Results of a Technical Cooperation Project to Develop Landslide Risk Assessment Technology along Transport Arteries in Vietnam (IPL-175)

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Abstract

Like other South-East Asia countries, Vietnam is a country with mountainous terrain, complicated geological structure and high rainfall, and as a result, landslides occur regularly, with serious consequences for the mountain road networks in the rainy season. Due to economic difficulties and a lack of deep knowledge of the phenomena, activities to prevent and mitigate landslides are not effective. The SATREPS project of research cooperation between Japanese and Vietnamese researchers in the years 2011–2016 has not only helped Vietnam in the development of human resources, research equipment and development of a standard system of landslide investigation, monitoring, forecast and early warning, but has also contributed to disaster prevention and reduction in Vietnam in the future. This project is considered as a success for a new landslide-training tool, in cooperation with Asia members of the International Consortium on Landslides (ICL), especially South-East Asia countries, for the mitigation of natural disasters.

Keywords

Technical cooperation • Landslide • Risk assessment • Transport • Vietnam

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Landslides Along Transport Arteries in Vietnam

Landslides have been a persistent problem in mountainous regions, and especially those distributed along transportation corridors. Landslides not only cause damage to properties (houses, buildings, vehicles, etc.) and large numbers of casualties, but also disrupt utility services and economic activities. Located on the Eastern Indochina Peninsula, Vietnam has mountainous areas that cover up to 3/4 of the area with steeply sloping terrain, due to the powerful tectonics of the earth's crust. Moreover, it also has a complex geological structure and a tropical monsoon climate, with an average annual rainfall of as much as 3000–4500 mm/year in some regions. Consequently, Vietnam is a typical tropical country, and has the most serious landslide disasters in Southeast Asia and the Mekong sub region.

Vulnerability to landslide hazards is the probability of movement of slopes by landsliding. There are many causes of landslide vulnerability, such as conditions of topography, geomorphology, geology, climate and artificial activities. Landslide vulnerability assessment is a major aspect, especially for risk assessment of reactivated landslides and landslide susceptibility (Tien et al. 2016a, b). To mitigate the effects of this phenomenon on human life, landslide risk assessment is a requirement.

Landslides Risk Assessment Project

For more insight into the phenomenon of landslides in general, as well as to control and mitigate the losses from this natural phenomenon for the traffic system, as well as for new projects in mountainous areas, a Technical Cooperation Project named "Development of Landslides Risk Assessment Technology along Transport Arteries in Vietnam" was proposed by the Vietnam Institute of Transportation Science and Technology (ITST) and ICL. It was one of SATREPS projects, which was established in 2008 as a part of the new "Science and Technology Diplomacy" implemented jointly by the Ministry of Foreign Affairs (MOFA) though (JICA) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT through JST). The project was approved as an ongoing IPL project (IPL-175) by the IPL Global Promotion Committee in 2011 (Han et al. 2017). It is the second SATREPS project proposed and implemented by ICL members after IPL-161 Croatia Project 2008–2014 (Arbanas et al. 2017).

The overall objective of the project is to socially implement the developed landslide risk assessment technology and early warning system, which will contribute to ensuring the safety of transportation arteries and residents in mountainous communities in Vietnam.

The project started in 2011 and ended in 2016, with a full implementation time of 5 years (Fig. 1).

Overview of Results of the Technical Cooperation Project

All results of the project were divided among four work groups (WG) as follows:

- Preparation of integrated guidelines for the application of developed landslide risk assessment technology and capacity development by a WG1 Joint Team of all groups;
- Wide-area landslide mapping and identification of landslide risk area by the WG2 Mapping Group;
- Development of landslide risk assessment technology based on soil testing and computer simulation by the WG3 Testing Group;
- Risk evaluation and development of an early warning system based on landslide monitoring by the WG4 Monitoring Group.

Development of Landslide Risk Assessment Technology and Education

Based on technological transfer from Japan to Vietnam, Vietnamese researchers have drafted intergrade guidelines for landslide risk assessment in the following six parts, with 33 guidelines, which cover (1) Mapping and Site Prediction, (2) Material Tests, (3) Monitoring, (4) Landslide flume experiments and (5) Software application. Those guidelines will be the first step for a strategy of national standard development for landslide risk assessment in Vietnam (Project report—Sassa et al. 2016).

