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IPL Symposium 2012

Time: 9:00-18:00 on 21 November (Wednesday) 2012

Venue: Room XVI (Ground Floor of Bonvin Building), UNESCO Headquarters, Paris

Opening Session (9:00-9:10)

Greeting	Gretchen Kalonji (UNESCO), Assistant Director General of Natural Science Sector together with Badaoui Rouhban (former director for Disaster reduction of UNESCO), Chair of IPL Award Committee
Facilitator	Bin He, Disaster Prevention Research Institute (DPRI), Kyoto University, Japan

Part 1 (9:10-11:15) Proposal of New IPL Projects

Chairpersons: **Matjaz Mikos, Alexander Strom**

9:10-9:25	Malaysia	Che Hassandi Abdullah	Slope Data Acquisition along Highways in Sabah State for hazard assessment and mapping
9:25-9:45	Honduras	Luis Eveline Aníbal Godoy	Latin-American Congress on Landslides by GIS and RS in Tegucigalpa, Honduras ; Study on geological disasters focusing on landslides in and around Tegucigalpa City, Honduras
9:45-10:00	Croatia	Željko Arbanas	Study of landslides in flysch deposits of North Istria, Croatia: sliding mechanisms, geotechnical properties, landslide modeling and landslide susceptibility
10:00-10:15	Czech	Adam Emmer	Database of Glacial Lake Outburst Floods (GLOFs)
10:15-10:30	ADPC	N.M.S.I. Arambepola	Introducing Community-based Early Warning System for Landslide Hazard Management in Cox's Bazaar Municipality, Bangladesh
10:30-10:45	Serbia	Biljana Abolmasov	Study of slow moving landslide Umka near Belgrade, Serbia
10:45-11:00	Nigeria	Igwe Ogbonnaya	Landslides in West Africa: impacts, mechanism and management
11:00-11:15	Brazil	Renato Eugenio de Lima	Characterization of landslides mechanisms and impacts as a tool to fast risk analysis of landslides related disasters in Brazil

(Note for Part 1: 10 minutes for presentation, 5 minutes for discussion, except the IPL project from Honduras-15 minutes for presentation, 5 minutes for discussion)

11:15-11:30 Break

Part 2 (11:30-16:45) Results of IPL Projects, WCoEs, and other research

Session 1

(11:30-12:30)

Chairpersons: **Zeljko Arbanas, Renato E. de Lima**

11:30-11:45	China	Wei Shan	Bedding Landslide Formation Mechanism and Traits in Lesser Khingan Mountain
11:45-12:00	China	Ying Guo	Using High-density Resistivity Method to research on permafrost landslide
12:00-12:15	Chinese Taipei	Ko-Fei Liu	Large scale simulation of watershed mass transport – a case study of Tsengwen reservoir watershed
12:15-12:30	India	Surya Prakash	-An Initiative for Development of a Web-based Self Study Programme for Landslide Risk Management. -Networking, Linkage and Coordination for Disaster Risk Management with a case example from South Asia Disaster Knowledge Network

12:30-14:00 Lunch

Session 2

(14:00-15:15)

Chairpersons: **Ko-Fei Liu, Mohammadreza Mahdaviifar**

14:00-14:15	Indonesia	Teuku Faisal Fathani	Lesson Learned in the Development of Landslide Early Warning System in Indonesia
14:15-14:30	Iran	P. Memarian M. Mahdaviifar	Distribution and characteristics of landslides induced by the Varzeghan earthquakes (Mw=6.4 and Mw=6.3) in 2012 in Azerbaijan-e-Sharghi, northwest Iran
14:30-14:45	Iran	Z. Shoaie	A New Approach to the Landslide Early Warning Using the Chemical Composition Fluctuation in the Leakage from Susceptible Slopes
15:00-15:15	Mexico	A. Irasema	Increasing awareness: the role of non-structural measures in landslides disaster reduction

15:15-15:30 Break

Session 3

(15:30-16:45)

Chairpersons: **Hideaki Marui, Teuku Faisal Fathani**

15:30-15:45	Nigeria	IGWE Ogbonnaya	Post-failure Mobility and the Importance of Stress Ratio in Strength Evaluation
15:45-16:00	Russia	Svalova Valentina	Mechanical-Mathematical Modelling and Monitoring for Landslides
16:00-16:15	Srilanka	A A Virajh Dias	A Comparative Analysis of Landslide Susceptibility by WAA and SINMAP Model

16:15-16:30	Ukraine	Iurii Kaliukh	Some results of field surveys building structures for landslide's resistance in Carpathian's mountains region of Ukrain
16:30-16:45	Vietnam	Dinh Van Tien	Technical Cooperation Project to Develop Landslide Risk Assessment Technology along Transport Arteries in Vietnam
16:45-17:00	Korea	Sangjun IM	Identification of rain-induced shallow landslides on mountain terrain
Closing Session (17:00-17:15)			
Concluding Remark	Giuseppe Arduino, Programme Specialist in Hydrological/Geological Sciences, UNESCO Office, Jakarta		
Closing Address	Kaoru Takara, ICL Vice President, Disaster Prevention Research Institute (DPRI), Kyoto University		
(Note for Part 2: 15 minutes for presentation, 5 minutes for question/answer.)			
Committee Meetings (17:30-18:30)			
Each committee may have its own meeting in a different location within the room.			

Bedding Landslide Formation Mechanism and Traits in Lesser Khingan Mountain

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Abstract In China's Heilongjiang Province, Bei'an to Heihe freeway utilizes the original second-class highway to widen and expand for freeway, widen subgrade of some sections locate in tailing edge of the landslides, influenced by the landform, geological condition and climate factors, are in unstable states, bring great difficulties to widening and expanding implementation. In the process of landslide researching, firstly identify the space form of landslide, analyze the formation mechanism of landslide, evaluate the stability condition and the development tendency of landslide, and then determine the prevention and treatment measures. Took the Bei'an to Heihe freeway K178+530 section landslide as the research object, employed the field survey, topographic mapping, geological drilling, indoor test, numerical simulation, field monitoring and theoretical analysis methods to carry an integrated study on the formation mechanism of the landslide. Study results show that: the K178+530 landslide belongs to bedding landslide, rupture surface is located at the bottom of subgrade spoil and silty clay; during survey, the landslide is in the limit equilibrium state, directly affects the stability of subgrade slope; atmospheric precipitation, snowmelt water and seasonally frozen soil thawing water provide a continued water source for landslide, surface water and ground water supply the Quaternary pore water by infiltration and lateral runoff through surface cracks and shallow high permeability rock and soil, low permeability rock and soil under the loose overburden form aquiclude, rock and soil of the aquiclude are saturated to be soften form rupture surface; the landslide have seasonal, gradual, low angle characteristics.

Keywords freeway, bedding landslide, formation mechanism, stability

Introduction

Landslide is a natural phenomenon that, rock and soil on the slope, affected by river scour, groundwater activity, earthquake, artificial cutting slope and other factors, under the action of gravity, slide down along a weak plane or zone (Kong et al. 2008; Qiao 2002). High grade highway constructed in mountain area, due to its special geology, geomorphology, hydrology and climatic condition, often appear landslide hazards (Sun et al.

2008). Landslide often interrupts the traffic, affect the normal transportation of highway, large-scale landslide can block the river, destroy highway, destruct factory, has great harms on building and traffic facility in mountain area (Zhu et al. 2007; Li et al. 2011).

Bei'an to Heihe highway utilizes the original second-class highway to widen and expand for freeway in Heilongjiang province of China, in the first-stage project construction process, many sections subgrade and slope of K159+000-K184+000 section which traverses the Lesser Khingan Mountains occurred landslide, in the most serious K176+500-K179+300 section, the subgrade lost stability due to landslides after construction, were forced to change the route to build (Shan et al. 2012). Design stage investigation results show that some sections are located in landslide body (see Fig. 1), affected by landform, topography, rainfall, freeze-thaw and other factors, foundations are in unstable state, bring enormous difficulties to widening and expanding implementation (Jiang et al. 2012).

Therefore, need comprehensively analyze the mechanism, scale and hazard of landslide; accurately reflect the characteristic, occurrence and development law of landslide, so that can employ effective prevention and remediation measures in the freeway construction period (Long et al. 2010). This article took the Bei'an to Heihe freeway K178+530 section landslide as the research object, employed field survey, topographic mapping, geological drilling, indoor test, numerical simulation, field monitoring and theoretical analysis methods to carry an integrated study on the formation mechanism of the landslide.

Natural geographic condition of study area

The study area is located in the China's Lesser Khingan Mountain island permafrost region. The climate of the area belongs to continental monsoon climate, the spring gets warm quickly, the summer is tepidity and rainy, the autumn gets cool fast, the winter is long and cold. The annual average temperature is -0.6°C , the lowest temperature is -48.1°C , the highest temperature is 35.2°C ; the frost free period is short, only 90-125 days. The average annual precipitation is 530-552mm, and the rainfall concentrates in July to September of the summer, accounts for about 61-67% of annual total precipitation.

The ground surface of the area can form seasonal frozen soil, the time of ground reaching maximum frozen depth is the late of May, and the maximum seasonal freezing

depth is 2.26-2.67m. There are many island permafrost distributed in the cheuch.



Figure 1 Aerial view of Beian to Heihe freeway landslide section

The research area is hilly topography, relative height difference is not big, and part of slope is steep. The tectonic is in the Wuyun-Jieya new rift zone, the south is Shuhe upwarping zone and the north is Handaqi virgation. Surface exposed stratum: the upper Cretaceous Nenjiang formation, Tertiary Pliocene series Sunwu formation, and Quaternary Holocene series modern river alluvium and stack layers. Rock is bedded, weak cementation and weathering resistant ability, weathering depth is larger, near surface portion substantially weathered. According to the aquiferous medium, supply and drainage conditions, groundwater is divided into Cretaceous pore water, Tertiary pore water and Quaternary pore water three kinds.

Field survey

We carried out geological survey and topographic mapping work in the study area, found five landslides distributed in the study section, this article aimed at the K178+530 landslide, as show in the Fig. 1 “C” area.

The landslide is located in the valley. The flat shape of landslide body presents a tongue (see Fig. 2). There are

conspicuous arc dislocation and ponding on the tailing edge of the landslide, upheaval on the front of the landslide and cracks on the surface of the landslide body (see Fig. 3).

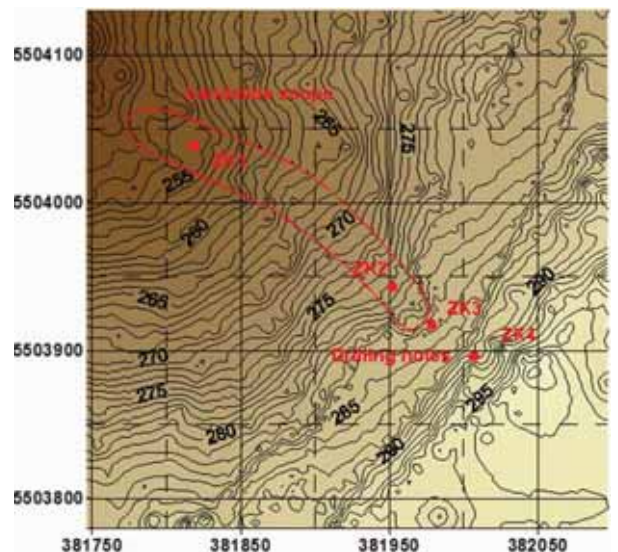


Figure 2 Topography of the K178+530 landslide region.



Figure 3 Landform characteristics of the K178+530 landslide

Geological exploration

To survey the geological condition of the landslide, we arranged 4 drilling holes and 6 resistivity measure lines, drilling holes position as shown in Fig. 2. According to the drilling and resistivity surveying results, drew the

engineering geological profile (see Fig. 4). Deformations monitoring equipments, temperature and pore water pressure sensors were respectively embedded in the drilling holes.

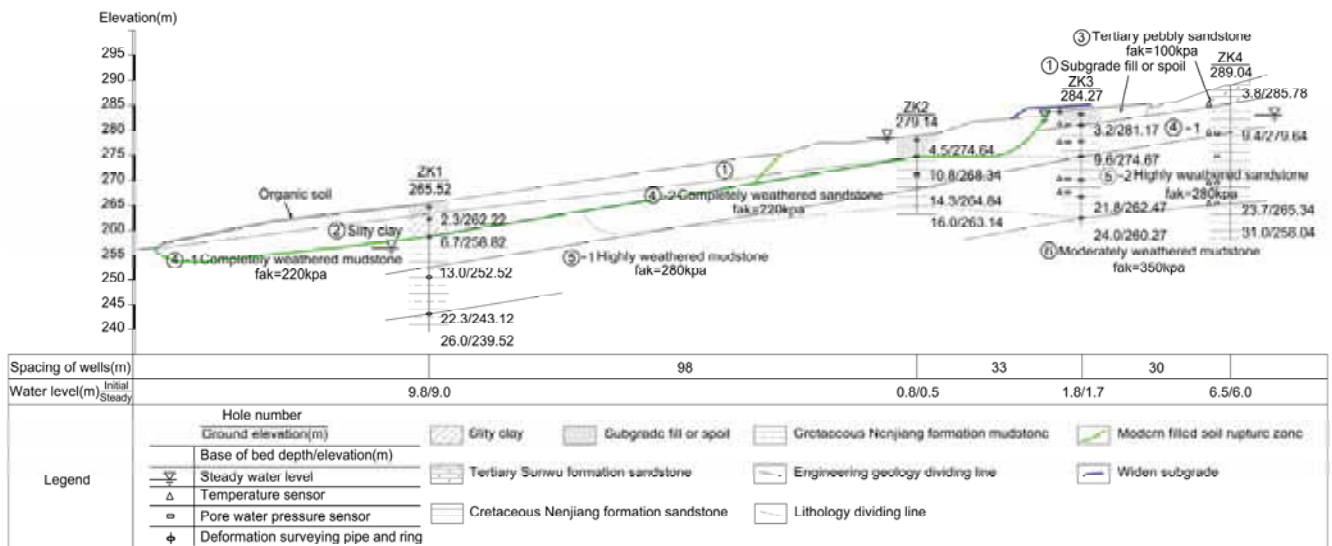


Figure 4 K178+530 landslide engineering geological profile.

The surface of landslide area mainly consists of Tertiary pebbly sandstone and subgrade spoil, high void ratio and weak integrity. There are many cracks on the subgrade spoil surface, and large free water in the cracks. Underlying subgrade spoil and silty clay, completely weathered mudstone and sandstone are relatively dense.

Through indoor test, permeability coefficient of subgrade spoil is $6.19 \times 10^{-8} \text{cm/s}$, silty clay is $3.84 \times 10^{-8} \text{cm/s}$, Tertiary pebbly sandstone is $4.11 \times 10^{-4} \text{cm/s}$, completely weathered mudstone is $6.34 \times 10^{-6} \text{cm/s}$, and completely weathered sandstone is $2.12 \times 10^{-7} \text{cm/s}$. There are many cracks on the slope surface and the permeability coefficient of the

upstream pebbly sandstone is larger, the permeability coefficient of the subgrade spoil and silty clay is smaller, when the water penetrates downward and accumulates at the bottom of subgrade spoil and silty clay, the water content of it increased gradually, shear strength decreases significantly. This judgment, the landslide belongs to bedding landslide, rupture surface is located at the bottom of subgrade spoil and silty clay.

Landslide stability numerical simulation

Limit equilibrium method is the most mature method in landslide stability study. The limit equilibrium method is characterized in that only considers static equilibrium

condition and soil Mohr Coulomb failure criterion, need assume rupture surface during calculating. Compared with limit equilibrium, finite element method namely considers the soil static equilibrium, also meets the strain compatibility and stress strain constitutive relation, can serve as a more rigorous theoretical system for slope stability analysis, it needn't assume the shape and position of rupture surface, determines the stability of landslide through stress and strain analysis.

Based on geological survey and indoor test results, employed the finite element method to simulate the safety factor of K178+530 landslide. Rock and soil finite element calculation parameters are shown in Tab. 1.

Table 1 Physical and mechanical parameters of K178+530 landslide calculation model.

Rock and soil name	Unit weight (g/cm ³)	Cohesion (kPa)	Friction angle (degree)	Modulus of elasticity (MPa)	Poisson's ratio
Subgrade spoil	1.87	13	1.5	0.63	0.47
Silty clay	1.91	14.2	7.2	2.2	0.43
Pebbly sandstone	1.98	5.9	31	28	0.22
Completely weathered mudstone and sandstone	1.76	23.4	11	58	0.35
Highly weathered mudstone and sandstone	1.83	35.6	13	75	0.33
Moderately weathered mudstone	1.89	48.3	17	90	0.30

During surveying, the subgrade spoil water content is 37.1% and saturation is 0.953, slity clay water content is 28.7% and saturation is 0.925, the slope safety factor is 1.02, the landslide total deformation before damage is shown in Fig. 5. The landslide is in the limit equilibrium

state, when the surface soil saturated with water or abandon soil loading or filling subgrade, the landslide will slide, and directly affect the stability of subgrade slope.

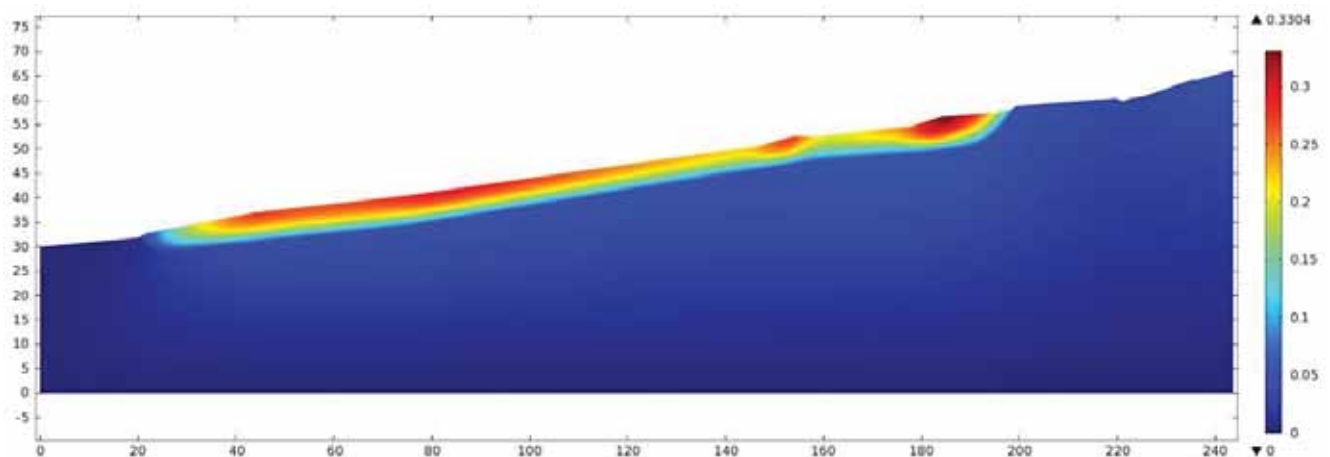


Figure 5 K178+530 Landslide total deformation cloud map before damage.

Field monitoring

After surveying, we began to collect monitoring data, found that ZK1 and ZK2 deformation monitoring pipe were sheared respectively in the depth of 6.5m and 4.2m under the ground; dislocation on the landslide trailing edge increased, striation appeared on the both sides of landslide, cracks on the landslide body increased. Based

on these data and phenomena, judged that the slope occurred slide. At that same time, employed GPS to monitor the tube nozzle moving data (see Fig. 6), and paid attention to the pore water pressure data (see Fig. 7), ground temperature data (see Fig. 8)and deformation data of ZK3, the vertical and horizontal displacement of ZK3 were very small.

The landslide began to slide at the rainy season, pore water pressure of the region was max of the year, and reached the steady state until winter, the maximum horizontal displacement respectively reached 32.2 and 60.0m, the landslide formation is mainly influenced by precipitation. The landslide slid again in the spring melts

period of the following year, the seasonal frozen soil layer of the area was completely melted at that time, pore water pressure increased rapidly, and the maximum horizontal displacement respectively reached 50.8 and 91.5m, landslide sliding again is mainly influenced by frozen soil melting and snowmelt.

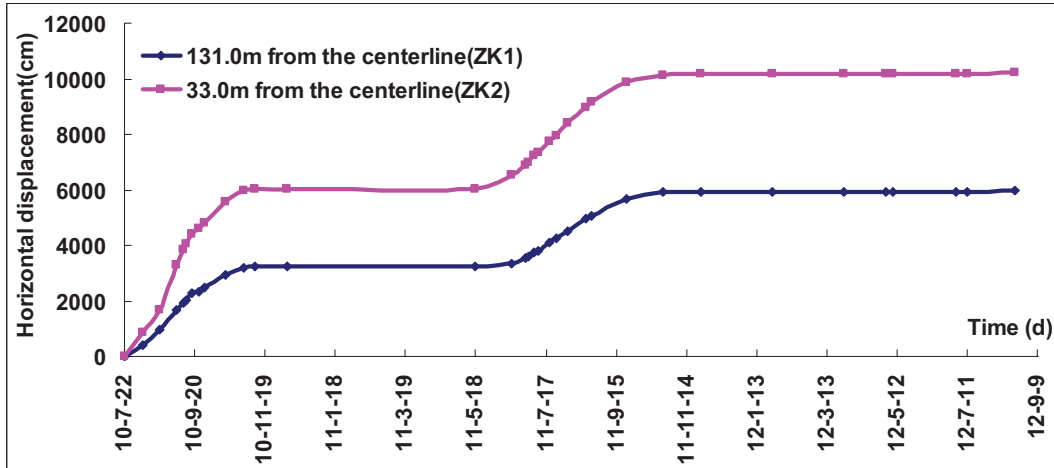


Figure 6 Curve of nozzle horizontal displacement changes with time.

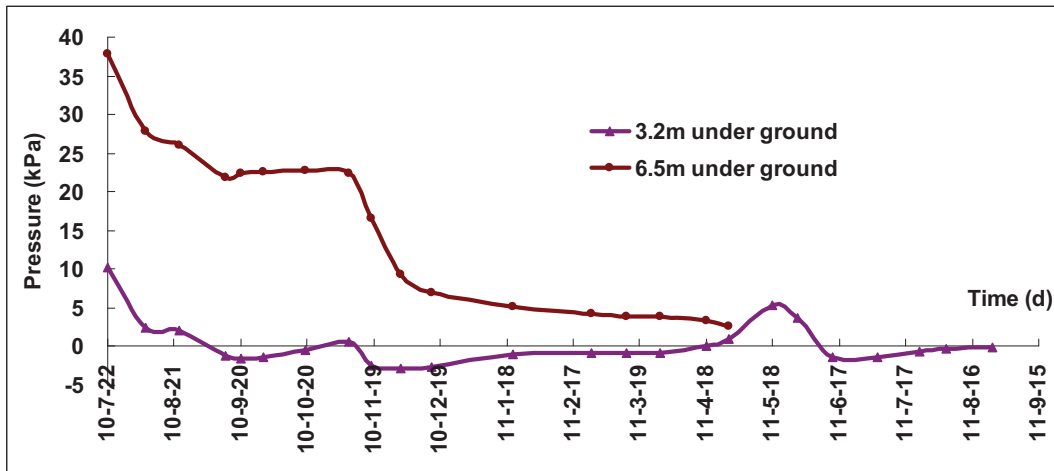


Figure 7 Curve of ZK3 pore water pressure changes with time.

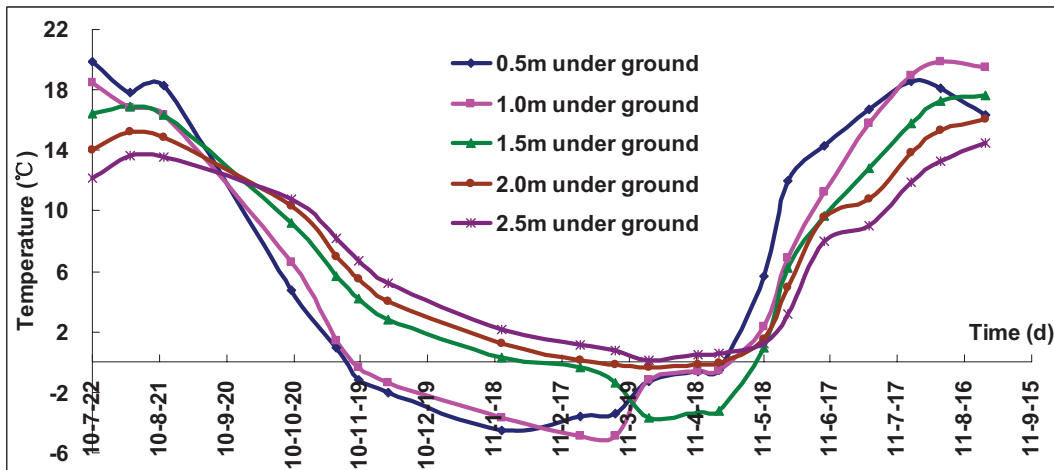


Figure 8 Curve of ZK3 ground temperature changes with time.

Landslide formation mechanism

Formation and development of the landslide is mainly affected by the landform, climate and water, geological condition and other factors.

Topography condition: topography of landslide is upper steep and lower gentle, around high and intermediate low(see Fig. 9), is avail for surface water and ground water to assemble in landslide; the rupture surface is so gentle to retain water for a long time.

The effect of climate and water: atmospheric precipitation, snowmelt water and seasonally frozen soil thawing water constantly supply the Quaternary pore water. Under the action of water, unit weight of the slide body increases and shear strength of rupture surface rock and soil decreases.

