslide movement in relation with triggering factors. In the final stage, practical method of hazard zonation and further land-use guidelines were formulated and also early warning system were arranged in the target areas for mitigation of landsldie disasters. During the performance process of the joint research project, both capacity development and dissemination of research results are also necessary tasks in parallel with performance of individual research items. It is targetted that reserach outputs such as new ideas and new methods dveloped through the project will be transferred to the neighboring countries in the Adriatic-Balkan Region including Bosnia and Herzegovina.The authors are going to carry out such technolgy transfer actions.

7. REFERENCE

[1] Arbanas Z., Jagodnik V.: Remote monitoring of a Landslide Using an Integration of GPS, TPS and Conventional Geotechnical Monitoring Methods, Proc. 1st Regional Symposium on Landslides in the Adriatic-Balkan Region, Zagreb, 2014, Pg. 39-44.

[2] Hamasaki A., Marui H.: Lumped mass damper model to predict landslide velocity, Journal of Japan Landslide Society, Tokyo, 2016, Pg. 12-17. (in Japanese)

[3] He B., Sassa K.: Manual of LS-RAPID Numerical Simulation Model for Landslide Teaching and Research, Proc. 1st Regional Symposium on Landslides in Adriatic-Balkan Region, Zagreb, 2014, Pg. 5-10.

[4] Krkac M., Mihalic S.: The Kostanjek Landslide – Monitoring System Development and Sensor Network, Proc. 1st Regional Symposium on Landslides in the Adriatic-Balkan Region, Zagreb, 2014, Pg. 27-32.

[5] Ostric M., Sassa K.: Manual of Transportable Ring Shear Apparatus ICL-1, Proc. 1st Regional Symposium on Landslides in the Adriatic-Balkan Region, Zagreb, 2014, Pg. 1-4.

[6] Sassa K.: Integrated landslide simulation model LS-RAPID Operation Manual, ICL and Godai Kaihatsu Corporation, Kyoto, 2010.

[7] Stanic B., Nonveiller E.: The Kostanjek landslide in Zagreb, Engineering Geology Vol. 42, Amsterdam, 1996, Pg. 269-283.