In terms of education and human resources development, three doctor and five master certifications have been obtained at the end 2016 through the training courses for Master (for 2 years) or Doctor (for 3 years) or short training programs at Kyoto University, Tohoku Gakuin University, University of Shimane Prefecture, Shizuoka University and Gunma University. Five other doctoral candidates are currently studying.

Wide-Area Landslide Mapping and Landslide Risk Identification

Based on landslides that have occurred in the study area, a general method to prevent and mitigate landslide activity along roads in humid tropical regions also was proposed. The

Fig. 1 Some pictures of landslides that have taken place and their location on a map of the Vietnamese transport system

core of the study is a new strategy to reduce the effects of vulnerability to landslides, by using a combination of landslide risk assessment maps, which are developed from risk assessments of landslides that have occurred, and landslide susceptibility maps, which are developed from evaluation of the sensitivity to sliding of natural slopes from landslide causative factors. A flowchart of WG2 is presented in Fig. 2.

After five years, six sheets of landslide inventory maps for the Ho Chi Minh route and detailed scale landslide distribution map (1:12,000) for a 60 km long section were established. Landslide risk assessment maps for the mentioned region and susceptibility maps for 150 km along the Ho Chi Minh route have been developed using an analytic hierarchy process (AHP) approach (Le et al. 2014; Tien et al. 2016a). For air-photo interpretation for the landslide inventory, a section of 25 km of National Road No.7 from Muong Xan to Tam Quang was the target for mapping (Ngo 2016).

The technology for identification of the precursor stage of landslides through a pattern analysis of a digital surface model (DSM) of the forest cover and others was developed. Technical analysis based on tree crown deformation using the comparative study of UAV and aerial photo data for the landslide survey was developed at a mangrove forest in Iriomote island, Okinawa, then applied to the Halong landslide trial site. (The application to identify the initial stages of landslide deformation is being used for the Aratozawa landslide, Kurikoma, Japan (Myiagi project report, 2016).

Those study results can contribute to forecasting, preventing and mitigating the negative impacts of landslides for planning, land use, construction of infrastructure, ensuring the safety of existing traffic roads and mountainous residential areas in Vietnam. It can be applied to areas with similar conditions to the study area.