Geological condition: surface cracks and shallow high permeability rock and soil provide infiltration and lateral runoff channel for surface water and ground water; dense subgrade spoil and silty clay form aquiclude, subgrade spoil and silty clay of the aquiclude are influenced by the Quaternary pore water to be saturated, shear strength decrease dramatically and form rupture surface.

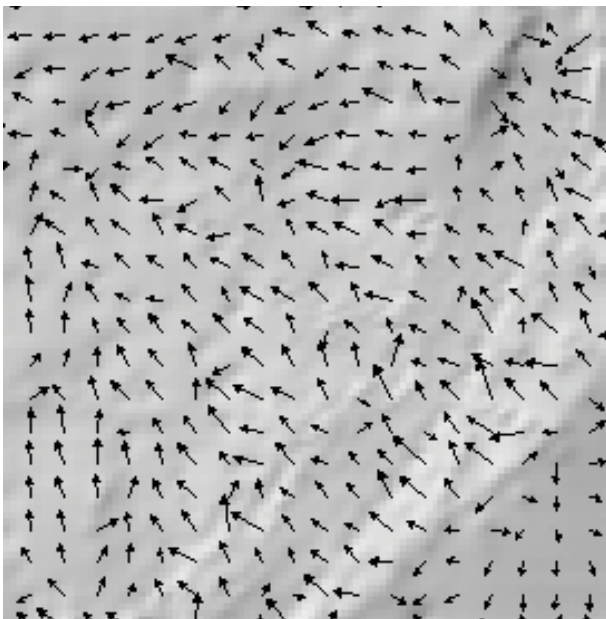


Figure 9 Landform vector graph of landslide region

Conclusions

This article employed the geological survey, topographic mapping, geological drilling, geophysical exploration, indoor test, numerical simulation, field monitoring and theoretical analysis methods to carry an integrated study on the formation mechanism of the Bei'an to Heihe freeway K178+530 landslide, drew the conclusions that:

The K178+530 landslide belongs to bedding landslide, rupture surface is located at the bottom of subgrade spoil and silty clay.

During survey, the landslide is in the limit equilibrium state, directly affects the stability of subgrade slope.

Atmospheric precipitation, snowmelt water and seasonally frozen soil thawing water provide a continued water source for landslide; surface water and ground water supply the Quaternary pore water by infiltration and lateral runoff through surface cracks and shallow high permeability rock and soil; low permeability rock and soil under the loose overburden form aquiclude, rock and soil of the aquiclude are saturated to be soften form rupture surface.

Due to the special climate, landform and geological condition, the landslide have seasonal, gradual, low angle characteristics.

Acknowledgments

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*Corresponding author: Wei Shan (1965-), male, professor, doctor of Engineering, doctoral tutor. Research interests: disaster prevention and mitigation of road and bridge engineering.
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Using High-density Resistivity Method to research on permafrost landslide

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Abstract Bei'an to Heihe expressway utilizes the original second-class highway to widen and expand for expressway, it is restricted by the original location of old road, widen subgrade of some sections locate in tailing edge of the landslides. The formation and development of the landslide at K178+530 section of Bei'an-Heihe Expressway mainly affected by the topography, engineering geology, hydrology and climate characteristics. Special topography, loose stratum, active groundwater, intense freeze-thaw erosion and human engineering activities are material conditions and power factor of the landslide. In process of landslide researching, we use geological drilling and high density resistivity method to research formation mechanism of landslide group along the expressway. The results show that: the high-density resistivity technology and the drilling exploration come to the same result at the position of the landslide sliding surface; the landslide soil resistivity values show a significant difference before and after the landslide. At the period when the landslide had not yet formed, the landslide resistivity value had no obvious stratification, and had no mutation phenomenon of the resistivity. After the formation of the landslide, the resistivity value at the sliding surface location showed significant stratification, and the resistivity values of its upper and lower were more obvious differences.

Keywords Landslide, Movement Mechanism, Drilling exploration, High-density resistivity method.

Foreword

Landslide is a natural phenomenon that, rock and soil on the slope, affected by river scour, groundwater activity, earthquake, artificial cutting slope and other factors, under the action of gravity, slide down along a weak plane or zone (Gu TF et al. 2009; He YX et al. 1991). High grade highway constructed in mountain area, due to its special geology, geomorphology, hydrology and climatic condition, often appear landslide hazards (Hu ZG et al. 2011). Landslide often interrupts the traffic, affect the normal transportation of highway, large-scale landslide can block the river, destroy highway, destruct factory, has great harms on building and traffic facility

in mountain area (Li TL et al. 2003; Liu LH et al. 2007; Hu RL et al. 2010).

Researches on landslide in cold regions were less in Lesser Khingan Range of Heilongjiang province. It is high latitudes permafrost regions, the ground slope in landslide area is low (Yang T et al. 2010; Hu LW et al. 2005; Duan YH 1999). The formation mechanism and movement characteristics of landslide have their particularity. At present, the theory and practice were immature in this research.

This article units the results of drilling exploration and high-density resistivity method to research on formation mechanism of landslide in permafrost region. Study area is at K178+530 section of Bei'an-Heihe expressway, located in Lesser Khingan Range central region, in the high latitude permafrost degradation of China. We use drilling exploration to survey the landslide geologic characteristic, uniting the high-density resistivity method to detect the resistivity of the landslide. analysing landslide geologic characteristics variation and internal physical characteristics, endeavouring to find a new breakthrough in the research on this type of landslide.

General situation of the study area

Geographical conditions of the study area

The study area geographical position showed in figure 1. It locates in Lesser Khingan Range central region, in the high latitude permafrost degradation of China. The climate of the area belongs to continental monsoon climate, the spring gets warm quickly, the summer is tepidity and rainy, the autumn gets cool fast, the winter is long and cold. The annual average temperature is -0.6°C , the lowest temperature is -48.1°C , the highest temperature is 35.2°C ; the frost free period is short, only 90-125 days. The average annual precipitation is 530-552mm, and the rainfall concentrates in July to September of the summer, accounts for about 61-67% of annual total precipitation. The ground surface of the area can form seasonal frozen soil, the time of ground reaching maximum frozen depth is the late of May, and the maximum seasonal freezing depth is 2.26-2.67m. There are many island permafrost distributed in the cheuch.

K178+530 landslide located at the left side of the embankment road, as showed in figure 2. Road abandon soil and subgrade filling soil slide along the gully, The 178+530 landslide presents a tongue shape, and its width is 20 ~ 30 meters, its acreage is about 5000m², the distance from toe to rear edge is about 200m, the

elevation of toe is 254m, and the elevation of rear edge is 285m. Leading edge of the landslide pushes up humus soil of original ground surface to slide forward. And arcuate dislocation in the rear edge, the dislocation was in rang of widen subgrade. There is trees tilt at leading edge of the landslide.

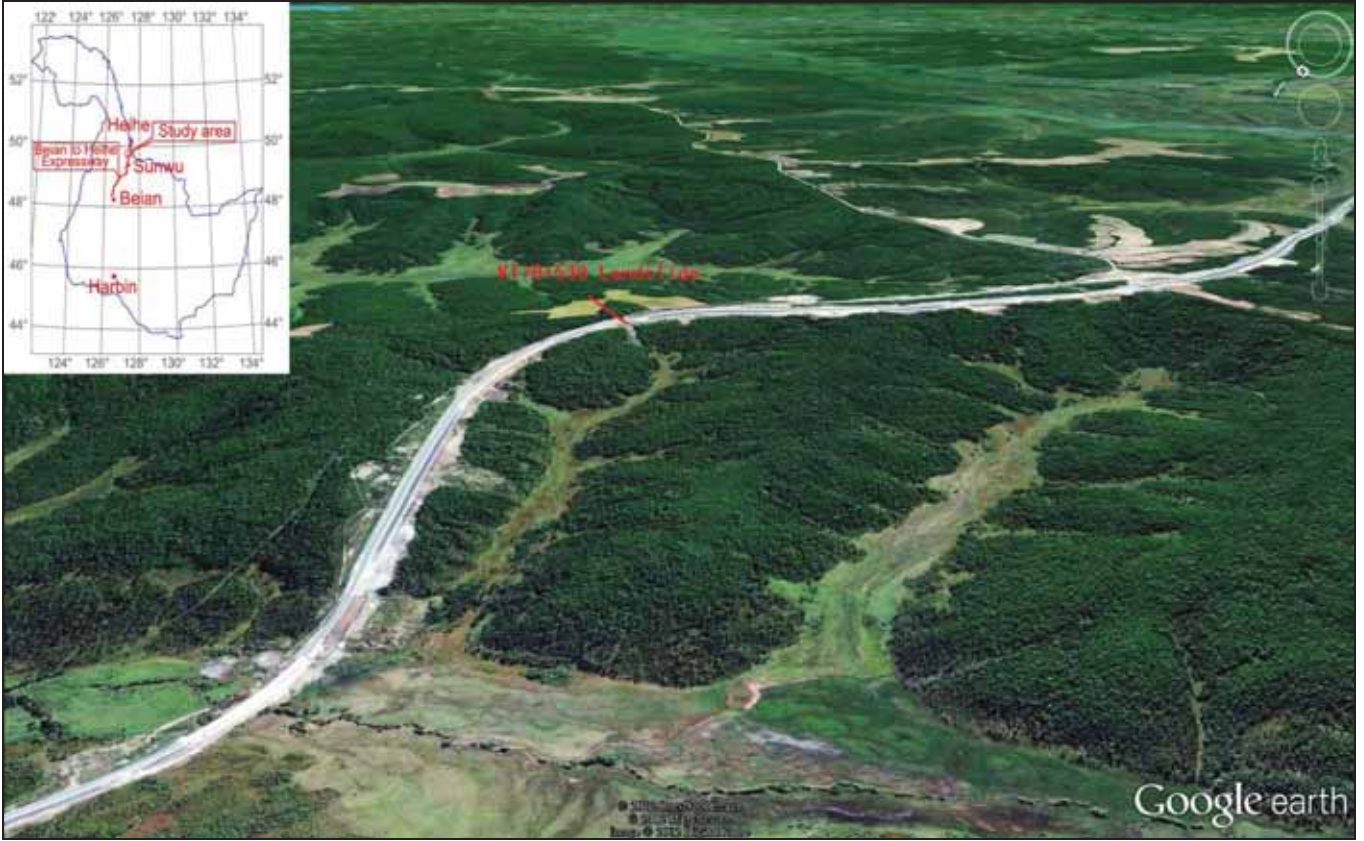


Figure 1 K178+530 section geographical position



Figure 2 K178+530 landslide photo

slide and bench slope, and there are Drumlin fields on the landslide slope.

Slip surface of upper sector is in the depth of 4.5 meters, located at the interface of gravel sand and siltstone, the soil under sliding surface is siltstone of weak penetrating power. Slip surface of the middle and lower sectors is in the depth of 6.5 meters, located at the interface of silty clay and mudstone, the soil under sliding surface is mudstone of weak penetrating power.

Based on High-density resistivity method for surveying landslide

High-density resistivity method measuring line layout

During application of high density resistivity method in K178+530 section, we use 2DRES 2D high-density resistivity method inversion software to inverse least square method, inversion of the program we use is based on least square method which based on quasi-Newton algorithms for Nonlinear optimization, and module width is set to one-second unit electrode spacing to improve monitoring precision. To ensure depth and accuracy, the unit electrode spacing is 3.0 meters in the test, sounding almost 30 meters.

At the K178+530 landslide section, as the centre of the landslide 9 high density resistivity method survey lines have been placed, as shown in Figure 5.

Along the slope tendency laying a total of 5 survey lines, which was named as the longitudinal 1, 2, 3, 4 and 5 respectively, electrodes numbers arrangement as follows: from medial divider of road to leading-edge of landslide orientation layout 1-60 in turn. The position of longitudinal 1 and 5 survey lines are 5 meters out of both sides of the landslide; Longitudinal 2 and 4 are on the landslide, at the distance of about 2.5m from the edge of the landslide respectively. Longitudinal 3 is on the landslide, located in the middle of landslide. We laid 4 survey lines perpendicular the direction of landslide, which were named as the transverse 1, 2, 3 and 4. and the

location are 30 m, 90 m, 110 m and 140 m away from the trailing edges of landslide, electrode codes number 1-60 are decorated from left to right. During the test procedure, Winner arrangement method is all used. Five Detection times of each survey line, the date is June 1st, 2010, September 10th, 2010, November 1st, 2010, and June 10th, 2011, respectively.

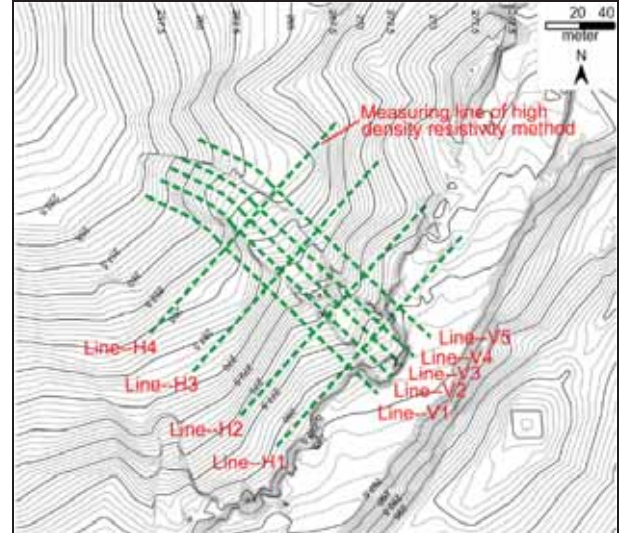


Figure 5 The high density resistivity measuring line

Contrast resistivity value of different positions on the landslide

Figure 6 showed the resistivity inversion images along the centre of landslide soil (measuring line V3). The measuring line was from median strip, respectively going through the landslide rear edge, drilling ZK2 and drilling ZK1 location and stretching into 177m along landslide to where is 32m distance from forefront of landslide, the distance of landslide back edge, drilling ZK2 and drilling ZK1 location from the first electrode respectively are 9m, and 42m, and 96m. From the figure, we can know that the resistivity of landslide soil layered apparently.

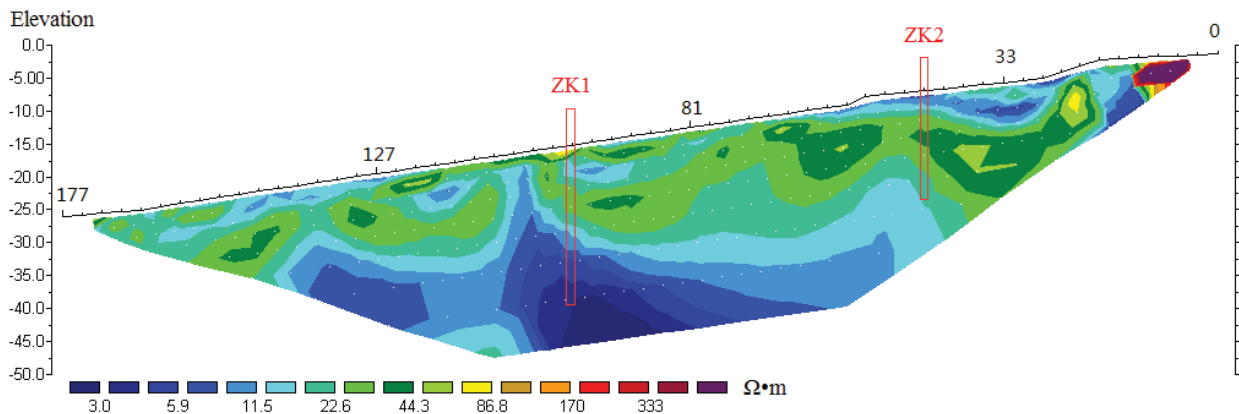


Figure 6 the inversion images of landslide soil resistivity on September 10, 2010

Drilling 1 position was away from the first electrode 96 meters. Depth 0~2.1 meters is silty clay, which containing about 15% of the organic matter as

grass roots, and resistivity value is 20 ~67 $\Omega \cdot m$; Depth 2.1~6.7 meters is silty clay, there are weathered sand sandwich on the local scale, and resistivity value is

15~32 Ω · m; Depth 6.7~8.0 meters is mudstone, and its structure is pieces, and resistivity value is 46~54 Ω · m; Depth 8.0~26 meters is gray mudstone, where is close to ground water level or below ground water level in the underground, and resistivity value smaller is 10~35 Ω · m. In 0~2.1 meters depth is silty clay that contains a lot of grassroots, water down the plant roots to infiltrate is easy; Below 6.7 meters is mudstone, the permeability coefficient is small, water is difficult to infiltrate, forming water-resisting layer. Water is easy to gather in the top surface of mudstone layer, mudstone in water softening disintegration and easy to form the sliding surface. Due to the local weathered sand sandwich, the silty clay in 2.1~6.7 meters depth can make water infiltrate easily. That site's resistivity value was as shown Figure 6 and Figure 7.

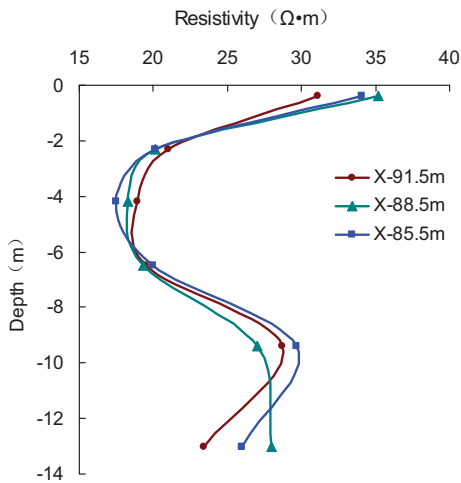


Figure 7 resistivity curve of drilling 1 position

The resistivity value at the slip surface location showed significant stratification, and the resistivity values of its upper and lower were more obvious

Drilling 2 position distance the first electrode of 42 meters, in 0~4.5 meters depth, resistivity value was 10~27 Ω · m, the surface layer roadbuilding abandon soil give priority to silty clay (Depth 0~3.8 meters), resistivity value is 15~27 Ω · m, resistivity value of sand gravel (Depth 3.8~4.5 meters) is 10~22 Ω · m. Depth 4.5~9.7 meters is siltstone, and resistivity value is 25~54 Ω · m. Depth 9.7~14.6 meters is sandstone, and resistivity value is 21~43 Ω · m; In the 4.5 meters, the position of sand gravel and siltstone handover, the resistivity apparent stratification. Depth 0~4.5 meters, the soil is good permeability, water infiltrates easily; Below 4.5 meters is siltstone, particles smaller and seepage ability is poor, forming water-resisting layer. The soil infiltration to 4.5 meters depth location is easy to gather and form the sliding surface. These resistivity values were shown as Figure 6 and Figure 8.

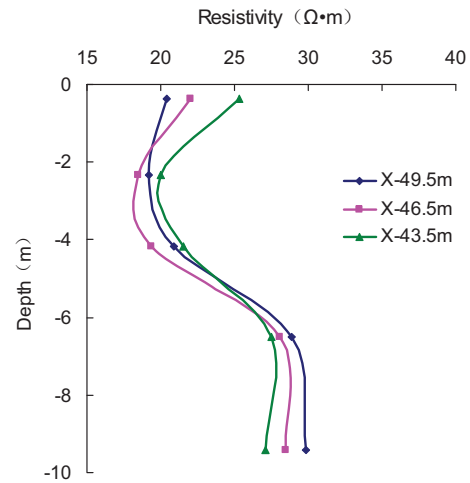


Figure 8 resistivity curve of drilling 2 position

differences. According to the typical characteristic of the slip surface, we can infer the position of sliding surface as shown in figure 9.

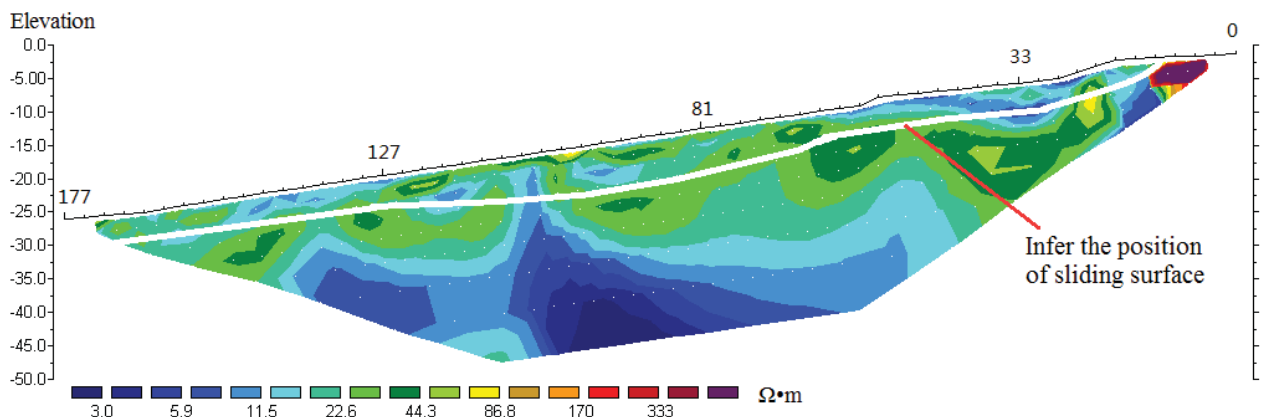


Figure 9 Infer the position of sliding surface of Line-V3

According to the mutations and layering of resistivity value at landslide position, we concluded the transverse sliding surfaces position of landslide, as

shown in figure 10 and 11, there were resistivity images of measuring line H1 and the measuring line H2 on September 10, 2010. The shape of Landslide was

approximately circular arc or inverted trapezoidal. The place near the central position of landslide sliding surface was deepest. They were 4.5 m and 6.5 m depth.

The position both walls of landslide was the shallowest, about 1 ~ 1.5 m depth.

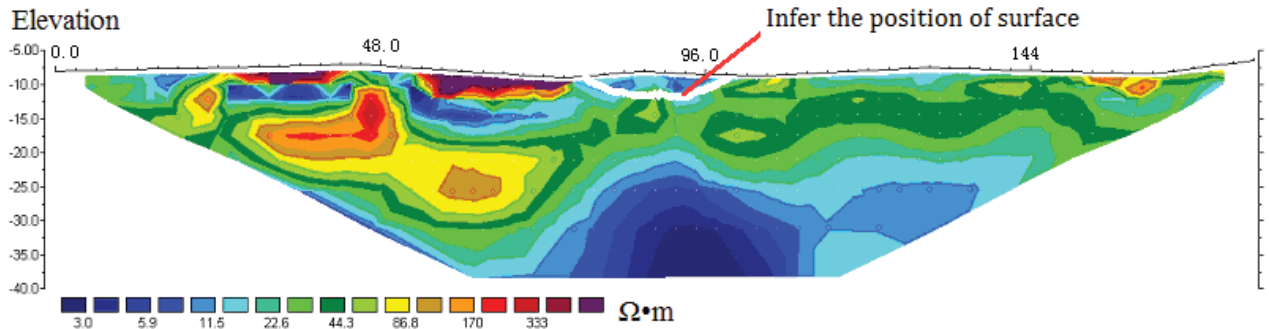


Figure 10 Infer the position of sliding surface of Line-H1

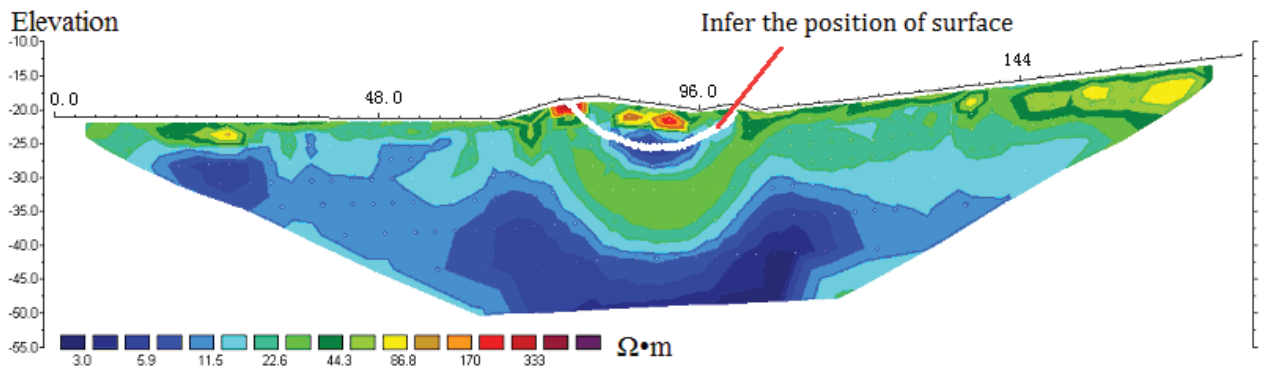


Figure 11 Infer the position of sliding surface of Line-H2

Contrast on soil resistivity value in and out of the landslide

From landslide rear edge 90 meters position, perpendicular to the landslide line (the measuring line H2) as an example, we contrasted on soil resistivity value in In and out of the landslide. Figure 12 was resistivity image of measuring line2 on November 1 2010. From the figure we could know that resistivity value

image out of the landslide only appeared higher resistivity in the surface, resistivity basically presented decreasing along with the depth. The resistivity values in and out of landslide soil were obviously differences. There were mutations and layered resistivity values in sliding surface. These resistivity values in up and down position of soil layers have obvious difference.