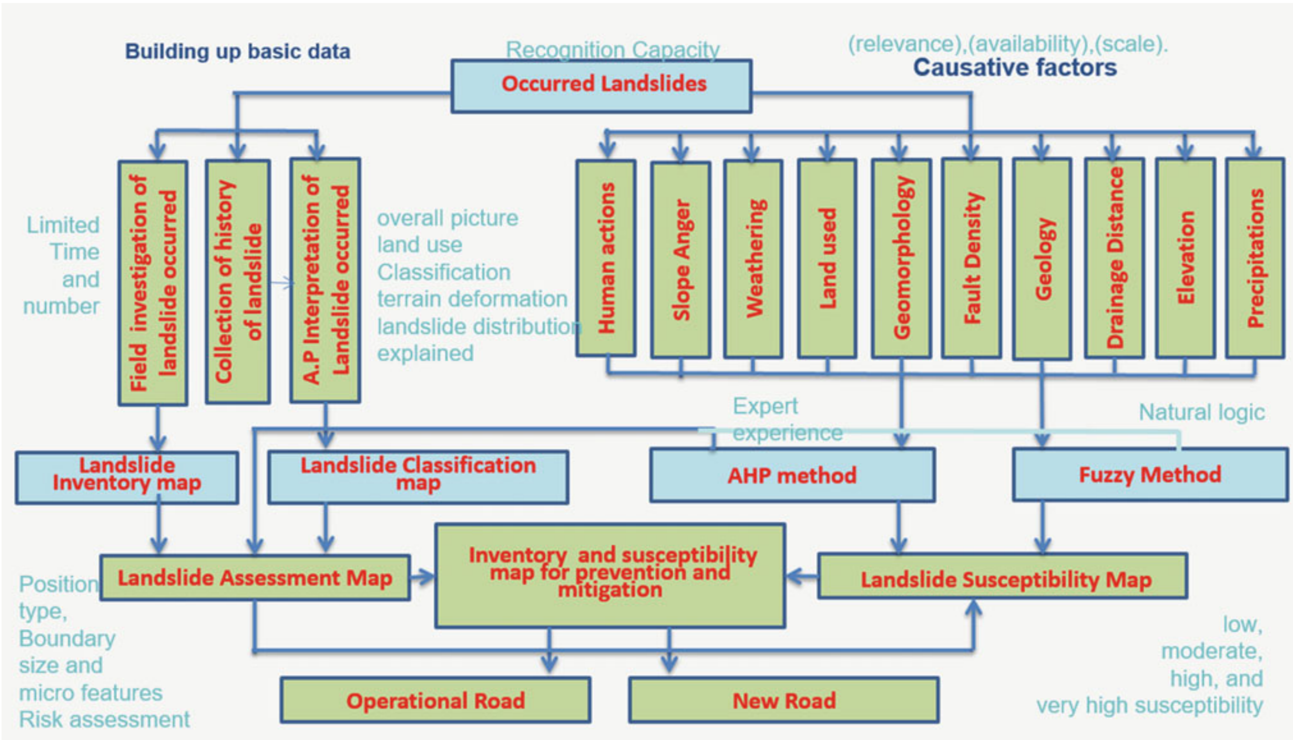

Fig. 2 Flow chart of research for landslide mapping

Soil Testing—Computer Simulation of Landslide Initiation and Motion

A testing group developed a high-stress undrained dynamic loading ring shear apparatus (ICL-2) which can be applied to deep landslides more than 100 m thick. The composition of new undrained dynamic loading ring shear apparatus is presented in Fig. 3. Its development and its first application to the Unzen Mayuyama Landslide, which killed 15,000 people in Japan, was reported in Landslides, Vol. 11, No. 5 in 2014.

The developed ring shear apparatus was revised in 2014–2015, based on the experiences of testing by Vietnamese short-term trainees as well as long-term trainees. A major revision was to add new two safety systems to protect the apparatus from mishandling by testing persons. The revised apparatus was installed in ITST in June 2015 and now it is available for testing (Lam, project report 2016).

Samples were taken from the ground and the drilled cores at various depths in the Hai van Landslide were tested using ICL-2, and a computer simulation was conducted based on the measured parameters by Vietnamese researchers. Output of the WG3 "Development of landslide risk assessment technology based on soil testing and computer simulation" was completed. A paper has already been written.

Adding the function that simulates tsunami generated by landslides was one of the targets of JST research that was completed to integrate the tsunami simulation code developed by the Intergovernmental Oceanographic Commission (IOC) and the landslide simulation code (LS-RAPID). The paper was accepted in February 2016 by the journal Landslides. This function was applied to assess tsunami levels possibly triggered by a large-scale rapid landslide from the Hai van slope.

Landslide Monitoring and Development of an Early Warning System

Haivan landslide is a deep-seated landslide, and a national railway runs over its body. It was selected as a target area for monitoring and early warning. For installation of monitoring equipment, both topographic and geology surveys had been carried out. Three boreholes were drilled. Figure 4 presents the 80 m depth bore-hole log at Haivan Landslide.

An integrated monitoring system, including rain gauges, extensometers, inclinometers, total station, and GNSS, was developed here. Most monitoring equipment was installed in Hai Van Station landslide until March 2015. However rainfall and slope deformation monitoring was started in May 2013 and number of slope deformation records during heavy rainfalls have been monitored from September 2013 until the present.