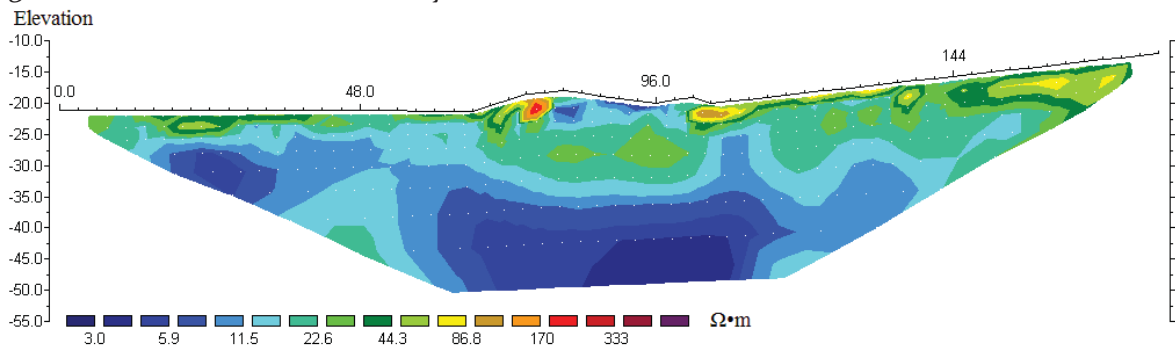


Figure 12 the inversion images of landslide soil resistivity of Line-H2 on November 1 2010

Figure 13 was soil resistivity curve in landslide and figure 14 was soil resistivity curve out of landslide. Both resistivity value curve of difference characteristics

showed that the resistivity in and out of landslide had obviously difference.

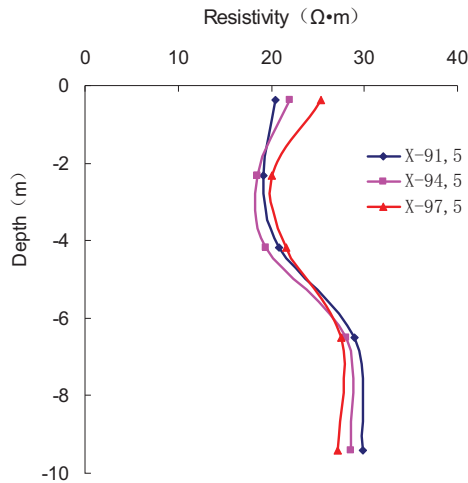


Figure 13 soil resistivity curve in landslide

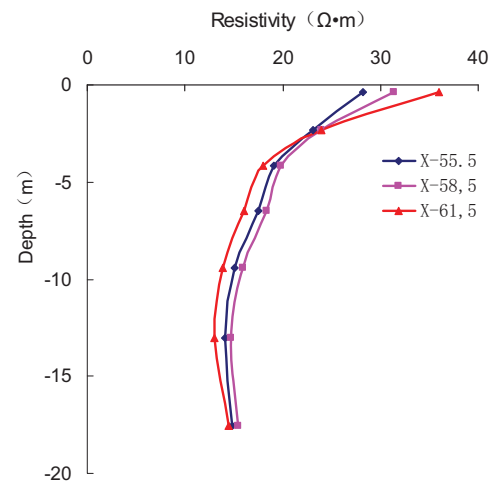


Figure 14 soil resistivity curve outside landslide

Conclusions

This article combines drilling exploration and high density resistivity method survey on the formation mechanism and geology characteristics of K178+530 landslide, and master their formation mechanism of landslide in permafrost area and internal dynamic variation of soil, and obtain conclusions :

(1) The landslide belongs to superficial and bedding landslide in permafrost region, sliding rapidly. The soil of sliding surface is silty clay, which is loose when dried, and soft plastic; snowmelt water, rainwater and fissure water provide water source for the landslide; tympanic cracks on the slope are beneficial to atmospheric precipitation pool in landslide and permeate to landslide, high permeability of landslide soil mass provide passage for water infiltration; mudstone and sandstone with low permeability form aquifuge; silty clay above the aquifuge is influenced by infiltration water to reach saturation, forming rupture surface. freezing and thawing have far-reaching consequences for the landslide, exhibiting intermittent slide and bench slope, and there are Drumlin fields on the landslide slope.

(2) Resistivity images of the soil outside the landslide appear high resistivity values only in the surface, as the depth increases, and resistivity values render essentially monotone decreasing; In the landslide sliding surface location, resistivity rendering mutation hierarchies, it is much obvious different between upper and lower soil resistivity values change. According to the characteristics of this anomaly mutations, we can conduct the differential sliding surface position of feature flags in practice. Using the high-density resistivity method to survey the landslide and its surrounding, accurately to detect the landslide resistivity value at different locations, according to characteristic of resistivity value, and combined with drilling results, to determine the position of sliding

surface: at rear edge, the position of sliding surface was at the depth of 3.2 meters apart from the ground; at 30 meters apart from rear edge, sliding surface was at the depth of 4.5 meters; at the middle landslide, sliding surface was at the depth of 6.5 meters; near the landslide toe, sliding surface was at the depth of 4 meters, at toe position, sliding surface was at the depth of 2.5 meters.

(3) The high-density resistivity technology and the drilling exploration come to the same result at the position of the landslide sliding surface. It concludes that the high-density resistivity technology is a quick, economic and reliable test method at site. It can quickly and correctly measure the position of the landslide sliding surface when high-density resistivity technology and the drilling exploration are used together, it can prove correctly reference to Linear engineering positioning and the relevant project measure.

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Large scale simulation of watershed mass transport – a case study of Tsengwen reservoir watershed

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Abstract We present the large scale simulation of watershed mass transport, including landslide, debris-flow and sediment transport. A case study of Tsengwen reservoir watershed under the extreme rainfall triggered by the typhoon Morakot is run for verification. This approach integrates volume-area relationship formula with inventory method to predict time-varying landslide volume and distribution. Then, debris flow model, DEBRIS-2D, is used to simulate the mass transport of debris-flow from hillslope to fluvial channel. Finally a 1-D sediment transport model, NETSTARS, is used for hydraulic and sediment routing in river and reservoir. The results give a very good agreement with the sediment concentration variation recorded downstream.

Keywords large scale simulation, watershed, DEBRIS-2D, sediment transport, landslide

Introduction

Landslide, debris-flow, and sediment transport are frequent phenomenon in the mountainous area in Taiwan. These three interrelated geological phenomenon can cause the mass transport from the hillslope to the alluvial fan. When typhoon strikes Taiwan, heavy rainfall triggers high density of landslides in slopeland. Then the deposit material from landslides is mixed with rainfall or overland flow to become debris-flow flowing downstream along hillslope or fluvial channel. Finally, mass from landslides or debris-flows transports into fluvial channel to increases river sediment concentration. This chain of mass transport presents multi-hazard potential to human lives, property and water resource infrastructures. A comprehensive approach to investigate and model this mass transport process has become a critical issue for disaster mitigation and water resources management in Taiwan.

In the past decades, there are various models developed to simulate landslides, debris flows, sediment transport process individually. As for landslide, researchers has used empirical or physical models to evaluate the landslide susceptibility (Guzzetti et al., 2005; Chang and Chiang, 2009) and estimate landslide volume (Khazai and Sitar, 2000; Guzzetti et al., 2009; Klar et al., 2011). For debris-flow simulation, several numerical models, i.e. FLO-2D, RAMMS, and DEBRIS-2D, have been

widely used in debris-flow assessment (O'Brien et al. 1993; Liu and Huang 2006, Liu et al., 2012). Especially, Liu et al. (2012) find that DEBRIS-2D can simulate the granular debris flow triggered by landslide very well. In sediment transport studies, various hydraulic models are developed for the simulation of sediment transport, e.g. HEC-RAS, NETSTARS, and CCHE2D (Rathburn and Wohl, 2001; Lee et al., 1997; Lee and Hsieh, 2003; Huang et al., 2006).

However, a comprehensive model for simulating this coupled mass transport process has not seen. In this study, we proposed a integrated approach to simulate watershed mass transport process, including landslide, debris-flow, and sediment transport from slopeland to fluvial channel. A case of Tsengwen reservoir watershed under extreme rainfall triggered by the typhoon Morakot is run for verification.

In what follows we briefly introduce the models for landslide, debris flow and sediment transport. The procedure of this integrated simulation is also presented. Finally, the case study of Tsengwen watershed is demonstrated.

Methodology

This integrated approach can be separated into three parts: landslide volume estimation and generation, debris-flow simulation, and sediment transport. Firstly, we developed a model of landslide volume estimation by mapping landslide inventory and calculating the volume production of individual landslide by volume-area relation. Then, we calibrated the relations between rainfall and landslide volume to develop this model. Secondly, we treat the outputs of landslide volume as the initiation condition input for the debris flow simulation, and then simulate transport of landslide mass using DEBRIS-2D. Finally, we use the simulation results of DEBRIS-2D to be the sedimentary boundary condition input of NETSTARS to simulate the hydraulic and sediment transport in channel and reservoir. The detailed descriptions of each model as below:

Landslide volume model

We collect event-based inventory data covered landslides triggered by typhoon and heavy rainfall data to develop empirical relations between landslide volume and rainfall. Landslide scars in the inventory were

mapped manually by comparing the Formosa-2 and SPOT-4 satellite images taken before and after typhoon events. Then, the volume of individual landslide was estimated by using a volume-area relation as below:

$$V_L = \alpha A_L^\gamma \quad [1]$$

where V_L [m^3] is landslide volume; A_L [m^2] is landslide area; α and γ are calibrated parameters. To link the landslide volume with rainfall variables, Uchihugi's empirical equation (Uchihugi, 1971) was used to model the volume of landslide (Fig. 1):

$$V_L = KA(P - P_0)^r \quad [2]$$

where K and r is calibrated parameters; A is area of watershed; P is cumulative rainfall, and P_0 is a critical rainfall threshold. The parameters K and r are calibrated parameters for minimum root mean square error.

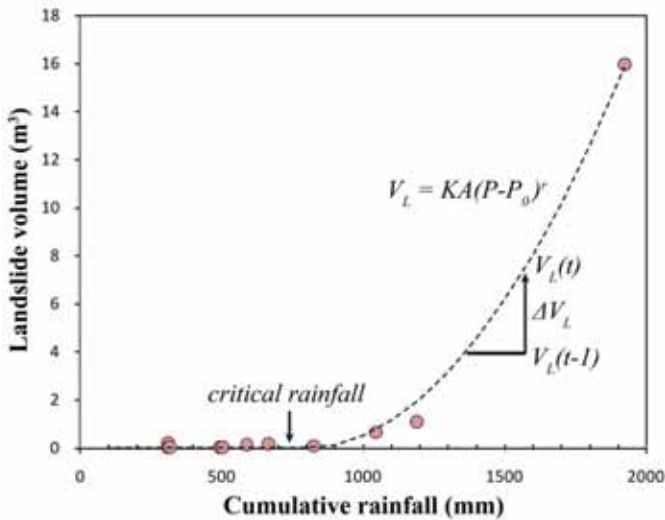


Figure 1 Landslide volume model.

Fig. 1 shows the volume change for different cumulative rainfall. Although this curve is obtained from event based data, but we can interpret it as the increase of volume in time for a landslide. Put it in another words, if this landslide event occurs suddenly and all debris slide down at the same time, we still treat it as produced gradually in time. When the volume is small, it will stay in the original location. The mass will slide down only if the accumulative mass is large enough.

With this interpretation, hydrograph of the landslide volume production can be calculated by [2]. Volume production from landslide in a specified time interval can be calculated by [3] as

$$\Delta V_L = V_L(t) - V_L(t-1) \quad [3]$$

The locations of landslide are determined by two approaches in this model: inventory method and logistic regression model. In the inventory method, we assumed

that new landslides tend to be reactivated where the landslide existed before in the past event, and small landslides occurred prior to large landslide, i.e. landslides occurred in the order of its size sequentially. On the other hand, we also use logistic regression model to predict the landslide probability. For the logistic regression analysis, we weight the relationship of landslide inventory and n independent variables, including topographical properties, distances to different geographical features, cumulative rainfall, and lithology. After calibration and verification, the resulting regression model of landslide inventory is

$$\begin{aligned} \text{logit}(y) = & -1.390 \times Elv + 0.025 \times Slp + 0.382 \times Sin \\ & - 0.085 \times Cos + 0.012 \times Wtn - 0.081 \times Fault \\ & + 0.158 \times Road - 0.199 \times Ridge - 0.129 \times River \\ & + 0.001078 \times Rc + Gel - 1.496. \end{aligned} \quad [4]$$

where Elv is elevation (m); Slp is slope ($^\circ$); Sin and Cos are aspect (1); Wtn is witness index (1); $Fault$, $Road$, $Ridge$, and $River$ are distances (m) from the given input location; Rc is cumulative rainfall (mm); Gel are lithology (1) coefficients and listed in Tab. 1. Using [4], the landslide probability can be evaluated as

$$p = \frac{\exp[\text{logit}(y)]}{1 + \exp[\text{logit}(y)]} \quad [5]$$

where $\exp[]$ stands for the exponential function. The occurrence locations of landslide are determined by the grids with the probability in descending order. However, using logistic regression model, i.e. [4], the landslide volume is still undetermined. Therefore, in this study, we use the inventory method to predict the landslide volumes and distributions.

Table 1 Input coefficients of lithology for Equation [4]

Lithology Name	Abbreviation	Coefficients
Changchihkeng Formation	Cc	0.141
Peiliao shale	Pa	-1.549
Tangenshan Sandstone	Tn	-0.679
Ailiaochiao Formation	Al	-0.756
Chutouchi Formation	Ct	-0.118
Maopu Shale	Mp	-0.055
Terrace Deposits	t	-2.593
alluvium	a	-0.187
Hunhuatzu Formation	Hh	0.392
Sanming Shale	Si	0.303
Lushan Formation	Ls	-2.001

Debris-flow transport simulation

Being mixed with water from rainfall or overland flow, landslide material on slopeland forms debris flow and transports downstream into the fluvial channel. In this study, this process is simulated by DEBRIS-2D model (Liu

and Huang, 2006). The fundamental theory of DEBRIS-2D is based on the mass and momentum conservation with shallow water assumption and depth-averaging method. The adopted constitutive relation between shear stress and strain rate is proposed by Julien and Lan (1991). The governing equations are all in conservative form and the Cartesian coordinates. The mass conservation equation is

$$\frac{\partial H}{\partial t} + \frac{\partial(uH)}{\partial x} + \frac{\partial(vH)}{\partial y} = 0. \quad [6]$$

The x- and y-momentum conservation equations are

$$\begin{aligned} \frac{\partial(uH)}{\partial t} + \frac{\partial(u^2H)}{\partial x} + \frac{\partial(uvH)}{\partial y} = & -gH \cos \theta \frac{\partial B}{\partial x} \\ & -gH \cos \theta \frac{\partial H}{\partial x} + gH \sin \theta - \frac{1}{\rho} \frac{\tau_0 u}{\sqrt{u^2 + v^2}}, \end{aligned} \quad [7]$$

$$\begin{aligned} \frac{\partial(vH)}{\partial t} + \frac{\partial(uvH)}{\partial x} + \frac{\partial(v^2H)}{\partial y} \\ = -gH \cos \theta \frac{\partial B}{\partial y} - gH \cos \theta \frac{\partial H}{\partial y} - \frac{1}{\rho} \frac{\tau_0 v}{\sqrt{u^2 + v^2}}, \end{aligned} \quad [8]$$

where $H = H(x,y,t)$ is debris flow depth; $B = B(x,y)$ is bed topography which assumed to be fixed; u and v are depth-averaged velocities in x - and y -direction respectively, and they are functions of spatial variables x , y and temporal variable t ; $\tan \theta$ is the average bottom bed slope; ρ is debris-flow density, which is assumed to be constant; g is the gravitational acceleration; τ_0 is yield stress, which represents the material property of debris flow. However, due to the fixed bed topography, the erosion effect is not considered during the simulation. In DEBRIS-2D, an initiation condition for any originally stationary debris pile is

$$\left(\frac{\partial B}{\partial x} + \frac{\partial H}{\partial x} - \tan \theta \right)^2 + \left(\frac{\partial B}{\partial y} + \frac{\partial H}{\partial y} \right)^2 > \left(\frac{\tau_0}{\rho g \cos \theta H} \right)^2. \quad [9]$$

Equation [9] means that debris flow can move only if the pressure and gravitational effects, i.e. two terms on LHS, exceed the yield stress effect, i.e. RHS.

For DEBRIS-2D simulation, the main input is debris flow mass volume distribution. The input of mass volume V , is the dry debris volume V_d obtained by the landslide volume model divided by the equilibrium volume concentration C_v (%) of debris flow (Takahashi, 1981)

$$C_v = \frac{\rho_w \tan \theta}{(\sigma - \rho_w)(\tan \phi - \tan \theta)}, \quad [10]$$

where ρ_w is water density; σ is the density of dry debris (around 2.65 g/cm³); ϕ is internal friction angle (about 37°); θ is average bottom slope angle in the field.

With the total debris flow volume V and the distribution obtained by the landslide volume model and a yield stress measured from the field or estimated with similar soil composition, we can simulate the transport of all landslide volume.

From the simulated result of DEBRIS-2D, we can obtain the locations that debris flow flows into creek and the volumes for sediment. Then, these inputs in space and time is used for sediment transport simulation in rivers.

Sediment transport

To model sediment transport process in creek and reservoir, we used NETSTARS (Network Sediment Transport Model for Alluvial River Simulation) (Lee et al., 1997). NETSTARS is a quasi-2D numerical model for hydraulic and sediment routing in alluvial channels. The flow in channel can be divided into several stream tubes that all physical properties will be averaged over one stream tube cross-section. For unsteady hydraulic routing, the de Saint Venant equations is used and reads (take flow in x -direction for example)

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad [11]$$

for continuity equation, and

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\alpha \frac{Q^2}{A} \right) + gA \frac{\partial \eta}{\partial x} + gAS_f - \frac{Q}{A} q = 0 \quad [12]$$

for momentum equation. In [11] and [12], A is channel cross-sectional area; Q is flow discharge; q is lateral inflow/outflow discharge per unit length; α is momentum correction coefficient; η is water surface elevation; S_f is friction slope; K is channel conveyance and $K=(A/n)R^{2/3}$ where n and R are Manning's coefficient and hydraulic radius respectively.

Based on the result of hydraulic routing, flow condition in the channel can be obtained and is applied as the input of sediment transport calculation. As for sediment routing, NETSTARS considers two flow conditions, including equilibrium and non-equilibrium one. If the flow condition is equilibrium, the total transport capacity of sediment load Q_s is calculated by the total load equations as below:

$$\frac{\partial Q_s}{\partial x} + (1-p) \frac{\partial A_{dt}}{\partial t} = 0, \quad [13]$$

where A_{dt} is the amount of sediment deposition/scouring per unit length of stream tube; p is bed sedimentary deposit porosity, and $(1-p)$ stands for the volumetric

sediment concentration (Julien, 2002). Equation [13] is also referred to as the 1-D Exner equation.

On the other hand, for non-equilibrium flow condition, the separate treatment method includes three equations, which are the sediment continuity, sediment concentration convection-diffusion equation and bed load equation. The Rouse number is used to separate suspended and bed load. Particle with Rouse number > 5 is treated as bed load, but suspended load if Rouse number ≤ 5. The sediment continuity equation is

$$\frac{\partial Q_b}{\partial x} + (1-p) \frac{\partial A_{dt}}{\partial t} + \frac{\partial}{\partial x} \sum_{k=1}^N (q_t C_k) = 0, \quad [14]$$

where Q_b and q_t are bed load transport rate and flow discharge in stream tube respectively; C_k is depth-averaged concentration of suspended sediment of size fraction k . This C_k is calculated using the convection-diffusion equations as

$$\frac{\partial (C_k A_t)}{\partial t} + \frac{\partial}{\partial x} (q_t C_k) = \frac{\partial}{\partial x} \left(A_t k_x \frac{\partial C_k}{\partial x} \right) + S_k + \left(h k_z \frac{\partial C_k}{\partial z} \right)_r, \quad [15]$$

where k_x and k_z are longitudinal and transverse dispersion coefficients; A_t is area across stream tube; h is flow depth; S_k is source term of suspended sediment of size fraction k , and it considers the effect of sediment resuspension and deposition. Therefore, the evolution of channel bed can also be assessed during the simulation.

For NETSTARS simulation, there are two categories of input. The first category is topography and channel cross-section data, and the other one is the BCs at the upstream and downstream boundaries. For hydraulic routing, a discharge hydrograph is needed at the upstream boundary, and a rating curve at the downstream boundary. For sediment routing, both the inflow suspended-load concentration and bed-load discharge are required at the upstream boundary. The zero concentration gradient is imposed at the downstream end. Besides, the simulation result obtained by DEBRIS-2D is also inputted as lateral mass input during the NETSTARS simulation.

Case Study – Tsengwen reservoir watershed

Introduction

Tsengwen reservoir watershed, with total drainage area of 480 km², is located in south-west Taiwan, as is shown in Fig. 2. Elevation ranges from 126 m near the Tsengwen dam (marked as square in Fig.2) to 2,610 m at the upstream boundary which is the Mount Ali (marked as triangular in Fig. 2). There are 15 sub-watersheds. Lithological setting in this watershed is dominated by sandstones and shale with weak rock strength of 10–64 MPa (Taiwan Central Geological Survey, 2012). Based on the data from the Water Resources Agency, Ministry of Economic Affairs of Taiwan (2008), the annual

precipitation of Tsengwen reservoir watershed is about 2,800 mm, of which 90% in the wet season (May–September). During this wet season, the main source of precipitation is typhoons. The heavy rainfall from typhoons usually causes numerous landslides and debris-flow in this watershed and brings abundant sediment into the reservoir.

During August 5-10, 2009, typhoon Morakot set a new rainfall record for a single typhoon event in Taiwan. The record is 3,059 mm at the Mount Ali gaging station in the Tsengwen watershed. This extreme rainfall induced countless landslides and produced a great quantity of sediment, which approximately equals to the total sediment volume producing in the past 19.5 years in the Tsengwen reservoir watershed. (Strong Engineering Consulting Co., 2011)

Therefore, we simulate the mass transport in this large watershed with extreme rainfall hydrograph, shown in Fig. 3, caused by typhoon Morakot.

Landslide volume

The landslide volume triggered by the past 8 typhoon events ranges from 0.21±0.09 to 49.86±6.36 Mm³. Typhoon Morakot triggered the largest landslide volume in this watershed, accounting for 88% of the total landslide volume from 8 typhoon events. The landslide area and total volume of each typhoon is shown in Fig. 2.

As in Chen et al. (2012), from 153 samples, the volume-area relation for the Tsengwen watershed is obtained as

$$V_L = 0.202 A_L^{1.268} \quad [14]$$

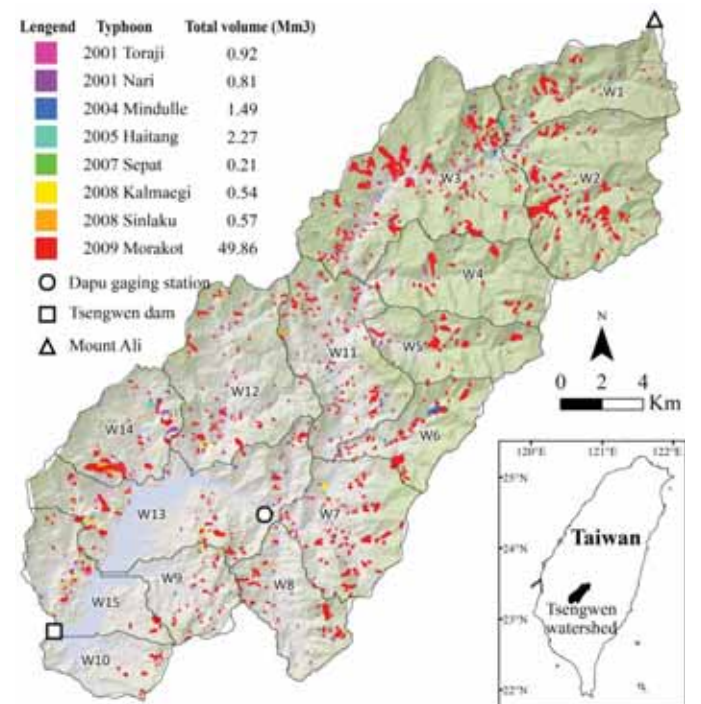


Figure 2 The distribution of sub-watersheds in the Tsengwen reservoir watershed and landslide inventory of 8 different typhoon event.

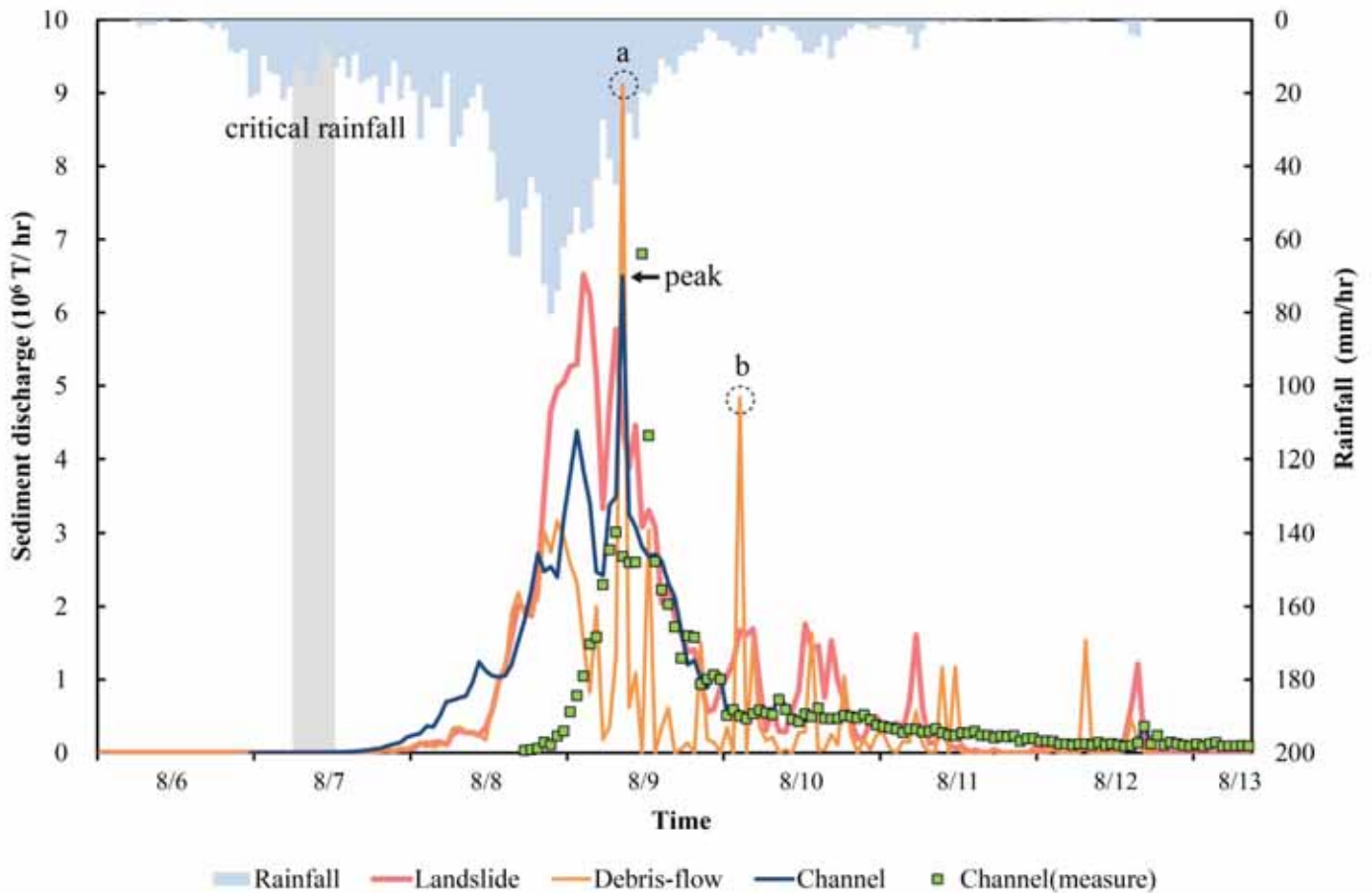


Figure 3 Hydrograph of rainfall and simulated landslide, debris flow, sediment and measured sediment discharges. The locations of landslides relating to the peak a and b are marked in the Fig. 4.

All parameters of landslide volume model, i.e. equation [2], for the 15 sub-watersheds are shown in Table 2. The root mean square errors range from 1.87×10^4 to $4.65 \times 10^5 \text{ m}^3$ and percentage error is between 17% and 53%. The exponent of the model r in [2], ranging from 2.4 to 3.0, implies that relatively small rainfall increase can result in large increase of the triggering landslide volume. The final output of the total landslide volume in typhoon Morakot is $49,075,413 \text{ m}^3$, and the landslide discharge hydrograph is also shown in Fig. 3.

Debris-flow transport simulation

The distribution of the final debris flow deposition and the fluvial channels (Water Resources Agency, Ministry of Economic Affairs of Taiwan, 2008) are both shown in Fig. 3. The discharge hydrograph of total debris flow and channel sediment inflow are both shown in Fig.3. In Fig.3, there are two peaks of debris flow discharge. The first peak comes from the landslide, located at point a in Fig.4, triggered in the W14 sub-watershed with the volume discharge of 2.46 Mm^3 per hour. The second peak is from the landslide located at point b in the W2 sub-watershed.

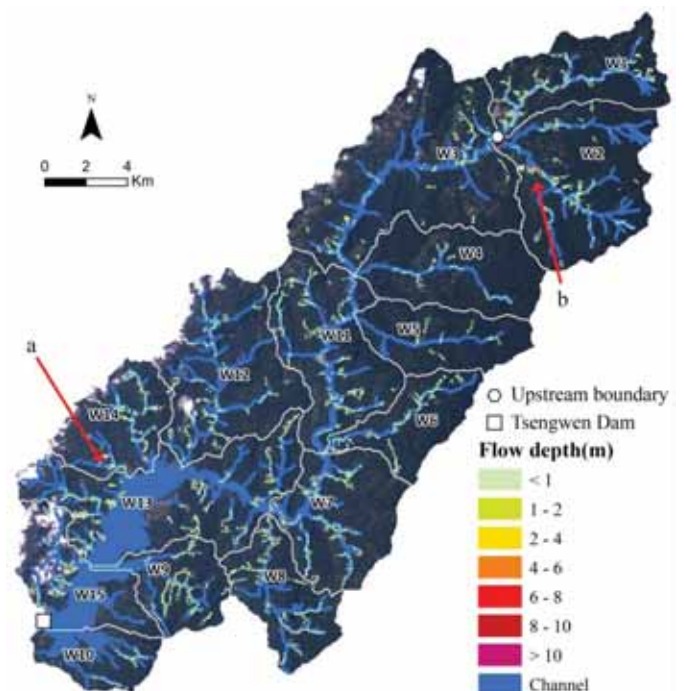


Figure 4 Final distribution of mass using DEBRIS-2D, sub-watershed is marked as W1-W15. The locations a and b causes the corresponding peaks a and b in Fig. 3.

Table 2 All parameters for landslide volume model, i.e. [2], and the volumes of landslide and fluvial channel inflow for the 15 sub-watersheds in the Tsengwen reservoir watershed. The fraction of total fluvial channel inflow volume to landslide one is 33.9%.

watershed ID	A (Km ²)	P ₀ (mm)	K	r	RMSE (m ³)	Percent error (%)	Landslide Volume (m ³)	channel Inflow volume (m ³)
W1	28.2	156	0.35	2.7	1.26×10 ⁵	43	1,970,125	668,087
W2	45.8	156	0.22	2.9	4.65×10 ⁵	41	8,384,991	3,605,216
W3	64.6	400	0.15	3.0	3.30×10 ⁵	19	12,428,657	2,950,378
W4	31.3	400	0.32	2.8	7.81×10 ⁴	25	2,186,534	474,199
W5	22.3	400	3.14	2.6	8.00×10 ⁴	23	2,497,126	549,704
W6	19.3	159	7.77	2.5	1.95×10 ⁵	43	2,545,912	853,018
W7	31.8	159	0.94	2.8	2.17×10 ⁵	53	3,078,364	1,211,712
W8	22.5	159	2.22	2.7	9.20×10 ⁴	34	1,953,766	369,982
W9	17.5	120	6.28	2.4	2.39×10 ⁴	30	585,776	155,834
W10	14.7	120	2.73	2.5	1.87×10 ⁴	37	403,793	86,137
W11	36.7	400	3.27	2.5	6.06×10 ⁴	25	1,685,969	918,750
W12	45.0	400	1.78	2.6	4.09×10 ⁴	17	1,636,836	700,049
W13	21.5	805	65.12	2.4	7.26×10 ⁴	17	2,986,346	1,214,953
W14	23.2	175	0.86	2.9	1.47×10 ⁵	19	5,264,517	2,136,202
W15	24.7	120	2.43	2.6	3.66×10 ⁴	18	1,466,701	723,947
Total							49,075,413	16,618,171

The detailed alluvial channel sediment inflow volume for each sub-watershed is also listed in Tab. 2. From the simulation result, the total fluvial channel sediment inflow volume from debris flow is about 16,618,171 m³. So the ratio of sediment inflow to total landslide volume is about 33.9%, and it is very close to the averaged value 33.3% in Taiwan (value published in the official website of Morakot Post-Disaster Reconstruction Council (2012).

Sediment transport

As for NETSTARS simulation, we have to input the cross-sections along the channel and water/sediment inflow at the upstream boundary.

The input of 240 cross-sections in fluvial channel and reservoir are obtained by digital elevation model (DEM), which is measured by LiDAR with 1 meter resolution and published by WRA (Water Resources Agency).

The water inflow discharge hydrograph at the upstream boundary is determined by area ratio method from transferring the measured discharge hydrograph recorded at Dap gauging station (location marked as the hollow circle in Fig. 2.)

The sediment rating curve is obtained by the measured datum of the suspended sediment concentrations and the river discharges recorded in Dapu gauging station. The rating curve is

$$Q_s = 0.6833Q^{1.9118} \tag{15}$$

with an acceptable R² of 0.9421. In this study, we use the water flow discharge with [15] to obtain the sediment inflow discharge at the upstream boundary.

In Fig. 5, the simulation result of sediment discharge is plotted by the blue line, and the sediment discharge measured at the Tsengwen dam is marked by the green box. When the cumulative rainfall exceeds the critical rainfall (05:00AM~12:00PM on Aug. 7), landslides start to form in all sub-watersheds. The peak of sediment and debris flow discharge happens at the same time, i.e. 8:00 AM on Aug. 9,. This peak comes from the large landslide located at point a in Fig.3 in the W14 sub-watershed. The value of this peak discharge is 6.5×10⁶ Ton/hr which is approaches the measured value of 6.8×10⁶ Ton/hr at 11:00 AM on Aug. 9.

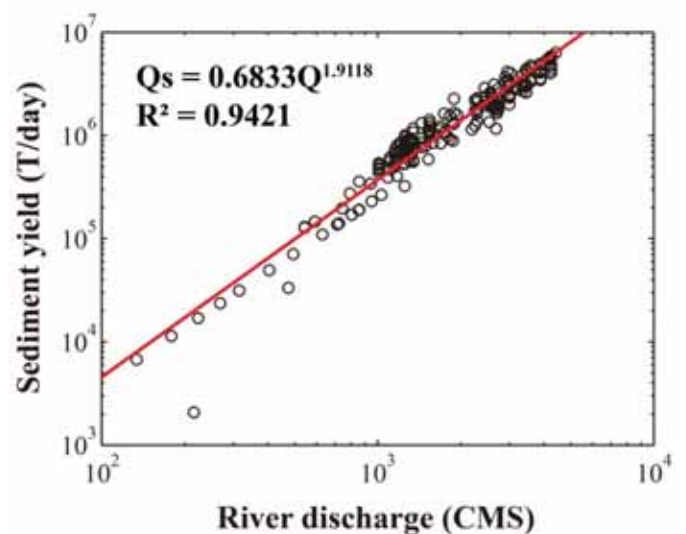


Figure 4 Sediment rating curve. The unit of sediment yield is ton per one day

However, the simulation result shows that the starting time of concentration increase is one day ahead of the measured data. This is due to the water discharge hydrograph at the upstream boundary. In our simulation, the input discharge is determined by the measured flow discharge at Dap station in the downstream with the area ratio method. So the upstream hydrograph starts too early. Therefore, the input hydrograph causes the advance of initialization time in the simulation.

The comparison of the simulation and measured sediment concentration of time variation is shown in Fig. 6. The time difference between the two peaks from simulated and measured data is 4 hours. This is also due to the early start of the assumed input discharge. Although the starting time of concentration increase from simulation is different from the measured one, the tendency of the concentration of time variation is similar. So if input discharge hydrograph is determined by other rainfall-runoff model, such as HEC-HMS, a better simulated result can be obtained.

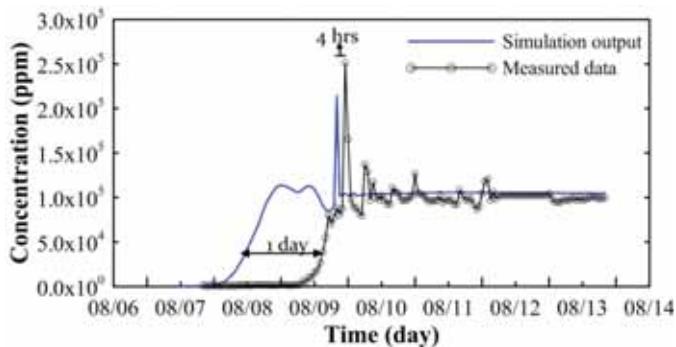


Figure 6 Comparison of sediment concentration between simulated result and measured data at the Dapu gaging station. The time difference between the simulated and measured peak is 4 hours; and 1 day for the starting time of concentration increase.

Concluding remarks

We conduct a large scale mass transport simulation including landslide, debris flow and sediment transport in a large watershed. The case of Tsengwen reservoir watershed under the extreme rainfall event triggered by typhoon Morakot is run for verification. In the integrated simulation approach, we can obtain the time-varying distribution and volume of landslides. Then, following the output of landslide model, the debris flow model, i.e. DEBRIS-2D, is able to simulate the mass transport process for the whole watershed. This simulation then provides the lateral mass input into the fluvial channel. Finally, the sediment model, NETSTARS, is used to estimate the time-varying sediment transport concentration in the fluvial channel.

As is verified by the measured sediment discharge at downstream, the simulation result of Tsengwen watershed shows a agreement of the trend of the concentration variation. However, the peak time prediction is early then the real measured data. This is due to the early start of upstream input. A rainfall-runoff model (e.g. HEC-HMS, ANN model, etc.) can provide

better time variation even without real measurement from upstream location.

With this comparison, the integrated approach for large scale mass transport simulation seems reasonable and practical and also provides reasonable result. Although early arrival of the peak is not precise, but this result can still be used as warning mechanism where early arrival gives more time for preparation. This approach can also give the sediment information in the fluvial channel and reservoir as the reference for the Tsengwen reservoir operation.

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Networking, Linkage and Coordination for Disaster Risk Reduction: A Case Example from South Asia Disaster Knowledge Network (SADKN)

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Abstract Disaster Risk Reduction (DRR) requires an integrated and holistic approach by all stakeholders in the disaster affected areas. The efforts made in isolation by any individual or organization may not suffice to meet the immense amount of physical resources, information, knowledge, skills and experiences needed for effective and efficient DRR. Thus, the pooling of resources and a synergized convergence is desired among all stakeholders through networking, linkage and coordination for integrating the initiatives made by different disciplines, sectors and programmes at local, provincial, national and international levels.

The paper cites an example of the South Asian Disaster Knowledge Network (SADKN) established by the SAARC Disaster Management Centre (SDMC) at the regional level and its linkages with the other networks like India Disaster Knowledge Network (IDKN) at the national level. It attempts to link the various programmes and activities as well as organizations in the region that contribute towards disaster risk reduction directly or indirectly. It has also established a coordinated response mechanism for DRR in the region. However, the main emphasis of the paper lies in emphasizing the importance of networking, linkage, coordination and integration in DRR.

Keywords: Networking, Linkage, Coordination, Disaster Risk Reduction, Integration

Introduction

Disasters have been affecting adversely the lives, economy and environment of the people, particularly in the developing countries like India, Nepal, Pakistan, Sri Lanka, Bangladesh etc. Although several attempts were made by the concerned national and state governments in the respective countries yet no effective outcomes could be achieved. A review of the disaster management system led to the conclusion that no government or agency can succeed in effectively reducing the disaster risks in isolation until all kinds of stakeholders are involved into the process in a partnership mode of participation. Sometimes even the physical resources, knowledge and experiences are not sufficient enough with the concerned specific stakeholders if these are not pooled together during the disaster times. However,

every stakeholder do have some capacity in terms of different types of resources, knowledge and experiences to meet the needs for disaster risk assessment, prevention, mitigation, preparedness, response and recovery. Therefore, a system has been devised to network all these capacities through a well laid out and defined system that helps in knowing the existing capacities within every stakeholder in the system and utilizing the same in reducing the disaster risks for humanitarian and environmental well-being.

Another critical observation that has been made in management of the disaster risks is lack of adequate linkages among different programmes, activities and plans related to development / safety. Disaster risk management was looked upon separately from the developmental activities. This has led to shortages of funds and human resources available for disaster risk reduction. However, if appropriate linkages can be established among the different programmes / projects / activities in any disaster affected area, it will help in avoiding duplication of activities and will complement the resources available for disaster risk reduction.

Further observations on networking and linkages led to the identification of issues related coordination and integration of these initiatives. As most of these projects / programmes are governed independently by different departments / organizations, the coordination among them seems lacking. Hence, the new disaster management system has also considered these issues of coordination and integration of efforts for disaster risk reduction.

The paper attempts to discuss the above-said issues of networking, linkage, coordination and integration for disaster risk reduction, with a case example from south Asia disaster knowledge network. It would be worthwhile to mention here that National Institute of Disaster Management, New Delhi has been mandated by the Disaster Management Act 2005 in India to carry out activities related to networking, linkage and coordination for DRR, indicating its importance in the new disaster management framework of the country.

Networking

Networking is a process of bringing people together for a common cause with mutually beneficial interests in a society or a community. It promotes collaborations in

regional programmes, including technical cooperation, capacity development, the methodologies and standards for hazard and vulnerability monitoring and assessment, the sharing of information and effective mobilization of resources for supporting national and regional efforts. The networks undertake and publish regional / sub-regional baseline assessments of the disaster risk reduction status, according to the needs identified and in line with their mandates. It helps in establishing or strengthening linkage and coordination for integrated research, training, education and capacity development in the field of disaster risk reduction. It provides an operational mechanism for sharing and exchange of resources, knowledge, skills, information and experiences. Thus, there is a need to develop working partnerships among different stakeholders who are expected to play an important role in DRR.

Who should join the network?

- Officials from UN Organizations, Government or semi-government organizations dealing with various aspects of disaster management
- Volunteers and Social Workers from Non-Governmental and Civil Society Organisations
- Officials and field workers from Local, District, Provincial, National and International level organizations
- Representatives of multilateral and bilateral agencies supporting projects and programmes pertaining to disaster management
- Academicians, researchers and other professionals involved in disaster management capacity development, training and research
- Corporate and other private sector professionals in the disaster management-related fields, including risk management and the insurance sector

Linkage

Linkages focus on the programmes and activities related to disaster risk reduction in the different organizations and sectors for evolving partnerships among these stakeholders in implementation of the risk management process effectively.

It can help in collaborative research activities with other stakeholders in the country and globally in coordination with the regional and international organizations. The activities establish linkages with governments at different levels, other organizations and NGOs for an integrated and holistic disaster risk reduction in partnership with the affected communities. It helps in preparing institutional agreements with government agencies, NGOs and the industry to secure funds for the DRR activities. For example, the social welfare programmes at community level and developmental activities in the disaster affected areas can always be linked to the disaster risk reduction programme and activities.

Linkages will also help each agency / organization fulfil its own mission. Few programs have the sufficient resources available to address the sometimes overwhelming number of problems faced by the stakeholders in the affected area. Increasingly, such programs are looking to strong collaboration and linkages with other service agencies to meet these needs. Thus, linkages and collaborations are particularly beneficial where lack of resources, skill, knowledge, information and experience are significant problems.

Most of the individuals / organizations who are engaged in DRR activities or services, generally have experienced the negative consequences of fragmented and disintegrated service systems. but the linkages provide a formalized approach to linkages of programmes, services and activities among different agencies. The different stakeholders have developed strategies to develop linkages with other programmes in the affected area to increase the capacity of their programmes. These linkages involve efforts to coordinate with different stakeholders and efforts to provide continuous services for DRR activities.

Coordination and Integration

Under this new paradigm, a formal structure for continuity of services and a process to oversee system-level coordination among agencies is established. While specific goals would vary from organization to organization, such systemic reform would enable stakeholders to create a collaborative infrastructure that, in turn, would allow programmes to implement DRR activities more effectively. The coordination and integration activities are

- Stakeholder specific focussing on their needs with appropriate services as opposed to fitting the affected communities into a predefined programme
- Holistic offering comprehensive services from a variety of agencies that are designed to respond to affected community's multiple needs: housing, food, water, sanitation etc.
- Flexible, i.e. the response action changes as the stakeholder's needs change
- Collaborative means multiple agencies can work together freely without any interference with the assistance process
- Accountable to encourage the affected community's input to the comprehensive DRR plan, adhering to standards or accepted best practices for DRR, establishes and tracks qualitative and quantitative outcome measures, and evaluates activities / services on the basis of community satisfaction.

Currently, most DRR programmes function as a series of parallel programmes with their own sources of funding, leadership, and constituencies. In the environment that would emerge after converting from parallel services to an integrated delivery system, cooperation on the stakeholder's behalf would replace

competition. Collaboration would eliminate duplication of services and execution of inappropriate services. Systemic reform on this scale requires structural and administrative changes at different levels. As a first step toward revamping DRR system to cater to the multiple-needs of the stakeholders, a mechanism is suggested that would help

- Coordinate planning among disparate agencies based on stakeholder's needs assessments
- Devise financing strategies that would allow for blended funding and strive for equitable allocation of resources among agencies
- Establish a vehicle for resolving any problems that emerge in implementation of integrated services.

Coordination may involve contracts or linkage agreements, or other mechanisms to ensure an efficient DRR system for all stakeholders. In collaborative relationships, difficulties can arise if one entity feels taken advantage of, perceives that the other is deriving more benefits from the association, receives more credit, or believes that power is unequal between the two groups. Balance is central to an effective collaboration that satisfies the expectations and needs of all involved.

A Case Example of a Regional Network from South Asia Disaster Knowledge Network (SADKN)

SDMC was set up in October 2006 at the premises of National Institute of Disaster Management in New Delhi. The Centre has the mandate to serve eight Member Countries of South Asia Association of Regional Cooperation (SAARC) - Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka - by providing policy advice and facilitating capacity building services including strategic learning, research, training, system development and exchange of information for effective disaster risk reduction and management in South Asia. It is networking through the National Focal Points of the Member Countries with the various Ministries, Departments and Scientific, Technical, Research and Academic institutions within and outside the Government working on various aspects of disaster risk reduction and management.

South Asian Disaster Knowledge Network (SADKN) is a gateway to knowledge and information on disaster risk management in South Asia. It acts as the common platform for sharing knowledge and information among the multiple stakeholders of the member countries of the South Asian Association for Regional Cooperation (SAARC) on the inter-disciplinary and cross-sectoral issues of disaster risk assessment, risk prevention, mitigation and preparedness and disaster response, relief, recovery and reconstruction. It provides ready access to clear, understandable and user-friendly information about real time, impending and historical disasters, details of hazards, vulnerabilities and risks of disasters in

structured layers of digitized maps in WebGIS platform, and wealth of resources, references, images and videos on practically every aspect of disaster management that the users would be interested to know.

The SADKN provides decision makers with the instant geospatial support for assessing risks and communicating about hazards and the exposure that vulnerable people and infrastructure have to these hazards and assist them in locating disaster occurrences and probable fall outs, and taking important decisions regarding evacuation, damage and loss assessment, recovery and risk reduction. It has dynamic features like Disaster Dashboard, Real Time Weather Forecasts, Networks, Discussion Forum, Chats and Blogs, FAQs, Kids Corner etc. that enable the users to meet and interact with each other to share their experiences and find solutions to their problems and issues. It provides an environment to encourage people to create, learn, organize, share, use and reuse knowledge on disaster management.

The SADKN (<http://www.saarc-sadkn.org/network.aspx>) is a network of networks, with one regional and eight national portals, that would involve the national, provincial and local governments, international organizations, scientific, technical and academic institutions, non-government organizations, media and corporate sectors, communities and individuals in South Asia in sharing knowledge and good practices on disaster management.

The SADKN intends to create one stop unified point of access to disaster management knowledge and services and thereby accelerate and improve the quality of disaster mitigation and response in the region.

India Disaster Knowledge Network (IDKN) – Example of National Level Network

India Disaster Knowledge Network (IDKN) is a web portal (<http://www.idkn.gov.in>), that offers a broad array of resources and services, such as knowledge collaboration, networking, maps, emergency contact information system and several other valuable informations related to Natural disasters. IDKN is an essential tool to share information for Managing disasters. The main goal of IDKN is to create an easy to use unified point of access to disaster management knowledge and services and hence an accelerated and Improved quality of disaster mitigation and response. Its main aims are:

- Provide consolidated source of disaster-related information and services. Information includes the definition of different hazards its Geographic distribution, Vulnerability of India (state level), Preparedness and Mitigation measures etc.
- Minimize loss of life and property by creating awareness at all levels

- Provide a platform to share knowledge and create an environment to learn about disaster management through interactive process.

ICL's Networks on Landslides – An Initiative

ICL has examined the proposals for initiating thematic and regional networks on landslides during its 10th anniversary meeting in January 2012 at Kyoto, Japan and decided to establish these networks to promote its thematic and regional activities on landslide risk reduction, environmental conservation and heritage protection, as part of its joint activities with UN ISDR in the International Programme on Landslides. This will help to intensify the collaboration among ICL members as well as enhance cooperation with the non-ICL member organizations.

The following 3 regional networks have been approved.

- i. ICL Adriatic – Balkan Network
- ii. ICL Latin – American Network
- iii. ICL North – East Asia Network

Besides the regional networks, 5 thematic networks have also been approved. These include

- i. ICL Landslide Risk Management Network
- ii. ICL Capacity Development Network
- iii. ICL Landslides in Cold Regions Network
- iv. ICL Landslides and Cultural & Natural Heritage Network
- v. ICL Landslide Monitoring and Warning Network

In addition to the above-said networks, ICL has already been working on a Landslide School Network that tries to bring together the experts and organizations engaged in landslide education, training and research.

Conclusion

The discussions in the paper lead to the conclusion that networking, linkage, coordination and integration for disaster risk reduction activities are crucial aspects of any disaster risk management framework or system. The establishment of networks such south asia disaster knowledge network (SADKN) at the regional level and India Disaster Knowledge Network at the national levels, has actually promoted and encouraged the disaster risk reduction activities at local, national, regional and international levels. Similar initiatives made recently by the international consortium on landslides in establishing the 3 regional and 5 thematic networks on landslides are likely to contribute significantly in landslides risk reduction. However, the effectiveness and efficacy of these networks would depend upon better linkages, coordination and integration of the programmes and activities among various stakeholders. Hence, an appropriate mechanism and a good structural arrangement is a pre-requisite to the successful implementation of landslide networks by the ICL.