Installation of the data transferring and displaying system was finished in Haivan and the project office in ITST, Hanoi

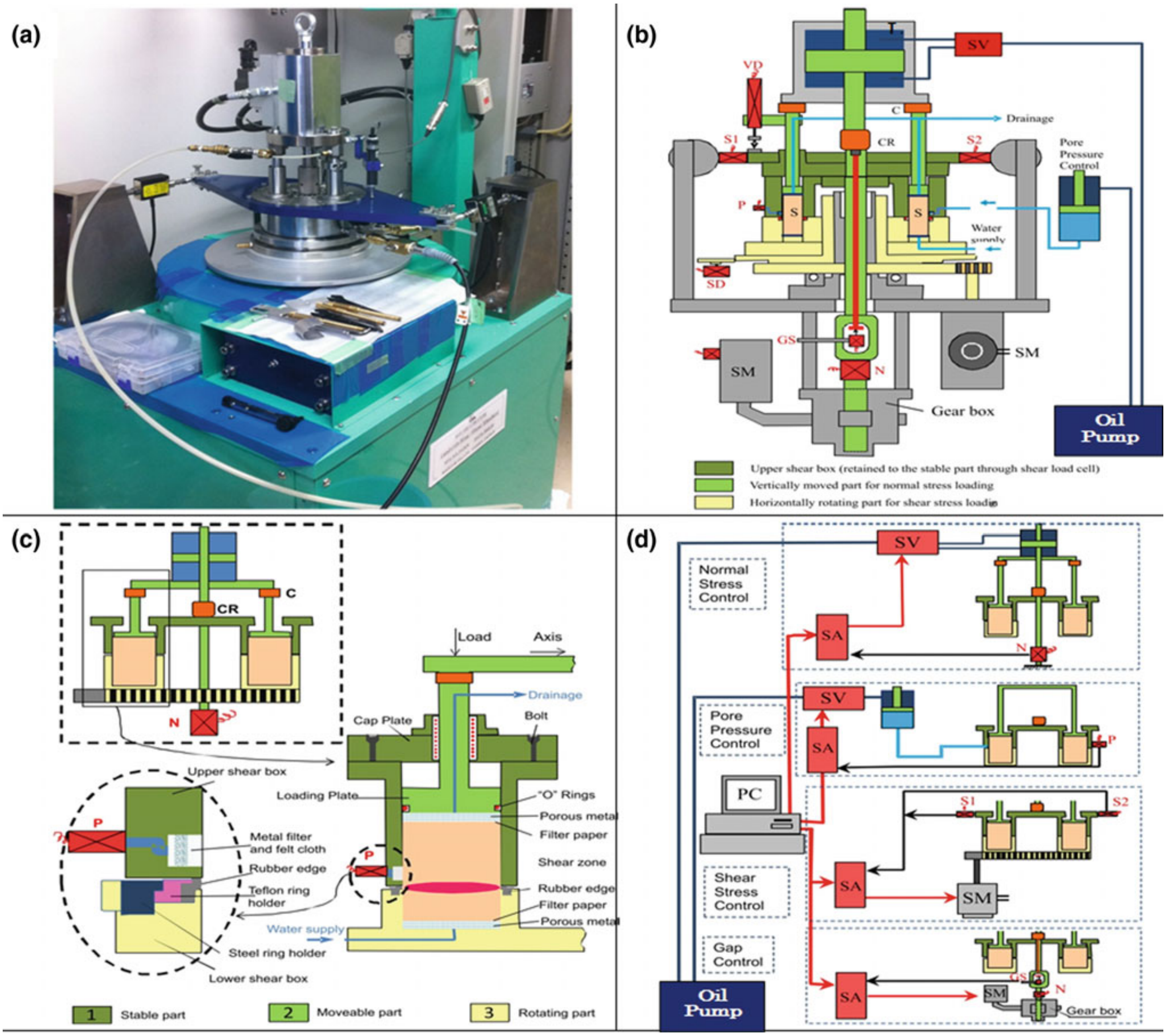

Fig. 3 Diagrams illustrating the new undrained dynamic loading ring shear apparatus

in March 2016. This monitoring system would allow monitoring in real time.

The landslide experimental facilities, including a landslide flume and data logging system and pore water pressure sensors, were provided and adjusted for ITST. The first landslide experiment using river sand was conducted in November 2015. The displacement of first landslide experiment using river sand is shown in Fig. 5.