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<http://www.idkn.gov.in>

<http://www.saarc-sadkn.org>

Lessons Learned in the Development of Landslide Early Warning System in Indonesia

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Abstract Since developed in 2007, landslide early warning system (EWS) in Indonesia has kept improving and many lessons learned can be gained. At the earlier stage of development, the system was only focused on technical aspects. The equipment for landslide monitoring and early warning was developed with the simple and low cost devices, followed by the use of advanced technology to produce the automatic devices with data recorder and devices connected to the online monitoring system. However, the technical approach did not ensure the success of the system, hence, socio-ecological approach is also required. The system was developed based on collaborative framework of multiple stakeholders. Integrated application of the system has been able to respond the community need to improve the preparedness and respond to the occurring disaster. The future challenge is to broaden the implementation of the system globally, improve the effectiveness of the monitoring, early warning analysis, and the visualization of the monitoring results.

Keywords: community development, preparedness, landslide monitoring, socio-technical strategic approach, risk assessment.

Introduction

Landslide prone areas are widely spread in Indonesia; therefore, a collaborative effort is necessary to reduce the risk. Landslide risk in several areas is mainly controlled by geological, geotechnical, and hydrological conditions and can be initiated by high rainfall intensity and earthquake. The vulnerability to landslide is worsened by land use change where agriculture is practiced in the areas with slopes.

The main issue to solve is the increasing density of the population in the landslide prone areas because those areas are generally fertile and have high economic values. The construction of slope revetment is very costly, hence, could not be applied to all areas. Furthermore, people relocation to safer areas is proven to a challenge due to socio-eco-cultural issues. On the other hand, the potential of ground movement keeps increasing due to the increase in rain intensity, earthquake occurrence, and human disturbance on the slope (Karnawati et al., 2005;

Karnawati and Fathani, 2008). One of the protective efforts for people living in the areas prone to landslide is the application of early warning and monitoring system involving community participation to increase their preparedness in facing the disaster.

The early warning system requires a set of monitoring and warning devices that works simultaneously and is coordinated in the disaster mitigation effort. Prior to the installment of the landslide early warning and monitoring system, preliminary investigation and survey are required to understand the physical condition, as well as the social, economic, and cultural condition of the local community. The next phase is design and installation of the adaptive early warning and monitoring devices, followed by intensive training to the local community on how to operate and maintain the devices (Fathani et al., 2010).

This paper discusses the lessons learned from the long experience of the implementation of community based landslide early warning and monitoring system in Indonesia. One of the challenges is to ensure that the low cost and simple landslide detection devices can be applied effectively and even can be made by the local community. Next is how to integrate the design and the implementation of the advanced technology for landslide early warning and monitoring system and the last is the application of the system can be well coordinated with central and local government, universities, private sectors, NGOs, and disaster preparedness team.

Stage of Development of Landslide Monitoring and Early Warning System

Based on a long experience on the implementation of landslide disaster risk reduction, one of the effective efforts of landslide mitigation is by developing low cost and simple landslide early warning and monitoring system in order for the local community to be able to operate and maintain the systems. In some of the study areas, the local community is able to reproduce the system to be applied in their area with a continuous support from the government, private sectors and other related institutions. The steps in developing the landslide early warning and monitoring system can be elaborated as follows:

- a. Conducting survey and investigation to the geological, geotechnical, and hydrological conditions, landslide inducing factors, the extent of the landslide prone areas and the condition of the people living in the landslide prone areas. The survey and investigation aim at determining the location of the installation of the landslide early warning and monitoring devices.
- b. Designing low-cost and adaptive monitoring and warning devices for certain areas. The design is based on the results of the survey; therefore, the technical system is adjusted to the different conditions of the areas and local community.
- c. Carrying out socialization and training to improve the capacity of the disaster preparedness team and the community living in the landslide prone area so that they can operate and maintain the systems.
- d. Installing the technical system and conducting consultation on the operation and maintenance of the devices and performing simple analysis based on the data obtained from the monitoring devices. Test and calibration of the devices are required to ensure the accuracy of the monitoring.

The applied landslide early warning and monitoring system is integrated system between technical system and community based social system (Fathani and Karnawati, 2010). In this system, the disaster preparedness team and the local community must participate actively in supporting the technical network. The effectiveness of the system depends on the initiative and active participation of the disaster preparedness team supported by the government (Karnawati, et al., 2011).

Through the application of landslide early warning and monitoring system, both aspects, namely technical and social aspects can be integrated. The operational and maintenance of the monitoring devices and warning system can be implemented and the capacity of the local community and their ability to respond to disaster can be improved (Andayani et al., 2008). On principle, through the system the local community is expected to be motivated and able to carry out landslide mitigation on their own.

The development phase of the devices began with low cost simple monitoring devices, followed by automatic devices with data recorder, and real-time warning and monitoring devices that will be discussed in the next section. Moreover, the development process of monitoring devices such as rain gauge, extensometer, tiltmeter, inclinometer, pore pressure sensor and other devices will also be discussed.

Simple and Low-cost Technology for Landslide Monitoring

Low cost simple ground movement monitoring devices has been developed by Universitas Gadjah Mada (UGM) starting from 2007. First, simple extensometer, tiltmeter and rain gauge were developed and installed in Central Java Province and East Java Province.

The first model is a manual reading extensometer made of wood and brass. The devices was equipped with anglemeter and compass to read the ground movement in three directions. Then, paper-recorded extensometer type that measure relative movement between 2 cross sections points of soil cracks. This type of extensometer has better accuracy compared to the manual extensometer. The rain gauge is also installed in the landslide prone area to compare the reading of ground movement to rainfall data. The whole system is connected to the alarm system to give warning to the local community on the possibility of landslide.

The application of the landslide early warning and monitoring system was developed with consideration to the socio-eco-cultural approach to support the technical aspect. The system starts to show some success in the areas where it is applied. One of the examples is the landslide occurring in Kalitelaga Village, Banjarnegara Regency on November 7th 2007 that was detected 4 hours prior to the occurrence. The local community, consisting of 35 families, evacuated to a safe place after hearing the warning and avoided the landslide that damaged 10 houses (Fathani and Karnawati, 2010). The application of low cost and simple landslide early warning and monitoring system in Kalitelaga is shown in Figs. 1 and 2.



Figure 1 Automatic extensometer installed at the upper slope at a densely populated area.



Figure 2 A manual extensometer could detect a collapsed slope and warns the community to evacuate.

Fig. 1 shows an automatic extensometer installed at the upper part of an unstable slope in order to monitor the ground movement, whereas 40 houses are located at the lower slope. Meanwhile, Fig. 2 shows the manual reading extensometer at the upper part of collapsed slope. This manual extensometer warned the local community about 4 hours before the occurrence of landslide and saved 35 families living at the hazard prone area.

The monitoring devices should be maintained in order to be able to send warning sign to the fieldserver and central operator which then passes on to the local community so that they can take necessary actions. The local government should determine how the information of disaster signs can be delivered to the community and how the authority should decide when the community should evacuate (Fig. 3). The simple devices commonly can deliver the warning sign directly and can be heard by everyone. After that, the head of the village or the head of the disaster preparedness team appoints the team responsible to deliver the status change for landslide and mobilize the people to evacuate.

The scheme is proven to run smoothly during landslide occurrence in Kalitelaga Village, Banjarnegara Regency on November 7, 2007. The team delivered the evacuation order from the head of the village. They mobilized the community to evacuate to a safe place while conducting monitoring the slope condition.

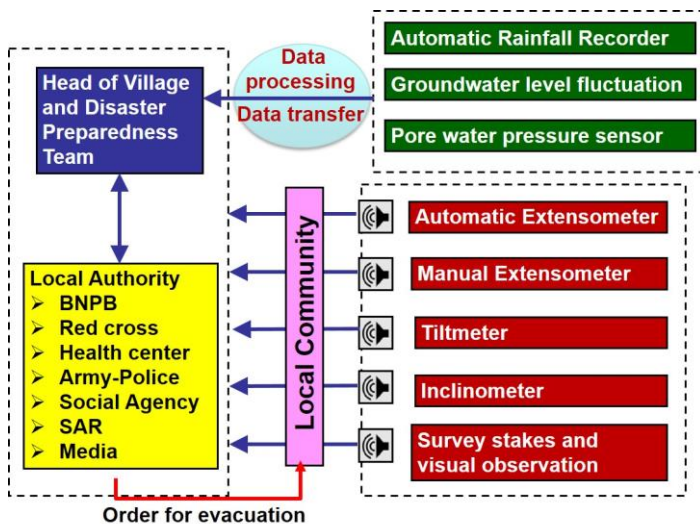


Figure 3 Arrangement of detection for landslide signs and evacuation order at village level.

Real-time Landslide Monitoring

In a high level of danger and or landslide occurrence with huge impact, real-time landslide monitoring can be used. The monitoring devices generally used comprises rain gauge, extensometer, tiltmeter, inclinometer, multi-layer movement meter, pipe strain gauge, pore pressure sensor, etc. The monitoring results by the devices are recorded in a fieldserver. The power issue is solved by using solar cell.

The devices transfer the data to a fieldserver that passes the data to a cloud network that can be accessed real time through website and can be disseminated and discussed in the social media.

The application of technical system in an area can be differed from other areas, depending on the physical and social conditions of the area. Fathani et al. (2011) gives warning criteria for rainfall-induced landslide in Central Java. Warning criteria are obtained based on the monitoring and the result of analysis on the effect of rainfall intensity and cumulative rainfall on the initiation of ground movement monitored by the devices. Furthermore, the combination of rainfall threshold that initiate slope movement can be analyzed to determine warning criteria that differ from one area to another.

The illustration of the mechanism of the monitoring system, data transfer and the warning system can be seen in Fig. 4. The system is used to provide real-time monitoring information. Various devices are used to monitor the rainfall, water table fluctuation, surface deformation and the movement on the slip surface.

The recorded data is then processed by the microcontroller and transferred to a fieldserver. A program that can receive, save, analyze, and send data to the central server from time to time is installed in the fieldserver. The determination of danger condition and the necessity of evacuation are decided by the program automatically or manually by a trained official who is standby in the central server. In the customary use, the maximum distance of the radio frequency is 2-4 km Line of Sight (LOS) between the sensor and local server while the distance from the local server to the central server is between 10 to 20 km (LOS) and even can be increased to 100 km. The central server has a receiver, PC and a monitor to display the rainfall data and ground movement. If the PC is connected to the internet, then the data will be uploaded automatically and can be accessed via internet or disseminated through sms blasting or social media.

Landslide Monitoring Devices

In the left side of Fig. 4, various landslide early warning and monitoring devices are shown. The devices are developed by Universitas Gadjah Mada (UGM) in cooperation with Indonesian National Disaster Management Agency (BNPB), Provincial and District Disaster Management Agency (BPBD), Ministry for the Development of Disadvantaged Regions (KPDT), the International Consortium on Landslides (ICL) and Kyoto University. The developed monitoring system and the connection can be seen in Fig. 5.

Extensometer and tiltmeter are the most common devices used to monitor surface deformation. As they are installed in the soil surface, they can easily be moved to other locations. This is not possible for the monitoring devices for slip surface movement such as inclinometer, multi-layer movement meter and pipe strain gauge.

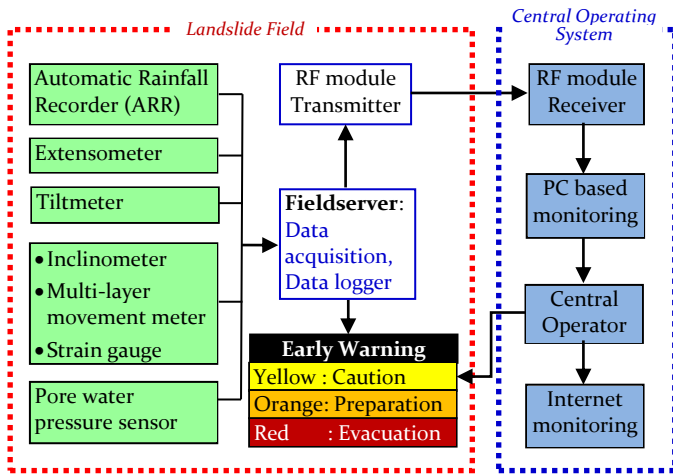


Figure 4 Mechanism of the monitoring system, data transfer and the warning system

The basic principle of extensometer is that the device is installed in between 2 points, one of which is installed on the moving ground. An invar wire or composite wire is connected to the devices at a stable ground and to the potentially unstable ground on the other end. When ground movement occurs, indicated by a change in the relative distance between 2 cross section points, the invar wire will be pulled or loosened. This will activate the sensor and the data recorder. The upper ground extensometer has been installed to monitor ground movement in a mining site in East and South Kalimantan as shown in Fig. 6. The international mining company prefers to utilize a rotary light signal, instead of a sound alarm system due to the noise from heavy equipment at the mining site.

An extensometer has mechanical and electrical mechanism. The mechanical system is supported by spring system that can hold the extension of invar wire to 20-40 m. The extensometer has 2 sensors that are absolute rotary encoder sensor and tilt sensor. The absolute rotary encoder sensor is used to detect a ground movement with the accuracy of 0.1 mm. The rotary encoder works with pulley and spring system. Micro-electromechanical systems (MEMS) are used on tilt sensor to measure a change in the slope variation. The recorded data are among other ground movement (mm) and changes in slope variation (degree) which are then sent to the fieldserver to be processed.

Another commonly used monitoring device is tiltmeter. Tiltmeter is used to monitor changes in slope inclination in the landslide prone areas. Tiltmeter measures changes in slope inclination in X and Y axis with accuracy up to 0.1 degree. It can also measure the diagonal angle value of ground movement direction. The newly developed extensometer and wireless tiltmeter are shown in Fig. 5. The tiltmeter will be further developed using sensor with higher resolution i.e. 0.01 degree.

The developed rain gauge uses the common tipping bucket system, as seen in Fig. 5. It calculates the number of times the buckets tip and converts it to rainfall unit (mm/hours). The data is transmitted to a data logger and can be seen in the LCD monitor. All the monitoring devices are equipped with alarm and rotary light if needed, that can give warning to the community before a disaster happens. The warning criteria can be adjusted to the fieldserver or directly on the monitoring device.

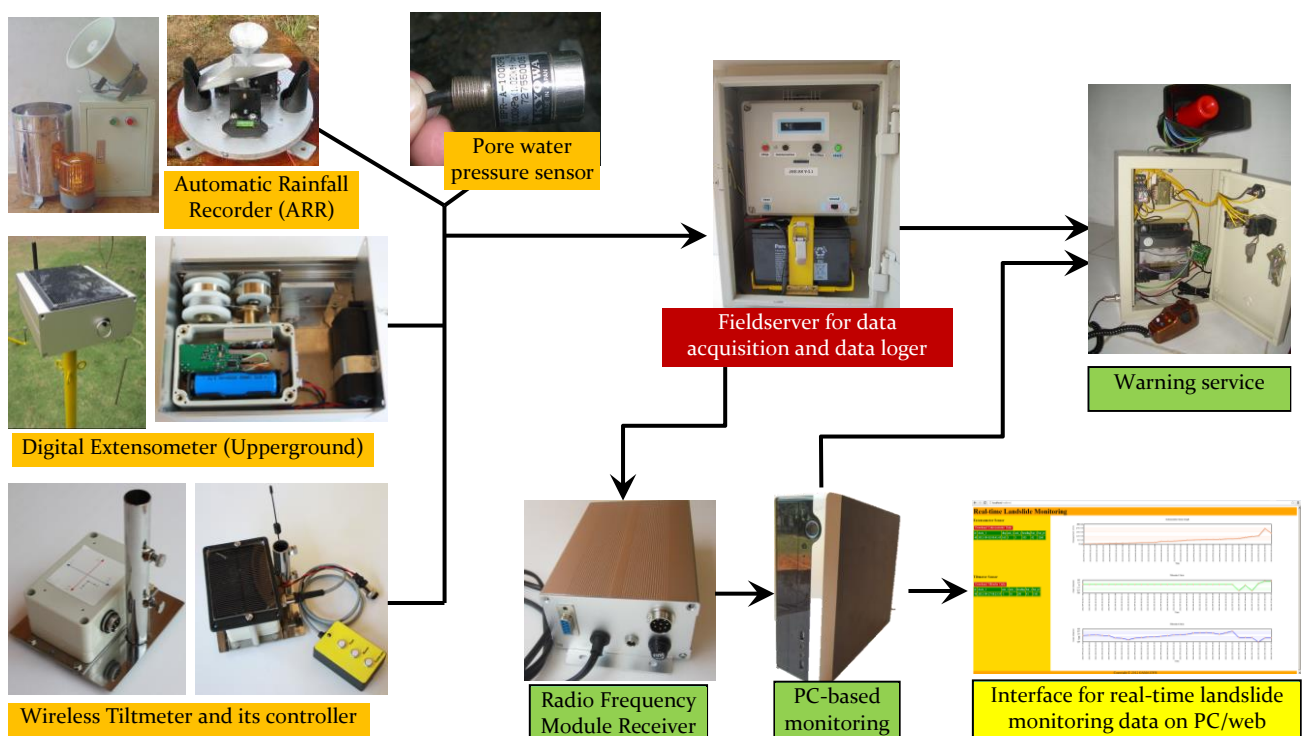


Figure 5 Newly developed devices for landslide monitoring on a network diagram of telemetric system.

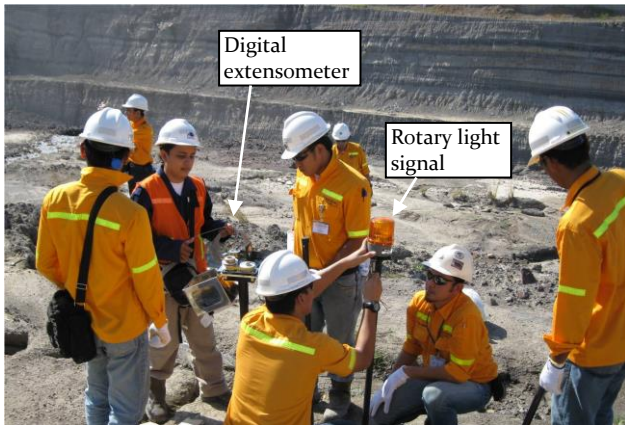


Figure 6 Installation of digital extensometer at a mining site.

Discussion

Many lessons learned can be gained during the implementation of landslide early warning system in Indonesia. Not only best practices but also failure are obtained. If the local community is not able to operate and maintain the technical system so that it cannot function optimally, it is considered failure. Meanwhile, lost devices can be reduced considerably since the social approach is applied to the local community.

Collaboration and cooperation among various parties can increase the effectiveness of the system significantly. The government, universities, NGOs, and private sectors are responsible to implement the landslide early warning system. Up until now, this landslide EWS has been implemented in Java Island, Kalimantan Island and Sulawesi Island in Indonesia and will be installed in a mining area in Myanmar (Fig. 7).

From the elaboration on the long experience in implementing early warning system in Indonesia and regional area of South East Asia, it can be concluded that the system needs to integrate technical system supported by social system through the involvement of community participation. Using this approach, the technical skill and social skill can be improved simultaneously and can support the landslide early warning system program.



Figure 7 Location of Landslide EWS installation (2007-2012).

The stage of EWS development starts with the technical and social surveys. Afterward the design of the devices can be conducted, following by the determination of warning criteria and the installation-operation-maintenance of the devices. The above phase can be achieved by performing regular training and evacuation drills to increase the community preparedness. For years, the efforts have shown satisfying results in various areas. The installations of the system in the pilot areas in several islands have received full support and commitment from the local community and local authority. The next challenge is to widen the scope of the program and integrate the result of monitoring data with other related institutions. The collaboration and cooperation among various stakeholders are the key to realize community resilience in anticipating disaster.

Acknowledgments

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Distribution and characteristics of landslides induced by the Varzeghan-Ahar earthquake doublet (Mw=6.4 and Mw=6.3) in 2012 in Azerbaijan-e-Sharghi, northwest of Iran

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Abstract In this paper earthquake-induced landslides and other geotechnical phenomena due to August 11th 2012 Varzeghan-Ahar earthquake doublet (Mw=6.4 and Mw=6.3) in the Varzeghan, Ahar and Heris regions (located in Azerbaijan-e-Sharghi province of Iran) are investigated. A 4 day site visit managed 17 days after earthquake occurrence, in order to determine types of earthquake-induced landslide, and their distribution and concentration. The most abundant landslide types were rock falls and rock slides. The farthest recorded rock fall was approximately 60 kilometers far from the second earthquake epicenter, and the volume of the largest recorded rockslide is 20000 cubic meters with a 5 meter high scarp. Several rock fall zones, some with more than 100 rock falls were recorded as well. Soil falls, soil slides and one soil flow are distinguished in the earthquake struck areas. The number of soil slides is less than expected for an earthquake with Mw>6 which is due to low moisture content of slopes in the summer when the earthquake occurred. Other geotechnical phenomena related to earthquake are distinguished including four liquefaction zones and two sinkholes, which the greater one have a width of 10 meters and depth of 3 meters.

Keywords Varzeghan-Ahar Earthquake, earthquake-induced landslides, earthquake-induced geotechnical phenomena

Introduction

Earthquake-induced landslides have an important role in fatalities, and financial losses resulted from earthquakes. In many earthquakes, the resulting landslides have caused as much or more damage than the other effects of seismic shaking (Wilson and Keefer 1985). In this paper earthquake-induced landslides and other geotechnical phenomena due to Varzeghan-Ahar earthquake doublet are investigated.

On August 11th 2012, two earthquakes with eleven minutes time delay and magnitudes of Mw=6.4 and Mw=6.3 struck Ahar and Varzeghan regions in northwest of Iran at 16:53 and 17:04 local time, respectively. The

epicenter of first earthquake was 23 kilometers west of Ahar and the second one was about 50 kilometers northeast of Tabriz, which were 13 kilometers far from each other. Focal depth of both events was about ten kilometers with strike-slip mechanism (Zare et al. 2012). These events resulted in 258 fatalities and about 1380 injuries and caused severe damages to the villages and cities in the region (Official Reports 2012).

Most fatalities and injuries were reported from Bajebaj, Gouradareh and Dabanou villages and Varzeghan city.

Maximum intensity of the earthquake in the scale of EMS98 was VIII+ at epicenter zone (especially in Varzeghan city and villages of epicenter zone); the intensity was VII, VI and V for Ahar, Heris and Tabriz cities, respectively. First event epicenter location and iso-intensity map are illustrated in Fig. 1 & 2, respectively.

Regional setting

Climate

Varzeghan-Ahar region located in northwest of Iran has a Mediterranean climate, characterized by seasonality in temperature. Such a climate in most places in the world has mild and rainy winters and long, hot and dry summers; but the winter of the Mediterranean climate in northwest of Iran is cold and snowy. The precipitation of the region is affected by Mediterranean wet air masses, cold northern weather effects, and temperature changes near Oroumieh Lake. Based on Ahar meteorological station data (19 kilometers far from first earthquake epicenter), mean annual precipitation of the region ranges between 205 and 340 mm. Annual precipitation in the earthquake year was 316.4 mm and the last rain before the earthquake, was on August 1st 2012, (10 days before the earthquake) when 4 mm of precipitation occurred, total precipitation from 1st May to 11th August when the earthquake occurred (more than three month period) was 109.6 mm (IRMO 2012).

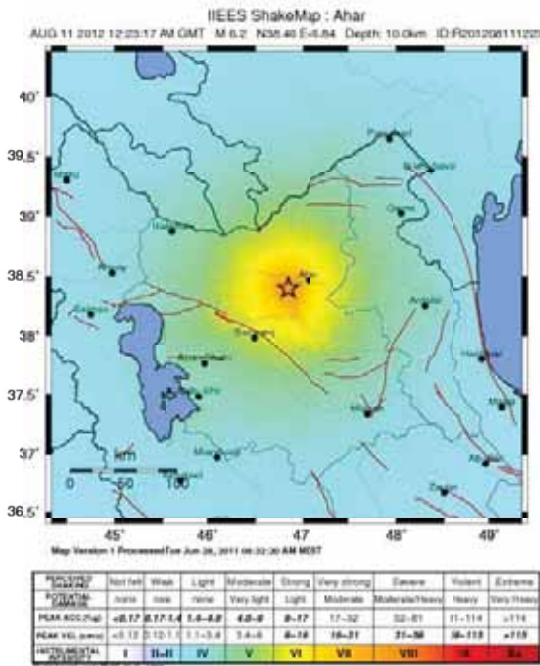


Figure 1 Epicenter map of first Varzeghan-Ahar event (Zare et al. 2012)

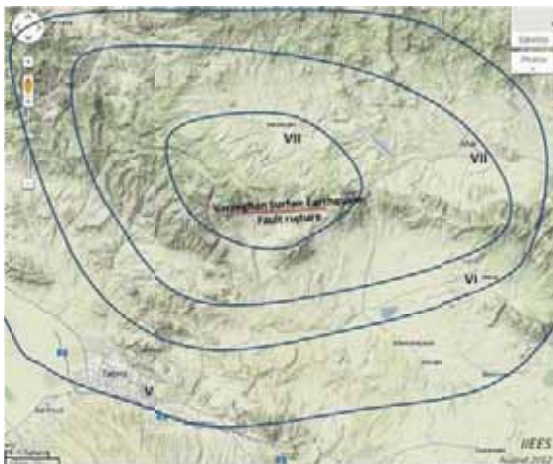


Figure 2 Iso-intensity map of Varzeghan-Ahar earthquake doublet (zare et al. 2012)

Topographic and Geographic setting

Study area locating in Azerbaijan-e-sharghi province of Iran, is a mountainous region with altitudes ranging from 1320 to 2860 meters above sea level. 4 towns and 236 Villages are located in the region.

Geologic setting

The Varzeghan-Ahar area is underlain by a wide variety of sedimentary and volcanic rocks and unconsolidated sedimentary deposits, most of which range in age from Cretaceous through Quaternary. The rocks vary greatly in composition, degree of consolidation and depth of weathering. Marl, Sandstone and Volcanic rocks predominate. Based on 1:250,000 geological maps of Ahar

and Tabriz-Poldasht (Fig. 3) the main formations of the area include:

1. Quaternary deposits including terraces and alluviums;
2. Pliocene conglomerate and siltstone;
3. Oligocene dasitic breccias.
4. Miocene gypsiferous and silty marl, siltstone and sandstone;
5. Cretaceous marl, molasses and sandstone;

Because of landslide-sensitive formations (such as Marls) and mountainous topography, the region has a high potential of landsliding; existence of old huge landslides in the region supports this fact.

Geotechnical phenomena resulted from Varzeghan-Ahar earthquake

Many geotechnical phenomena occurred due to Varzeghan-Ahar earthquake, including different types of landslides, liquefaction and sinkholes.

Earthquake-induced landslides

Due to lack of post-earthquake aerial photos of the region, besides studying documents, maps and other existing data, a site visit was organized 17 days after earthquake to determine earthquake-induced landslides characteristics and distribution.

.Many landslides including rock and soil slides and falls besides one soil flow were induced by Varzeghan-Ahar earthquake.

In the below landslides are categorized and described based on Keefer classification. Keefer (1984) classified seismic landslides in five groups: disrupted slides and falls in rock, disrupted slides and falls in soil, coherent slides in soil, coherent slides in rock, and lateral spreads and flows in soil (Keefer 1984).

Recorded landslides and probable landslide zones due to Varzeghan-Ahar earthquake are illustrated in Fig.4.

Disrupted rock falls and slides

Rock disrupted landslides are the most common landslide types induced by earthquakes (Keefer 1984). Hundreds of rock falls and slides up to 60 kilometers far from the earthquake epicenter were distinguished, which some are shown in Fig. 5 & 6.

Fig. 7 shows rocks trajectory of one of the farthest rock fall zones of Varzeghan-Ahar earthquake near Tabriz and 50 kilometers far from the second event epicenter, boulders has fallen due to strong ground motion and the resultant scratches created by falling rocks on the in situ boulders is shown in Fig. 8.

Some losses were occurred because of these rock falls and slides such as: the Khaje-Ahar road was blocked due to several rock slides immediately after earthquake, 40 sheep from a flock were killed by rock fall near Choupanlar village, and many trees were broken and gardens were destroyed due to rock fall in Gouradareh village.

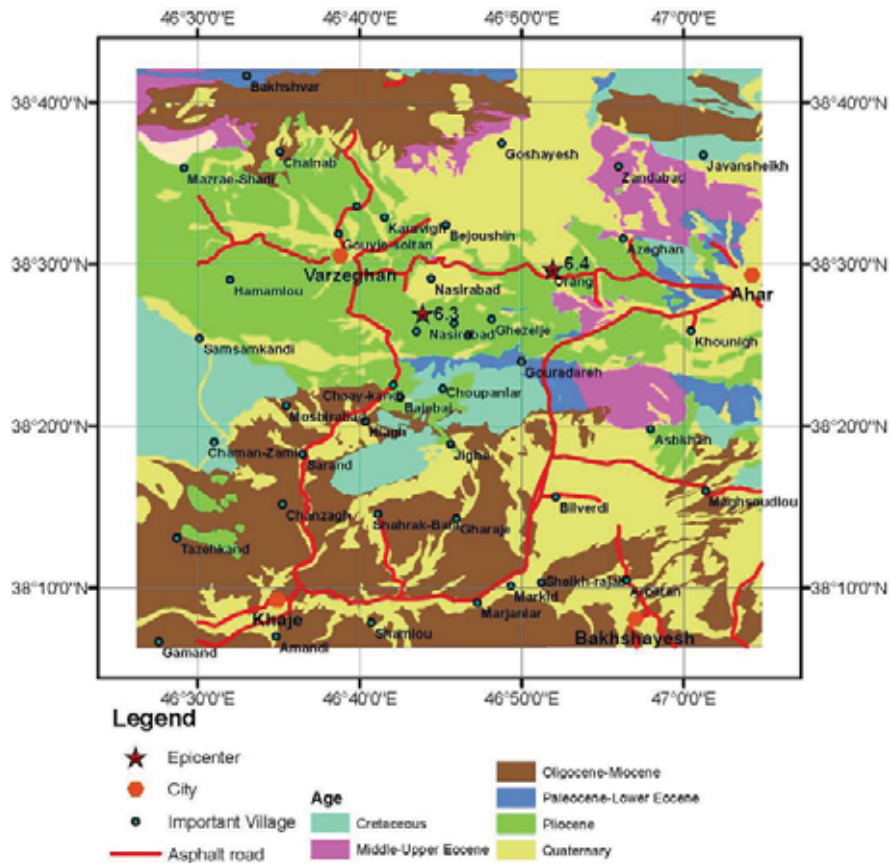


Figure 3 Geology map of the study area

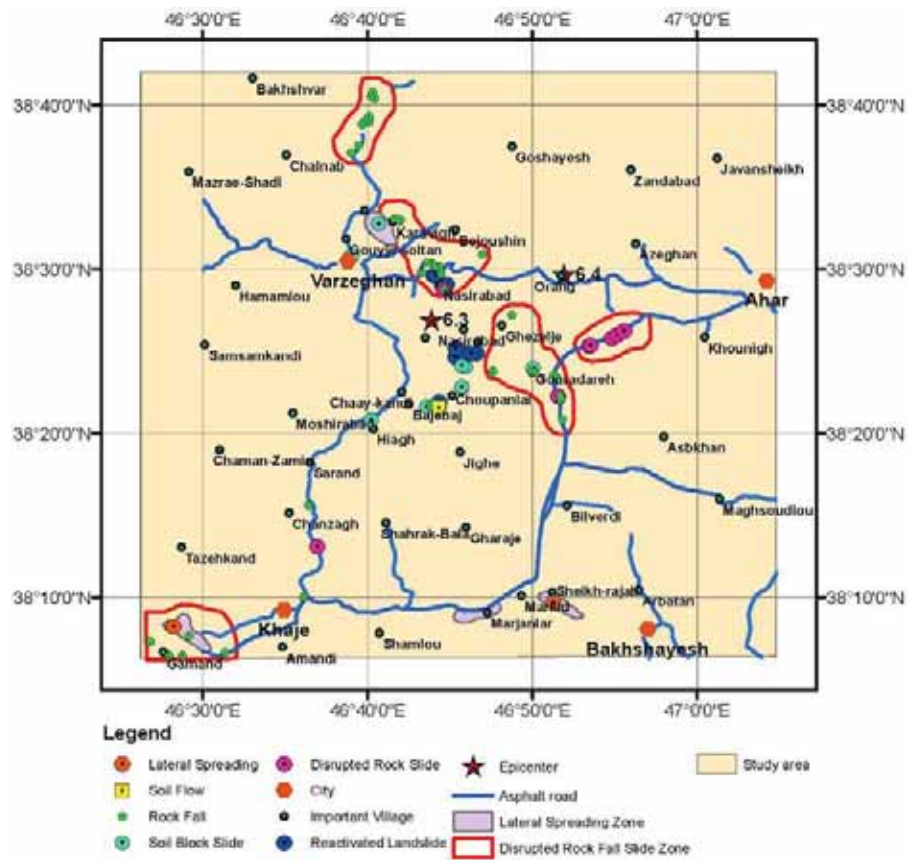


Figure 4 Earthquake-induced landslides and probable landslide zones



Figure 5 Rock slide in the Sattar khan Dam access road (zare et al. 2012)



Figure 8 Scratches resulted from falling rocks



Figure 6 Rock slide accompanying with rock fall near Nasriabad-e-ghadim village



Figure 9 Soil block slide 3 kilometers northwest of Choupanlar village



Figure 7 Rock fall trajectory



Figure 10 Soil block slide near Karavigh village

Coherent Soil slides

After disrupted rock falls and rock slides the most abundant types of landslides are soil block slides and soil slumps; but despite high sensitivity of formations of the region, number of these landslides is lower than what is expected. This is probably because earthquake has occurred in the season of summer when the ground was dry. Ground moisture is one of the most important and facilitating factors in soil coherent landslides occurrence (Keefer 1984). The occurrence of seismic soil coherent landslides in near springs, rivers and wet regions support this fact. For instances a soil block slide occurred in the vicinity of a spring near Bajebaj-Choupanlar road, and a soil block slide triggered next to Dourigh chaay river near Karavigh village. Also several soil slides occurred in a humid valley 3 kilometers northeast of Choupanlar village (Fig. 9 & 10).

Coherent rock slides and disrupted soil falls

In earthquakes, coherent rock slides and soil falls are infrequent comparing to two previous landslide classes (Keefer 1984). The number of soil falls and coherent rock slides due to Varzeghan-Ahar earthquake was low as well. Though, one of the biggest and most important recorded landslides was a big reactivated rock block slide.

Soil lateral spreads and flows

Soil lateral spreads

Lateral spreading is defined as the mostly horizontal deformation of gently sloping ground as a result of soil liquefaction (Rauch and Martin 2000).

Two lateral spreads occurred during Varzeghan-Ahar earthquake, the first one with length of about 100 meters and width of 8 meters was in Nosham plain near Gamand village, the cracks were developed up to 20 meters far from the river (Fig. 11). The settlement due to this lateral spreading was approximately 0.5 meter. Another lateral spreading was developed 1 kilometer south of SheikhRajab village in the vicinity of Aaji-chay River.



Figure 11 Lateral spreading in Nosham plain near Gamand Village with 0.5 meter settlement of the river bank

Soil flow

Because the Varzeghan-Ahar earthquake occurred in a dry season, slopes were dry and only one soil flow occurred during the earthquake. This soil flow was found near Bajebaj-Choupanlar road, in the vicinity of a spring on the upper part of a slope. As a result of earthquake shaking a soil block slide was initiated on the slope which then was converted to a soil flow near the spring (Fig. 12).



Figure 12 Soil flow near Bajebaj-Choupanlar road (zare et al. 2012)

Reactivated landslides

Some old landslides reactivated during Varzeghan-Ahar earthquake; the most important one was a big rockslide in the Bajebaj-Choupanlar road. The scarp height of this rock slide is 5 meters and the maximum width and length are 95 and 60 meters, respectively. About 20000 cubic meters of rock mass has been moved due to this rock slide (Fig. 13 & 14). New cracks were tracked 50 meters far from the main scarp which shows considerable movement of the rock mass during the earthquake. Slip surface slope of the slide is about 25 degrees.

Other instances of reactivated landslides due to Vaezeghan-Ahar earthquake are Nasiraabaad village soil slides (in marly deposits) with about 0.5 to 1 meter downward movement and a soil slumps in the northern parts of Choupanlaar village and south parts of Saariyarghan village. As mentioned before, most of reactivated landslides are located in regions with high ground moisture as well.

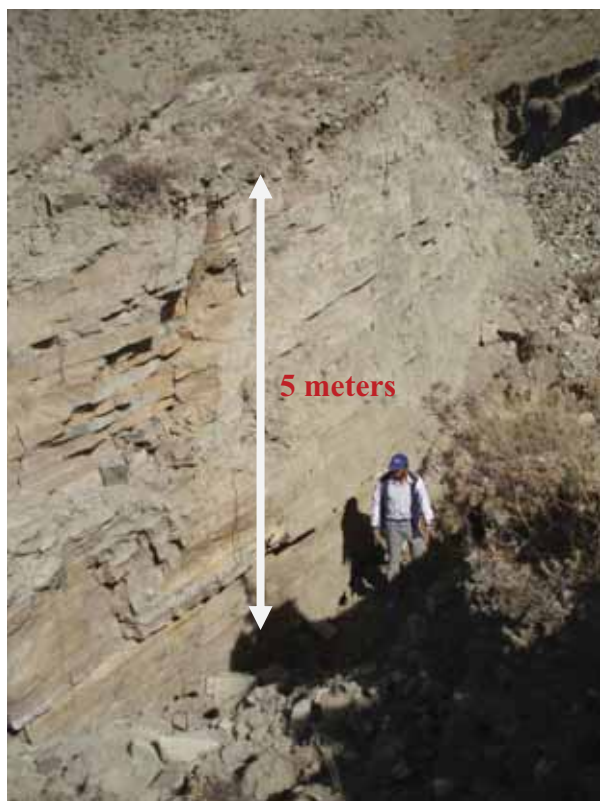


Figure 13 Rock slide mass with about 5 meters depth

Liquefaction and sinkholes

Liquefaction prone areas as well as recorded sinkholes are shown in Fig. 15.

Liquefaction

Liquefaction is defined as the transformation of a granular material from a solid to a liquefied state as a consequence of increased pore water pressure and reduced effective stress (Marcuson 1978). Increased pore water pressure is often induced by the tendency of granular materials to compact when subjected to earthquake-induced cyclic shear deformations.

Liquefaction zones were found in Nosham and Lavarik plains near Marjanlaar and Gamand villages, respectively as well as near Karavigh village. The recorded liquefaction zones materials differ from small grained sand to silt (Fig. 16 & 17).

Sinkhole

Two sinkholes were recorded related to Varzeghan-Ahar earthquake; the first one located near the access bridge of Markid on the river bed with a diameter of approximately 2 meters. The second and bigger one located near Marjanlar village, the sinkhole diameter is about 10 meters and its cracks were developed up to 15 meters from the sinkhole (Fig. 18).

Only 25 meters farther and on the river bed a liquefaction zone was found which relates to the big sinkhole occurrence.



Figure 14 Bajebaj-Choupanlar road rock slide scarp

Summary and Conclusions

Varzeghan-Ahar earthquake triggered many landslides and other geotechnical phenomena.

A big reactivated rock slide with more than 20,000 cubic meters of mass volume and several rock falls including rock fall zone with more than 100 rock falls, a soil flow, two lateral spreading zones, two liquefaction zones, and two sinkholes were among them.

Disrupted landslides such as rock falls, rock slides, and soil falls are affluent in the landslide struck region, but coherent landslide types are much less than expected.

Moisture content of slope has an important role in the occurrence of coherent landslides especially in soils. Taking into account the existence of landslide sensitive marly sedimentary deposits all over the area as well as mountainous topography, the Varzeghan_Ahar earthquake ($M_w=6.4$) was strong enough to trigger large number of coherent landslides in the region, but only a few landslides of this type occurred as a result of low moisture content of slopes. As mentioned before Varzeghan-Ahar earthquake occurred in summer when the slopes were almost dry, last rain had occurred 10 days before earthquake with 4 mm of precipitation, and total precipitation from 1st May to 11th August when the earthquake occurred (more than three month period) was 109.6 mm, all these circumstances resulted in low water content of slopes as the reason of low coherent landslides occurrence and reactivation.

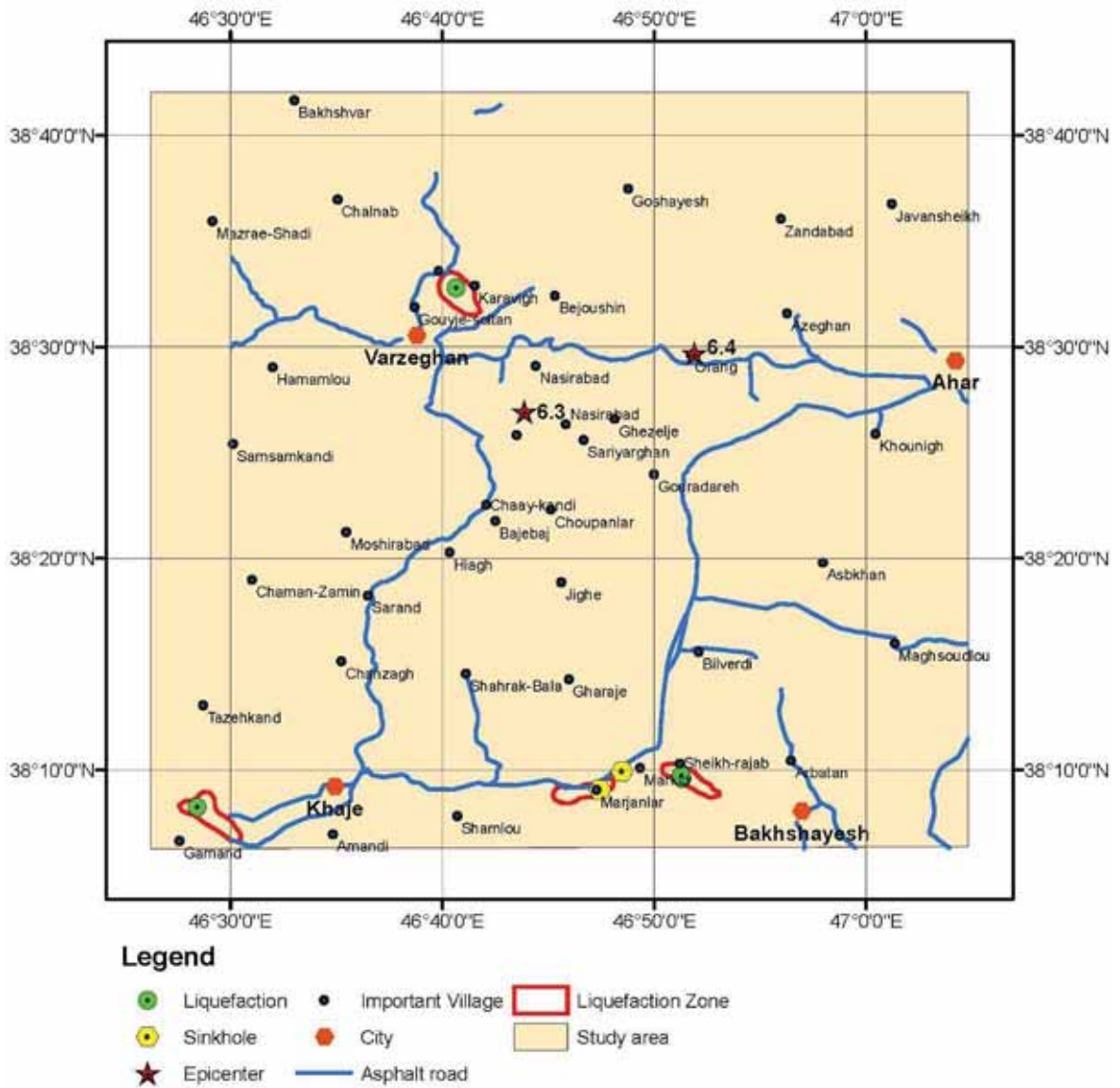


Figure 15 Liquefaction, liquefaction probable zones, and sinkholes due to earthquake



Figure 16 Liquefaction in the vicinity of Marjanlar village



Figure 17 Liquefaction zone in the vicinity of Marjanlar village



Figure 18 Sinkhole with ten meters width in the vicinity of Marjanlar village

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A New Approach to the Landslide Early Warning Using the Chemical Composition Fluctuation in the Leakage from Susceptible Slopes

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Abstract Landslides are natural disasters that annually inflict great damages to public and private properties and may be associated with loss of life and injury. In recent decades, research on developing methods of predicting the time of landslide occurrence has been one of the important attempts made by scientists.

Since in some type of material, landslides are preceded by the occurrence of undetectable movements that cannot be recorded and revealed by conventional detection instruments, recording of the chemical changes of the water flowing out from the toe of the slopes susceptible to sliding can provide important and reliable indicators of landslide activities and early warning. In the present study, the changes in the chemical composition of the water seeping out from the toe of the landslide, which can be affected by the landslide activities, were investigated. This process was studied in a laboratory model, in which a sliding surface was simulated and the changes in the ion concentration of potassium, sodium, magnesium, calcium, sulfate, chlorine, and bicarbonate as well as EC and pH in the stable state and in the conditions of slight rupture along the sliding surface were investigated. The results indicated that the chemical changes in the out-flowing water, particularly changes in the concentration of some ions, could be used as suitable indicators for early warning of the landslide occurrence.

Keywords Landslide, Monitoring, Leakage Chemical Composition, Early warning.

Introduction

Study of natural disasters, has been in the focus of research by scientists and scientific societies in recent decades. The main objective of most of these studies has been to understand the phenomena and the factors affecting their occurrence in order to develop some methods for their prediction and control. Considering the available technologies and the high costs of monitoring, the majority of these studies and the prediction methods for events such as earthquake, flood, and landslides are based on statistical analyses, with reasonable success. Along with the progress in developing suitable

technologies for monitoring instrumentation and information transfer in recent years, research has begun on prediction of the time of occurrence and post-event behavior of natural phenomena. Landslides are also among such events that have been recognized by human since old times and many studies have been conducted for their understanding and control. However, the complexity of the sub-surface structures from the standpoint of geology and geological engineering, together with the uncertainties associated with precipitations forecasts, the diversity in groundwater behavior in slopes, the unpredictability of the time of earthquakes and its severity, and many other unknown factors add to the difficulty of understanding the processes leading to landslides. Therefore, it may be said that one of the most effective and reliable methods in prediction of time and behavior of landslides occurrence is the monitoring of the movement behavior of some slope areas in a region together with the changes in other effective factors in order to provide a remedial work plan and issue early warning.

In order to monitor the behavior of slope activities, in addition to measurement of surface motion that is a direct measurement of the slope displacement with time, other environmental factors affecting the slide should also be monitored (Shoaie et al. 1996). Some of these instruments directly measure the observable displacement along the sliding surface in one direction, while others, such as dual frequency global positioning system (DGPS), measure the changes in the geographic position of a point on the sliding surface in three directions (Shoaie and Imamjomeh, 2002). Besides these surface instruments, other equipments have been designed for determination of in-depth displacement distance of the actual slide surface. However, in addition to high procurement and maintenance costs, each of these instruments has technological limitations that eventually lead to a series of uncertainties in the obtained information.

Usually, most landslides have early signs that could be used in predicting the occurrence of the main failure

(Shoaiei et al., 2001). Therefore, the most important issue in prediction of the main failure in potentially unstable slopes is the presence or absence of observable early warning signs before the main slide occurs. In some research, it has been shown that, usually, in fine-grained soils, the sliding behavior is creeping type, in which prediction will be possible, if the phases of the creep consisting of the primary, secondary, and tertiary creep, are carefully monitored and recognized (Shoaiei and Karamsoltani, 2011). Also, Shoaiei (2010) showed that in coarse textured soils such as loess and sand, landslide occurrence is sudden and there is almost no sign of movement before the main failure that can be recorded by the conventional instruments.

Considering the mechanism of formation of a sliding surface in a soil mass, it is acceptable that, in most cases, before any movement can be observed on the surface or in the observation wells, a very slow movement starts along the sliding surface that gradually continues to form the sliding surface. After this surface is formed, observable movements can be recorded by the conventional instruments. In many landslides, the short time interval between the formation of the sliding surface and occurrence of the landslide does not allow provision of the necessary mitigation and risk management services. Therefore, if the small and slow movements within the sliding surface can be sensed and revealed, it will be possible to issue early warning notices in a suitable time interval. In the present study, the possibility of monitoring the initial and undetected movements of the sliding surface is investigated through the impacts of those movements on the changes in the chemical composition of water seeping out at the surface of slope and using it as an early warning sign.

Review of the research on landslide shows that the presence of water is one of the main factors in provoking slopes and usually 90% of landslides occur on saturated or semi-saturated surfaces (Yan, 1994). Even in some landslides, in spite of the total sliding mass being unsaturated, the presence of a saturated clay layer in the body of the masses can activate the landslide (Mollard and Hughes, 1973). The saturated layer may be thin and limited to the shearing surface whose fine structural changes can be an important factor in changing the shear strength of the whole slope (Moon, 1993). In some clay layers, the decrease in shearing strength is proportional to the amount of water absorption, such that, at saturation of the layer, it is at the minimum, that in soils with more sensitive clay, this process proceeds faster (Soderblum, 1974). In the first part of the study, determination of soil characteristics provides a good criterion for estimating and evaluating landslide behavior. The more the similarity of a soil behavior to those of clay soils, the more there will be early signs of sliding (Zung et al., 2008; Shoaiei, 1996). The sliding process in these soils is in the form of successive and

gradual movements that, unusually, take place on more gentle slopes (Chatwin et al., 1994). In fine grained soils with high plasticity, 90% of soil shearing strength may be lost upon absorption of water. This loss is probably due to soil expansion and disruption of the bonds between soil particles (Leroueil and Vaughan, 1990). Following this phenomenon, the soil mass may experience small shears and disruption in its natural drainage, which could in turn result in changes in the chemical composition of the water percolating through the soil profile. The relationship between changes in the opening of the surface cracks in a landslide and changes in the ionic composition of water seeping out of the sliding mass has been reported in some research (Sakai, 2001, 2009). In those researches, it was shown that the increase in ionic concentration had a direct relationship with the opening of cracks and the fissures newly formed as a result of movement on the slope.