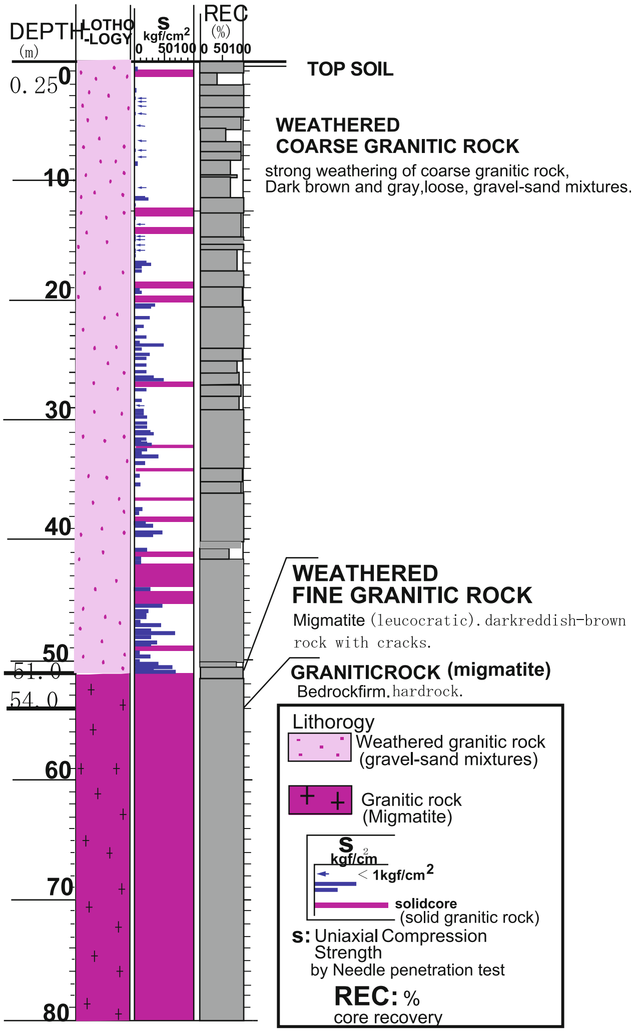

Fig. 4 80 m depth borehole log at Haivan landslide

Fig. 5 The displacement of the first landslide experiment using river sand

Reproduction of a landslide test using the granitic soils taken from the Hai van slope was a success. And new multi-depth wireless tensiometers were developed in Japan and utilized in landslide experiments by ITST.

Discussion

The new technology of interpretation of paired photos taken from a UAV for landslide identification of micro-features was developed as a trial. The scope of the application should be taken into consideration. The first trial was successful using a topographic landslide map with a scale of 1:500–1:1000.

For the Haivan landslide, the landslide initiation mechanism of the deep-seated landslide, which took place in the past, could be understood and explained using a ring shear apparatus. However, over time a transition in the landslide from occurrence to termination occurred. Minor landslides appeared on the body of the large landslide, together with erosion. So the sensitivity to mass sliding should be considered based on a multi-slip surface at the depth for early waning.

The principle for landslide early waning on Haivan is based on a prediction method using the inverse number of Velocity (Fukuzono 1985). However, as we have just gathered measurements on displacement over time for such a short period, the trend of landslide inverse velocity is not clear. It should be determined after a longer monitoring period.

Conclusion

Vietnam is a country on the coastal area of the Pacific Ocean. Due to its mountainous terrain, complicated geological structure and high rainfall, landslides occur regularly and cause serious damage to the mountain road network in the rainy season.

For the project, a wide-area landslide map and identification of landslide risk areas had been studied and developed by the WG2 Mapping Group. Development of landslide risk assessment technology based on soil testing and computer simulation had been carried out by the WG3-Testing Group. The relationship between landslide displacement and other causative factors such as precipitation, and pore water pressure by depth was studied at the landslide experimental facilities, and included landslide flume and data logging systems and pore water pressure sensors. The early warning system based on real-time landslide monitoring was installed by the WG4 Monitoring Group. The results of the project are not only very important developments in the scientific field of risk assessment but also in developing the research capacity of ITST in part and to Vietnam in general. Landslide risk assessment is a very important issue in the strategy to "proactively prevent natural disasters" of the Vietnamese government. This success from the research results could be applied in other tropical countries with similar conditions.

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