It has been well established that cation exchange is one of the important properties of clay soils. Due to its structural network resulting from octahedral and tetrahedral arrangement, a clay unit has a negative charge on its surface which attracts and adsorbs the free cations in its surrounding environment. These cations surround the clay particles with different absorption forces. The surface and outer part of this layer of ions is under weaker force and can be leached and drained out by the flowing water. In addition to the important role of clay particles in ions exchange capacity of the soil, the type of clay is also very effective in this respect. For example, in clays such as chlorite and montmorillonite, the ions are not only adsorbed to the surface, but they also occupy the interlayer spaces of clay that can be exchanged with surrounding particles. However, the latter ions have no high exchange capacity. Ion exchange capacity in sandy soils is low or non-existent.

The summary of the concept used in this work can be summarized as follows;

1. Water that has infiltrated a sliding mass of soil moves through the pores in certain pathways toward lower positions down the slope.
2. The draining water will dissolve different compounds along its way depending on their composition and pH and will transfer them out of the soil mass.
3. If the soil structure remains intact, the chemical composition of the water will also remain constant.
4. In case the structural is disrupted by events such as displacement of the sliding surface, the drainage condition and path of the water movement will also change, resulting in changes in dissolution of the ions and ion exchanges of the water with the surrounding environment, thereby affecting the concentration of the ions in the water seeping out of the soil mass.

- In case such changes are recorded continuously, their monitoring could be used as a sign of the onset of a landslide that can be used for monitoring landslide behavior and possibly prediction of its time of main failure.

Considering the diversity of the chemical composition of the natural soils, chemical analysis of soils for recognition of the compounds and elements susceptible to leaching in each region should precede the establishment of the chemical monitoring plan.

In the present research, this process was investigated in a laboratory model, in which a sliding surface was simulated and the changes in the ion concentration of potassium, sodium, magnesium, calcium, sulfate, chlorine, and bicarbonate as well as EC and pH in the stable state and in the conditions of slight rupture along the sliding surface were investigated.

Materials and methods

Saturated sliding surface model

The sliding model made had basal dimensions of 130x170 cm and a height of 70 cm that was placed in a container box of transparent Plexiglas with the same dimensions. Figure 1 shows a longitudinal cross section of the model. As shown in the figure, in order to control and direct the seepage water along a sliding surface, the lower part of the model is made of a unified impermeable block in which all the joints are waterproofed with silicon glue, preventing any leakage downstream of the block. The external surface of this block with a slope of 30 degrees constitutes the lower part of the sliding surface. On this surface, the soil layer is laid as the model of sliding surface. To prevent soil sliding during shearing displacement, a number of nails have been driven into the surface with an effective height of about 2 cm in the soil.

On the upper part of the soil layer, a moveable plate is placed which has a number of nails, similar to those in the lower surface, to ensure its complete contact with the upper part of the soil and prevent its sliding over the soil surface. In order to control soil compaction and the original soil structure of the sliding surface at the time of leaching and shearing displacement, two guiding beams, were installed on the wall of container along the slope, on which the moveable plate rests and cannot move vertically. A complete view of the physical model made in the laboratory is shown in Fig. 2.

Considering the necessity of using the constant chemical composition of the inflowing water throughout the study, the total water needed for this work was stored in a 180-liter tank at a proper hydraulic head (Fig. 2). Also, to control the hydraulic head of the water flowing over the sliding surface, a secondary tank was attached to the

model to provide the inflow water needed for the model ("w" in Fig.1). The height of water in this tank is controlled by an automatic water tap.

Since the sudden change in the hydraulic gradient at the inflow and outflow sections of the model could cause turbulent flow and disturbance of soil structure, two felt filters with a thickness of 2 cm were placed at the upstream and downstream sections of the sliding surface. At the downstream part of the slope, a narrow groove was made across the model width to collect the outflowing water (Fig. 1). The water in the groove was guided out of the model and was collected in a graduated cylinder to be taken to the laboratory for chemical analysis.

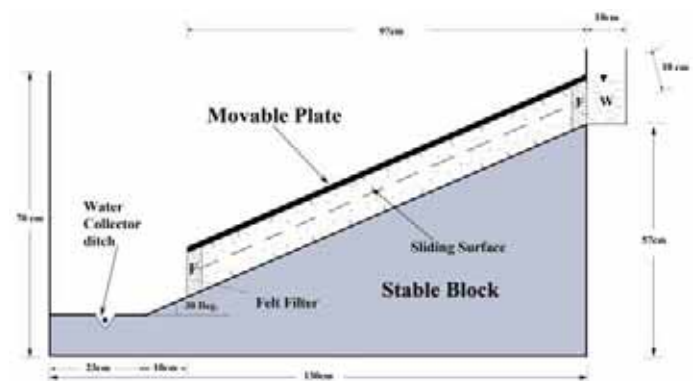


Fig. 1. Longitudinal cross section of a physical model made for a saturated sliding surface.



Fig.2. A complete view of the physical model made in the laboratory.

Preparation of the sample

Considering the objectives of the study, the soil should have the proper compaction for simulating the sliding surface, and adequate permeability to allow water movement through it. Besides, the soil should contain suitable clay minerals to participate in the ion exchange processes. To this end, a silty-clayey soil from a mine in southwest Tehran, was selected and sampled. Study the bulk composition through X-ray diffraction analysis

showed the presence of chlorite, illite, and montmorillonite in the sample with the latter being less than the others. Also, to determine the general physical and mechanical characteristics of the soil, grain analysis, Atterberg limits, direct shear test under saturated condition, and permeability with a bulk density similar to that in the model were performed. The results of these tests are shown in Table 1. Considering the presence of 27% clay, 43% silt, and 30 % sand, this soil is in class CH according to the Unified Classification.

Table 1 Physical and mechanical properties of the soil used in the physical model.

Soil Strength Parameter (Saturated)	K cm/sec	PL%	LL%	γ_d g/cm ³	Soil Class	
ϕ Deg.	C Kg/cm ²					
16	0.8	3.8 X10 ⁻⁷	16.69	59.2	1.70	CH

Since steady flow of water in the soil is necessary; the soil sample should be relatively homogeneous with isotropic compaction. Therefore, extra care must be taken while pouring the soil in the model and its compaction. For this purpose, after selecting adequate soil sample, it was wetted and uniformly compacted. It was poured into the model in several layers and that was compacted separately.

The pouring and compaction of the soil sample was continued until the thickness of the soil in the model reached the value of 10cm. Then, the upper-layer plate, which had been equipped with 2-cm nails similar to the lower plate, was placed on the soil surface. It tapped and pushed gently so that the nails penetrated the soil. At the end of this step, the bulk density of the soil was measured as $\gamma_w=1.7$ g/cm³, which was relatively similar to that of soils in natural earth slopes.

Operation of the model

After soil was placed in the model, the water tank was connected to the model and its operation started. Once the secondary tank ("w" in Fig. 1) was filled, water was flowing slowly through the upstream felt filter (F) into the sliding surface and, under the influence of hydraulic gradient, passed along the slope downward to the lower parts of the sliding surface. At this point, water permeated through the lower felt filter (F) and was collected in the water collector groove at the bottom of the model. The collected water was later sent to the lab in special containers for chemical analysis. Generally, the model operation was conducted in two phases as explained below.

First phase

The soil sample was taken from the mine as a disturbed sample and was poured in the model unsaturated. It was expected that in the first run of the study, the

concentration of different elements in the outflowing water would be high. Therefore, the first run of the model operation was continued until the inflowing water saturated the sliding surface and leached elements and free or exchangeable ions, while their concentration remained constant. Therefore, to control the changes in the concentration of the elements under consideration and changes in the chemical parameters, water sampling started at the toe of the sliding surface immediately after water left the model outlet. This was followed by chemical analysis of the water samples. As stated previously, changes in the ion concentration of potassium, sodium, magnesium, calcium, sulfate, chlorine, and bicarbonate as well as EC and pH were investigated. The first run was continued until the changes in ionic concentrations reached a minimum value. Water samples were collected in a 1000 ml container and sent to the laboratory. In the first run, a total of 24 such samples were collected from the start of the run to the time when the ionic concentrations remained constant. This phase of the study lasted for 637 hours, during which almost all of the ionic concentrations reached a reasonably constant level. Once this constant level was reached, the second phase of the study started.

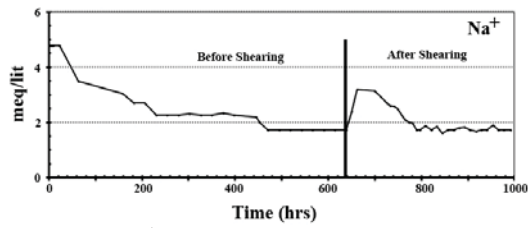
Second phase

This phase started immediately after ionic concentration in the outflowing water was constant. A 5 cm shearing was made along the sliding surface. This was done after the inflow was stopped temporarily to avoid disruption in the saturated soil of sliding surface. During shearing in the sliding surface of the model enough weight was placed on the upper surface to prevent separation of the upper plate from the soil and uncontrolled disturbance of soil. Afterwards, the water was turned on again and sampling of water from the toe of the sliding surface was continued. In this phase, all lab analyses and sampling procedures were similar to the first phase. Water sampling continued till the concentrations of the ions under consideration remained constant. A total of 27 samples of 1000ml were taken during 355 hours.

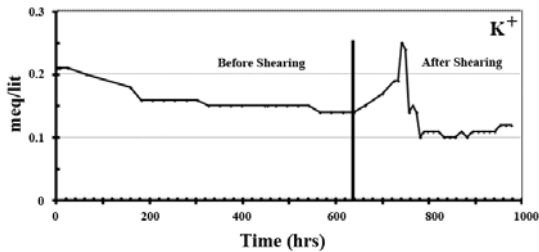
Results from the model tests

The total time for the first phase was 637 hours and, for the second phase, 355 hr, thus, the total time spent for both phases was 992 hr. A complete chemical analysis was carried out to determine the concentration of cations and anions as well as the EC and pH of the inflowing water (Table 2).

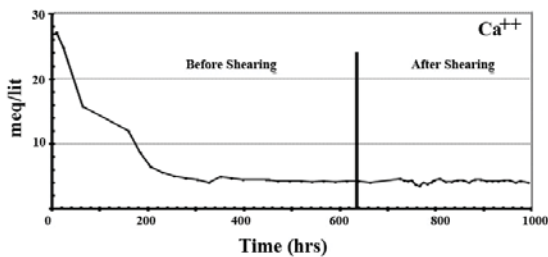
The amounts of chemical elements in the inflow water were subtracted from the corresponding values in the outflowing water, since they were considered as external elements added to the system. Thus, the changes in ionic concentrations of the outflowing water showed the net changes resulting from the passing of water through the soil profile. It is noteworthy that in all laboratory measurements, the procedures and conditions were kept the same.



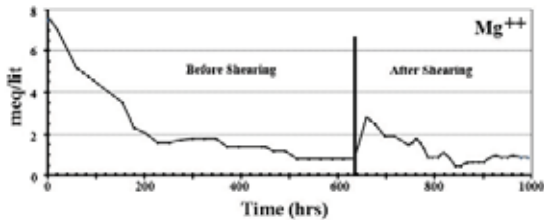
A. Changes in Na⁺ concentration



B. Changes in K⁺ concentration



C. Changes in Ca⁺⁺ concentration



D. Changes in Mg⁺⁺ concentration

Fig. 3 Diagrams of changes in cations of the water flowing out at the foot of the slope in the first phase (till constant concentration) and after the soil cut.

Results of changes in the cation and anion concentration of the outflow water in the two phases of the study are shown in the diagrams of Figs.3-6.

The first cation studied was the monovalent sodium cation (Na⁺) of which the results are shown in Fig. 3-A. Generally, this cation is more abundant in soils of Iran compared to other cations (IAPE, 2004). In the beginning of the first phase of the study, Na⁺ concentration was measured at 7.15 meq/lit, while the Na⁺ concentration in the inflow water was 2.28 meq/lit (Table 2). Subtracting the latter value from the former gives the total sodium cation leached from the soil body as 4.87 meq/lit, which is the result of water passing through the soil pores of the sliding surface in the model. With continued drainage in some 490 hours, the change in concentration of sodium cation was almost negligible and, after 637 hours, reached a relatively constant value of 1.75 meq/lit. In the second phase, when a shearing of about 5% of the slope

length was made in the sliding surface, the concentration of Na⁺ showed a clear increase to 3.2 meq/lit in 20 hours after displacement, which reflected the excellent sensitivity of this cation to displacement in this soil.

Table 2. Chemical properties of the water used in the study.

Ec ms/cm	pH	HCO ₃ ⁻ meq/lit	Cl ⁻ meq/lit	SO ₄ ⁻ meq/lit	Ca ⁺⁺ meq/lit	Mg ⁺⁺ meq/lit	Na ⁺ meq/lit	K ⁺ meq/lit
0.61	8.03	1.7	4	1.33	4.2	0.5	2.28	0.05

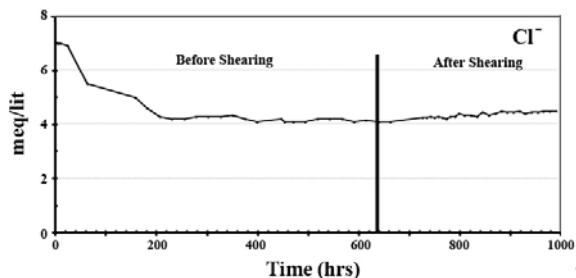
Forty hours after the Na⁺ concentration was fixed at a maximum level, it started to decline and, in 85 hours, it reached 1.74 meq/lit, which was close to the value before the soil was sheared. Afterwards, it remained almost constant till the end of the test (992 hour).

The second monovalent cation investigated was K⁺, whose results are shown in Fig. 3-B. In spite of its relatively lower concentration in soils of Iran, K⁺ showed a behavior similar to Na⁺. In the beginning of the test, K⁺ concentration was 0.26 meq/lit. Thus, considering potassium concentration of 0.05 meq/lit in the inflow water (Table 2), the increase in K⁺ due to the dissolution of this cation from the surrounding soil was 0.21 meq/lit. The K⁺ concentration in the first phase of the study reduced to 0.14 meq/lit after 566 hours and remained at this level till the soil was sheared (637 hr). After the second phase and the displacement of the sliding surface, the concentration of this ion in the outflow water at the toe of the sliding surface showed a relatively significant increase i.e. 118 hours after the soil was sheared, the concentration reached 0.26 meq/lit. With continued leaching of this ion till 147 hours after sliding, its concentration declined to approximately 0.13 meq/lit and remained close to this level till the end of the test (992 hr).

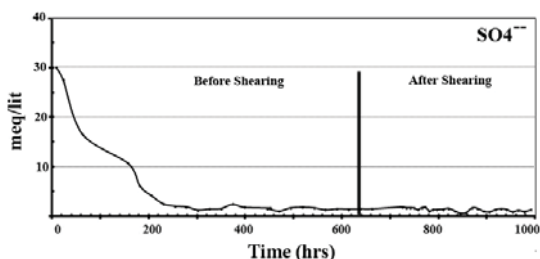
The next cation investigated was the divalent ion of calcium (Ca⁺⁺) and the results are shown in Fig 3-C. In the soils of Iran that are mostly calcareous, this ion is most prevalent. As shown in Fig 3-C, the concentration of this ion in the beginning of the first phase reached 31.2 meq/lit. Subtracting from this value the concentration of Ca⁺⁺ in the inflowing water, which was 4.2 meq/lit (Table 2), its concentration in the outflow water due to the dissolution of this cation from the surrounding soil was calculated at 27 meq/lit. In spite of the high concentration of this ion in the beginning of the test, it showed high sensitivity to leaching and, in a time period of 320 hours, it decreased to 4.1 meq/lit and remained at that level till the end of the first phase (637 hr). The interesting behavior shown by this cation after the second phase and displacement of the sliding surface was that, in spite of calcium ion high concentration and quick leaching in the first phase, it did not display appreciable sensitivity and detectable changes in its concentration in the second phase.

The other divalent cation studied was magnesium (Mg⁺⁺), the results of which are depicted in Fig. 3-D. The concentration of this cation in the outflowing water at the toe of the slope was 8.0 meq/lit. Subtracting from this value the concentration of Mg⁺⁺ in the inflowing water, which was 0.5 meq/lit (Table 2), the increase in its concentration in the outflow water due to the dissolution of this cation from the surrounding soil was calculated at 7.5 meq/lit. With continued leaching of this ion till 520 hours after sliding, its concentration declined to approximately 0.8 meq/lit and remained close to this level till

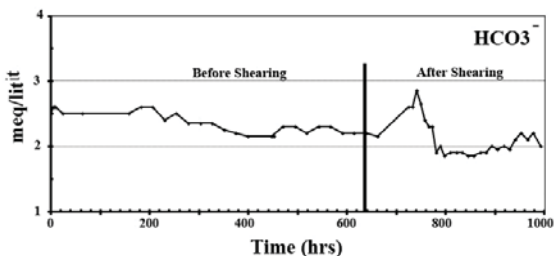
the end of the first phase (637 hr). In the second phase, when a shearing was made in the sliding surface, this cation showed a reasonable sensitivity to the displacement and its concentration increased from 0.8 to 2.75 meq/lit in 20 hours after displacement. With continuation of water seepage and outflow and 207 hours after the start of the second phase, Mg^{++} concentration decreased again and was almost fixed at the original level of 0.8 meq/lit.



A. Changes in Cl^- concentration



B. Changes in SO_4^{--} concentration



C. Changes in HCO_3^- concentration

Fig. 4 Diagrams of changes in anions of the water flowing out at the foot of the slope in the first phase (till constant concentration) and after the shearing at sliding surface.

The first monovalent anion studied in this model was chlorine (Cl^-), of which the results are shown in Fig 4-A. The concentration of this anion in the outflow water at the foot of the slope was 11 meq/lit. Considering Cl^- concentration in the inflowing water, which was 4 meq/lit, the increase in its concentration in the outflow water due to dissolution from the soil of the sliding surface was 7.01 meq/lit. With further leaching, the concentration of this anion decreased relatively quickly and, after 205 hours, was fixed at 4.1 meq/lit and did not show detectable change to the end of the first phase (637 hr). As depicted in Fig 4-A, there was no appreciable change in the concentration of this anion after the displacement of the sliding surface. Indeed, the observed gradual, but insignificant, rise in the concentration was slight and reflected the insensitivity of this ion to displacement.

The second anion investigated was divalent SO_4^{--} , which behaved similar to calcium and chlorine ions (Fig. 4-B). In the beginning of the test, its concentration was 31.36 meq/lit, which, after subtraction of its concentration of 1.33 meq/lit in the inflow water, showed that some 30.03 meq/lit had been drained from the bulk soil of the sliding surface. This anion showed a relatively high susceptibility to leaching in the first phase, but, in about 200 hours, its concentration decreased to 1.6 meq/lit and was fixed at this level. As Fig 4-B shows, in spite of SO_4^{--} high sensitivity to leaching, it did not show appreciable sensitivity to the displacement in the second phase and there is no significant change in its concentration in the outflow water after shearing took place i.e. the concentration remained at the level fixed in the first phase.

The third anion studied was monovalent bicarbonate (HCO_3^-), the results of which are shown in Fig 4-C. The concentration of this anion in the outflow water in the beginning of the test reached a level of 4.3 meq/lit, which, after subtraction of its concentration of 1.7 meq/lit in the inflow water, showed that some 2.6 meq/lit had been drained from the bulk soil of the sliding surface. This concentration decreased at a slight rate and was almost fixed at 2.2 meq/lit. In the second phase and 140 hrs after the shearing, the concentration in the outflowing water reached 2.80 meq/lit. With continued leaching after the shearing, the concentration decreased, it was 1.8 meq/lit and remained almost fixed at this level.

Throughout the study, two important factors, namely, EC and pH, which are generally affected by the total ions and dissolved salts, were studied. The results obtained for these factors are depicted in Fig 5 and 6. As shown in these figures, in the beginning of the tests, due to a relatively high dissolution potential as a result of presence of free ions in the original soil, the EC of the outflow water was 2800 $\mu s/cm$ (Fig 5). However, during the first phase of the study, this value quickly decreased to 700 $\mu s/cm$, which was almost the same as that of the inflow water. Upon displacement in the second phase, no appreciable changes were observed for EC; in other words, EC did not show detectable sensitivity to displacement.

In the case of pH, the pattern of change was sporadic (Fig. 6), scattered and irregular in both phases of the study. The changes of pH followed a zigzag pattern due to rapid variations and did not show an acceptable stable value, although the general trend of pH values were descending in the first phase and ascending in the second phase (after soil cut).

Discussion and conclusion

Considering the burgeoning population in recent decades, residential and economical zones are expanding toward higher and more elevated lands that are more susceptible to landslide. Therefore, monitoring of slopes and the factors affecting their stability is very important and necessary. The main objective of such monitoring is prediction of the time of rapid and main failure in order to save people's life, since, in the process of risk reduction and management, the time span between early warning and the time of the main sliding event has a key role in the success of the program. In some landslide events, use of ordinary devices and instruments for monitoring movements and predicting the time of sliding event has

not been quite successful due to the undetectable movements of the sliding surface. Notably, the fact is that in most such events, prior to the main failure occurrence, some slight movements take place at the sliding surface which are not picked up and revealed by most of the monitoring instruments. Therefore, in the present study, the possibility of monitoring changes in the ion concentration of the outflow water as a result of those movements, and using those changes as early warning signs of the sliding event, has been investigated.

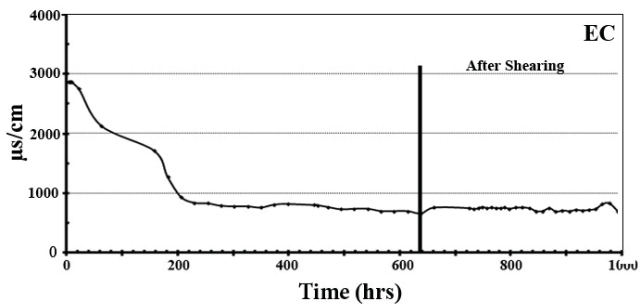


Fig 5 Changes in EC of water flowing out of the model

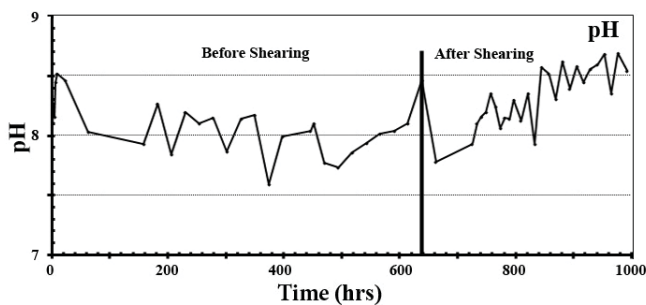


Fig 6 Changes in pH of water flowing out of the model

The present research was based on the aforementioned hypothesis. The results of the study showed that some of the ions in the water flowing out at the toe of the slope (including cations and anions in the soils through which the outflow water has passed) can act as good indicators for this purpose. As stated in the discussion of the results, the ions sensitive to slight movement of the sliding surface could be different depending on soil properties; therefore, to identify the ions sensitive to sliding event, it is necessary to carry out several studies with soils having different properties. In our case, use of the model for the selected soil sample showed that, among the ions studied i.e. Na^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , SO_4^{--} , and HCO_3^- , ions of sodium (Na^+), potassium (K^+), magnesium (Mg^{++}) and, to some degree, bicarbonate (HCO_3^-) have acceptable relative sensitivity to the occurrence of landslide in the tested soil. In contrast, ions of calcium, chlorine, and sulfate do not have adequate sensitivity to be used as early warning sign in slight movements of a potentially unstable slope.

Generally, in selecting an ion to be used in monitoring programs for early warnings, the most important characteristics include the increase in concentration

upon soil displacement, the time taken to reach equilibrium, the maximum concentration after displacement, and the time taken to return to equilibrium. In the present research, the index R_I , which is the ratio of concentration in the outflow water at the toe of the slope before the soil shearing to that after the shearing was introduced as a suitable parameter for monitoring and early warning in slope areas susceptible to sliding. Fig 7 shows this index for the ions studied in the present study. It is expected that, under normal conditions, R_I will be equal or greater than unity. The closer is this ratio to unity; the less is the sensitivity of the ion to soil displacement. In this research, the maximum R_I belonged to magnesium, followed by, respectively, potassium and sodium cations. The R_I index of calcium, sulfate, and chlorine was close to unity that reflects their insensitivity to the shearing in the sliding surface. Among the anions studied, bicarbonate's R_I was greater than unity and could be selected as a cation sensitive to displacement.

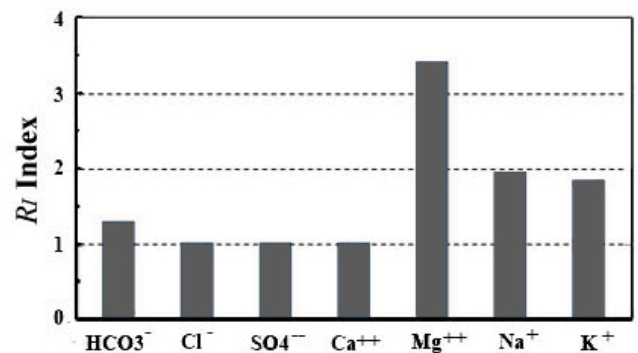


Fig 7 Graph of R_I index for ions studied in the model.

Since E_c (electrical conductivity) of water is directly affected by the concentration of dissolved ions, although E_c increased after the shearing was made, but its rate was not appreciably high. Therefore, changes in E_c cannot reflect changes in the activities of the sliding surface. Although the general trend of pH values were descending in the first phase and ascending in the second phase (after soil cut), but the changes were gradual with much ups and downs. This shows the susceptibility of pH to the effects of many factors, therefore, it cannot be considered a reliable indicator for detection of the activities of the sliding surface.

The summary of the results of this study are as follows:

1. The change in the concentration of some cations and anions in the water flowing out of the sliding surface after each activity can easily be proved.
2. Considering the limited sensitivity of the monitoring instruments and the relatively long time span between the slight activities of the sliding surface and the appearance of observable signs on the ground surface, the changes in concentration of ions can be used as

effective early signs of the activity of a sliding event to control and reduce the risks.

3. Changes in the ions concentration is dependent on the soil properties and clay types present in the soil. Therefore, it is necessary to run the model test for each region to identify the ions and factors sensitive to soil movements in that area.
4. Generally speaking, the most important characteristics to be considered in selecting an ion for monitoring programs and early warnings include the increase in concentration upon soil displacement, the time taken to reach equilibrium, the maximum concentration after displacement, and the time taken to return to equilibrium. In the present study, R_1 , which is the ratio of concentration in the outflow water at the toe of the slope before the soil shearing to that after the shearing, was introduced as a suitable parameter for monitoring and early warning in slope areas susceptible to sliding

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Increasing awareness: the role of non-structural measures in landslides disaster reduction

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Abstract The impact of disasters world-wide has been unexpectedly high during the last decade in both developing and developed countries. Consequently, one of the main aspects visualized by the United Nations International Strategy for Disaster Reduction (UNISDR) to build up resilient societies is devoted to increasing public awareness. Under such framework, activities associated to promote a culture of disaster prevention require dissemination of information to the exposed communities. In Mexico, landslide disasters triggered by precipitation have caused numerous human losses and major economic impact in recent years. However, landslide investigations have been neither stimulated nor extended as needed. In a mountainous terrain, such as the Mexican territory, addressing this issue from a pure scientific or engineering perspective is rather difficult. Taking into account these circumstances, non-structural measures need to be valued and used as a real, quick and cheap opportunity to reduce vulnerability in terms of increasing people's knowledge and awareness. Therefore, a webpage –in Spanish- was created in order to gather basic information on line to be shared through internet with people living on landslide risk areas. In addition to the general hazard aspects, a data base format was also introduced to facilitate the use of both general public and people with some technical knowledge, to report existing mass movements. Besides providing easy to understand landslide information to the communities, the webpage is aiming at contributing to the development of a national landslide inventory. In this paper, the role of non-structural measures expressed throughout the construction of a webpage and a landslide database for the Spanish speaking world is presented.

Keywords landslides, vulnerability, non-structural measures, landslide webpage, Spanish.

Disasters and public awareness

The impact of disasters world-wide has been unexpectedly high during the last decade in both developing and developed countries. Catastrophic consequences derived from events such as the 2004 Indian Ocean tsunami and the 2011 Tohoku earthquake,

have produced skyrocketing tolls producing concern and calling the attention and efforts of the international community. Therefore, the United Nations International Strategy for Disaster Reduction (UNISDR) has envisaged a strategy comprising four major objectives: 1) Increasing public awareness; 2) Obtaining commitment from public authorities; 3) Stimulating interdisciplinary and inter-sectoral partnership and expanding risk reduction networking at all levels; and 4) Improving further the scientific knowledge of the causes of disasters and the effects of natural hazards and related technological and environmental disasters on society. Within the particular rationale of public awareness, public information, education and training are considered the most significant issues to be addressed.

Structural vs. Non-Structural measures

According to the UNISDR (2009), any physical construction to decrease or prevent likely impacts of hazards, or application of engineering techniques to carry out hazard-resistance and resilience in structures or systems can be considered as a structural measure. Contrastingly, non-structural measures are those which do not involve physical construction but are based on knowledge, practice or agreement to reduce risks and impacts, especially by means of policies and laws, public awareness raising, training and education.



Figure 1 Structural Landslide measures in the locality of Necaxa, Puebla.

Structural measures are specific actions that aim at understanding the hazards, in this case landslides, in addition to reducing their physical impact by means of identifying landslide mechanisms and thresholds; undertaking remedial works (diversions, terraces, water disposal systems, drainage, sediment controls, land levelling, biotechnical protections, etc.), instrumentation and monitoring; and modelling and the implementation of sophisticated hazard warning systems (Fig. 1). On the other hand, and as complement, non-structural measures include complex social processes that need to consider the resilience or vulnerability conditions of societies. Those processes are strongly linked to disaster risk reduction management necessities including land use planning, community based early warning systems, knowledge transfer, education, preparedness, participatory mapping, risk perception understanding, environmental consciousness, and disaster prevention co-responsibility.

Reliability of slope structural measures against landsliding is based on variability of controlling factors, climatic scenarios, financial capability and engineering skills and commitment. Quite commonly, the time requirement for implementation is not that long in comparison with non-structural measures. Nonetheless, the life expectancy of such structural measures is assumed with uncertainties associated to hazard recurrence periods, magnitude and frequency of events, and the need of protecting its integrity, correcting damages, correcting the deterioration of structural components and upgrading of the structures to meet the dynamic conditions of the environmental context where they have been put into operation (Fig. 2).

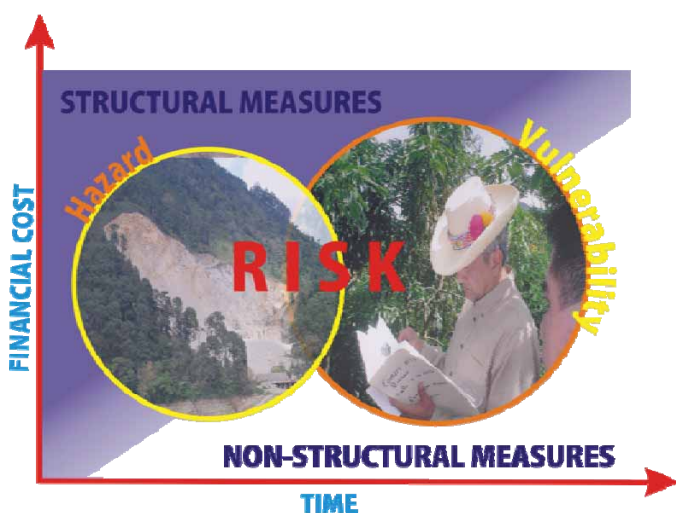


Figure 2 Effectiveness of Structural and Non-Structural Landslide measures in terms of financial cost and time.

Public understanding of science

Science dissemination refers to the transmission of information in only one direction; from somebody who knows something to someone who is not acquainted in the subject. However, in a wider spectrum, science

communication involves a dialogue among actors, including an exchange of knowledge and experiences. According to Lewenstein (2003), there are four main models for science communication: 1) the deficit model; 2) the contextual model; 3) the lay expertise model; and 4) the public participation model.

The deficit model describes a shortfall of knowledge that must be fulfilled, assuming that after correcting the shortage, the situation will be improved. This model has proven to be far from reality. Consequently, attention has been paid to new science communication models. The contextual model is based on the fact that individuals do not merely react as empty recipients to information, but process information according to social and psychological backgrounds resulted from their previous experiences, cultural context, and personal circumstances. Despite of recognizing the presence of social drivers, this model is still focused on the response of individuals to information. Local knowledge is the main component of the lay expertise model. It is centered in the lives and histories of real communities, at local level. Therefore, it is assumed that local knowledge may be as relevant to solving a problem as technical knowledge. The public participatory model also known as dialogue model aims at stressing the significance of seeking public input into science issues (Lewenstein, 2003).

Not only science but also risk communication requires using a combination of elements derived from the different models. First of all, it has to be agreed that risk communication is a multidisciplinary task aiming to communicate knowledge by different means to the public taking into account besides the knowledge *per se*, the context of the communities' livelihoods and their environment. Second and equally important, risk communication must be pieced together on a horizontal approach, on which integrated understanding and management of hazards and vulnerability turn out to be the essential sound practice needed to reduce disaster risk. Therefore, under such scheme, it is clear that it is communication of science and not only dissemination, what is needed as a key instrument to contributing to disaster risk reduction.

Notwithstanding the very recent interest associated to the disasters occurring in the last decades in the globe, risk communication is one of the oldest manners to communicate risk. In ancient Babylonia, dating back circa to the third millennium BC, different mechanisms to anticipate, respond and communicate food shortage and other natural hazards were utilized (Krimsky and Plough, 1988; Kasperson and Stallen, 1991). Considering technological and scientific advances and progress, risk communication clearly ought to provide all possible alternatives to enhance risk disaster reduction.

A risk communication programme points towards achieving several missions, including enlightenment, right-to-know, attitude modification, legitimate function, risk reduction, behavioural change, emergency readiness, and public enrolment and participation (Renn and Levine

1991). Risk communication can be on the whole viewed as a cyclic process on which feedback plays a very significant role. As information is attractively transmitted to the public, hazard understanding and acceptance can be achieved. Environmental consciousness at local, regional and global scale then turns into an essential component of this dynamic and cyclic process and risk awareness is progressively built (Fig. 3).

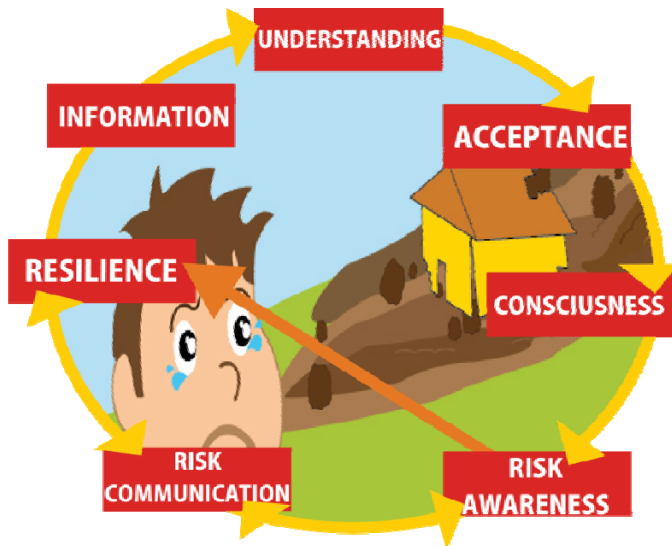


Figure 3 The cyclic process of risk communication.

Channels of communication

It is important to bear in mind that communication media depends on the public target, and literacy and communication skills must be also considered. Posters, brochure, leaflets, newspapers, television, radio, songs, radio-stories and novels are among the most common. Moreover, messages to be sent across willing to assist disaster prevention and risk reduction, must generally fall in the dimensions of trust, understanding, credibility, satisfaction, cooperation and agreement, but particularly during a crisis period (Marra, 1998).

In a similar fashion than public relations, communication processes need to rely on different elements, considering aspects including credibility, context, content, clarity, continuity and consistency, channels, and capability of audience (Cutlip et al., 1985).

Ensuring relevance and effectiveness is a major challenge of risk communication and awareness. Internet can be regarded as a valuable way to reach a large young sector of the population of mountainous areas who have computer and internet access in their homes, towns and schools given that direct engagement with remote centres of population is in that case very difficult. Creating and putting on line a landslide webpage in Spanish targets at guarantying an accessible source with a clear, understandable message that can help to improve people knowledge and awareness on landslides and disasters risk reduction.

The globalization of risk messaging has taken place so rapidly that mass media such as TV, the medium that brought risk messages to the largest possible audiences, has been overwhelmed by the use of internet. As the Internet expanded, access to information by population, public interest groups and individuals has been unparalleled in human history up to now (Krimsky, 2007).

According to the Internet World Statistics, there were 2,279,709,629 internet users worldwide in the first quarter of 2012, the equivalent to about one third of the total world population. Asia is by far the region with more internet users in the globe (45%), followed by Europe (22%), America (12%) and Latin America and the Caribbean (10%) respectively. In the international internet users ranking, Mexico is placed in the top 20, as number twelve, after countries such as China, USA, India, Japan, Brazil, Germany, Russia, Indonesia, UK, France and Nigeria. In 2012, 42,000,000 people were declared as internet users, meaning that 37% of the total population was connected through the cyberspace. The largest percentage of users was under 35 years of age; 17.7% were studying basic education, 24% secondary school, 29.2% high school, 25.5% university level and 2% postgraduate studies. Accordingly, youngsters and children are the main cyber-users and hence the group that can be targeted in terms of using internet as an alternative to enhance risk knowledge and raising awareness in order to reduce vulnerability and increase resilience.

Aiming at landslides risk disaster reduction

Landslides in Mexico

The significance impact of landslide disasters in Mexico has been recently pointed out in terms of historical accounts (Alcántara-Ayala, 2008) and also derived from specific cases. According to information collected from the data bases EM-DAT and *Desinventar* in addition to historical archives, during the period 1920-2010, 1080 disasters took place nationwide.

A total death toll of 6133 victims and 719 wounded people resulted from those disasters. Not surprisingly, 997 events, in other words 92% of the total number of disasters, were linked to hydrometeorological events, particularly to precipitation derived from cyclones and hurricanes. The other episodes were associated to anthropic activities (16), seismicity (10), faulting (7), volcanic activity (2) and others not specified.

The largest number of events took place in the province of Chiapas; 170 disasters, the equivalent to 16% of the total caused considerable damage and 232 human losses. In Veracruz, Guerrero and Mexico City, 129, 122 and 120 events were respectively registered, they account individually for 11-12% of total events. Estado de Mexico, Puebla and Hidalgo accounted for 94, 88 and 84 events (Fig. 4).

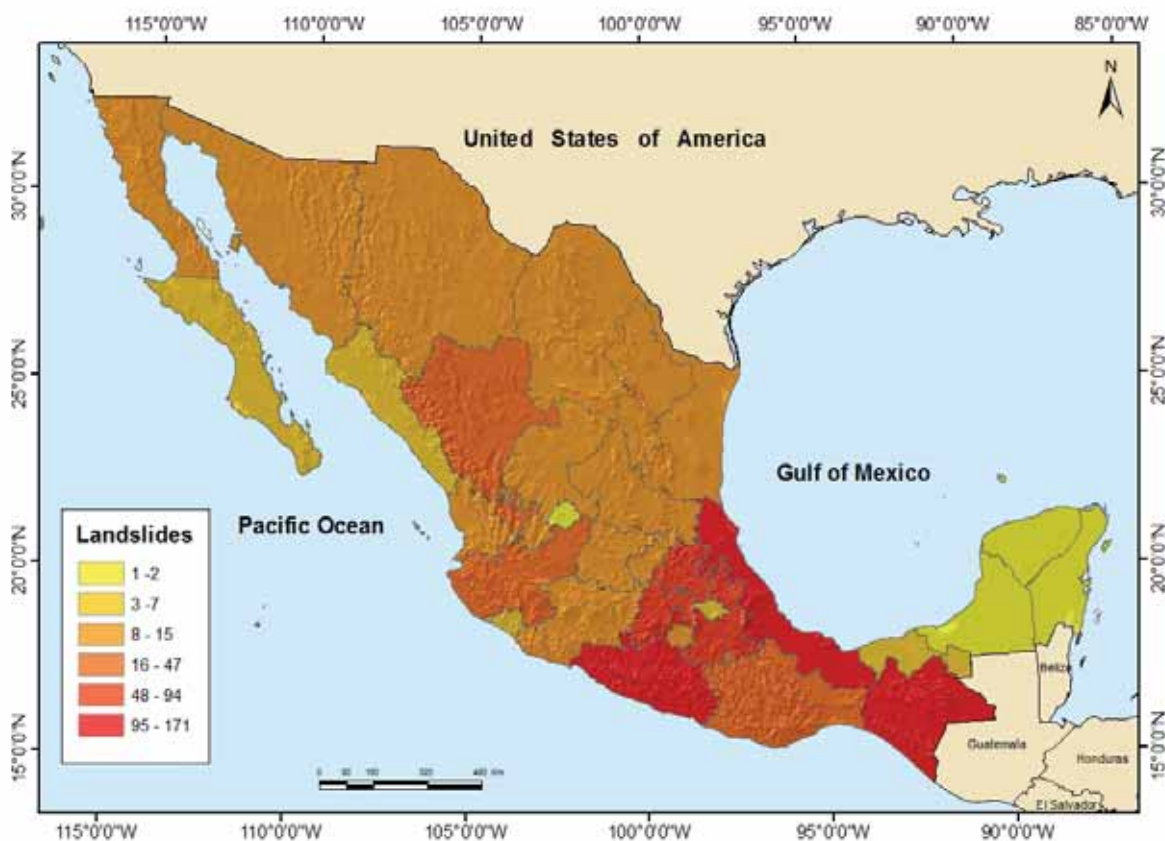


Figure 4 Affected provinces of Mexico due to landslide disasters (number of events registered 1920-2010).

Considering the number of casualties, the worst episode took place in Baja California Sur province; 1000 casualties occurred in La Paz during a period of intense precipitation of Hurricane Liza associated to flash-floods and mudflows produced by the collapse of a dike (see Alcántara-Ayala, 2008). The second worst disaster occurred in Minatitlan, Colima; due to rainfall triggered landsliding a natural dam was formed in the area of the Copales and Juanillos hills, where soon after, a catastrophic overtopping of the dam caused three mudflows that swept the town of Minatitlan (Padilla, 2006; Alcántara-Ayala, 2008). The third worst episode took place in October 1999, resulting from the interaction of a tropical storm and a cold front intense rainfall was produced in the Sierra Norte de Puebla region; hundreds of landslides occurred and 247 people died (Bitrán, 2000; Alcántara-Ayala, 2008).

Among landslide disasters, particular attention ought to be paid to the Grijalva landslide due to the considerable mass extent involved. After an intense period of precipitation, on November 4th, 2007, a catastrophic landslide took place in San Juan de Grijalva, Chiapas (Fig. 5). It involved a volume of circa 50 Mm³, blocking the Grijalva river with a run-out distance of 800 m. The initial movement was followed by a 50 m wave that damaged several houses and a church; the official death toll included 19 casualties and 6 people missing.

More than 3500 were evacuated as a substantial quantity of hillslopes was evaluated as unstable and rainfall persisted within the region causing major floods and numerous smaller landslides (Alcántara-Ayala and Domínguez-Morales, 2008).



Figure 5 The Grijalva landslide, Chiapas, November 4, 2007.

Increasing awareness: creating a landslide webpage

Public awareness is understood as “the extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually

and collectively to reduce exposure and vulnerability to hazards” (UNISDR, 2009).

One of the simplest and cheapest means to promote and enhance disaster risk reduction is nowadays offered by internet. Websites allow sharing resources, and updates can be easily carried out and followed by end users.

Table 1 Advantages and disadvantages of web activities (IFRC, 2011).

Advantages	Disadvantages
Can be comprehensive of resources	Requires professional user-friendly design
Can enhance accountability and transparency	Requires good search and browse design and tools
Can accommodate many versions for different target audiences, languages and preferences	Requires regular addition of new content
Can be supported with visuals	Can be difficult to access with low bandwidth
Can describe resources and invite more inquiry	Can be difficult or expensive to access
Can be tracked by users for new content	Must be designed with low bandwidth in mind
Can become a trusted source of information	Must be designed for delivery on different browsers
Can raise profile and enhance credibility	Must be adapted to handheld and mobile devices as well as computers

The expectations of the successful use of internet for risk awareness should not be exceeded. This high-speed growing communication tool has a wide variety of advantages and disadvantages that have to be assumed in order to be realistic and efficient (Tab. 1). Nonetheless, clearly the selection of creating a landslide webpage in Spanish sets sights on enhancing risk knowledge and raising awareness as a non-structural measure to reduce vulnerability and increase resilience.

The preliminary version of the webpage presented in this paper comprises five major sections: disasters, landslides, prevention, a landslide database, and other information and links (Figs. 6 and 7). In the first part, answers were given to questions including “What are disasters and why do they occur?”, “What is the impact of disasters worldwide?”

Landslide classification, causes, controlling factors and triggering mechanisms were carefully explained in the second section. In the third component, hillslope instability symptoms, and specific actions to be undertaken before, during and after a landslide were integrated. A specific area in the webpage was destined to include an online register to feed a national landslide database. Two types of users were considered: general public and people with technical expertise or knowledge capable of inputting scientific information. Validation of all entries is contemplated to be carried out as information fields requires data concerning type of

movement, material involved, triggering mechanisms, affected area, presence of vegetation, slope, slope orientation, affected population, casualties, damages in housing, infrastructure and crops, among others.



Figure 6 General view of the created landslide webpage (in Spanish).

The last section, general information and materials were incorporated in addition to listing other useful internet resources. A photo gallery associated to the pictures presented at the Second Landslide World Forum was set up. Popular science literature, songs, and several kind of national and international links were also integrated.

After finishing the first complete version of the webpage, an evaluation and feedback from young people living at a landslide risk area was sought out. The assessment took place in the municipality of Teziutlan, Puebla, near an area devastated by landslides in 1999. A visit to the Technological Institute of Teziutlan was paid with the intention of getting different points of view from the local population. Fifty people participated in the test. The later was divided into three parts. The first one consisted of an oral appraisal on which individuals were asked if they considered themselves at risk, their acquaintance with the landslide 1999 disaster and the actions to be undertaken in case a disaster takes place. During the second part, 45 minutes were given to the participants to use the landslide webpage; there were no instructions for navigating. Finally, a questionnaire was applied to get feedback from the layout and contents of the website (Cruz-Jerónimo, 2012).

Design, images and functioning of the webpage was improved thanks to the performed assessment. Participants were between 17 and 50 years old; 60% were at university level, 22% postgraduate studies and the rest did not specify educational level. Interestingly enough, 75% percent of contestants indicated that landslides were the major risk in their community, followed by delinquency (13%) and floods (12%).

Moreover, also 75% of the interviewed people mentioned that they had lived a disaster event, whereas the corresponding 25% had not had such an experience. Out of the total people involved in the survey, 94% understood what landslides are and the reason for their occurrence; 72% of them explained that according to the information given in the webpage they are placed at risk, while the corresponding 28% did not identify such condition. Disappointingly, only 3% of the participants acknowledged the fact that human activities can influence landsliding.



Figure 7 Some of the elements included in the landslide webpage.

All respondents affirm that they would recommend the webpage to family and friends to broaden the transmission of information on landslide risk disaster reduction considering that there is lack of precise disaster knowledge and understanding within their community context. Regarding the design, structure and functioning of the webpage, 66% of the contestants indicated that the website was good and easy to understand, 19% considered it interesting but boring, 6% thought it was interesting and fun, other 6% judged the page as confusing and difficult to understand, and only 3% regarded it unexciting.

Concluding remarks

Social media will continue to expand through social networks (Facebook, MySpace), blogs, mobile text messaging, twitter, video sharing (YouTube), podcasts, wikis, image sharing, and internet forums, among others. They are prevailing and influential as they fulfil the human necessity of innovation and connection. Engagement in knowledge cyber dialogue, encouraging risk awareness and communication, and enhancing disaster risk reduction within a computer-generated framework is with no doubt one of the challenges to be faced by the scientific community and the society as a whole. Consequently, promoting and implementing landslide sound practices in disaster risk management, engaging local communities and empowering the social

order will play a significant role in both the national and international agendas in the forthcoming years.

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Post-failure Mobility and the Importance of Stress Ratio in Strength Evaluation

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Abstract The undrained post-failure behaviour of three soil types - volcanic soil, pumice and silica sand - was assessed in a ring shear apparatus to understand the factors affecting the residual strength (and hence the potential travel distance) of slope materials. The stress paths of medium to dense soils were dilatant in nature. The soils exhibited a typical three-phased behaviour starting with initial gradual generation of excess pore pressure followed by a period of temporary strain-hardening during which peak strength is attained and failure occurs; and a post-failure phase characterized by rapid generation of excess pore pressure and progressive decline in effective normal stress until a residual state is reached. The residual strength of the volcanic soil is nearly same as that of poorly graded, fine silica sand but higher than that of pumice. While the volcanic soil required higher strain to mobilize both peak and residual strength, the pumice soil readily liquefied and rapidly reached low residual state. Taking account of all the undrained mechanical properties of the soils we arrive at a new premise that soils with constant stress ratio at peak, phase transformation and residual states may be less resistant to liquefaction, and may travel long distances after a slip. The constant stress ratio phenomenon is more likely to be associated with cohesionless soils than cohesive soils.

Keywords Excess pore pressure, residual strength, stress ratio

Introduction

Landslides occur in nearly every terrain in the world. Hundreds of millions of dollars are lost annually to mass movements on steep as well as gentle slopes. Nature of slope material, slope angle, fluid dynamics, geology and climate are important factors in prevention and mitigation measures. To understand the mechanism of slope failures, two landslides - Las Colinas landslide, El Salvador (Fig. 2) and Stromboli landslide, Italy (Fig. 3) were investigated. The El Salvador landslide occurred in 2001 killing over 3,000 people while the Stromboli landslide occurred in 2003. Results of the investigation are compared to those of silica sands to gain insight on the pre- and post-failure behaviour of the soils associated

with the landslides. The objectives of the research are to understand the mechanism of excess pore pressure development in soils during undrained loading and to model the post-failure behaviour of different types of soils and the factors that affect their residual strength.

Investigation procedure and sample characteristics

Field techniques and sampling

Field measurements and sampling were undertaken at two landslide sites in El Salvador and Italy. Important features measured include position, elevation of landslide source and toe, slope height, slope inclination, aerial extent of moving block, direction of movement, depth and inclination of slip surface, rock type, degree of weathering and composition of slip surface. Soils were collected at the source of the landslides for laboratory analysis.

Topographic map interpretation was carried before and during the field work. During the fieldwork strikes, dip direction and magnitude, and foliation trends were determined. Slope angles were measured, using an Abney level. Geological map interpretation was carried out to obtain additional information on the geology of the area. Soil and sediment textural and physical properties have an influence on the susceptibility of materials to failures. Sampling of soils was undertaken in order to determine physical characteristics that have a bearing on soil structural strength. Soil samples were analysed for the following: particle size, natural moisture content, compaction, liquid limit, plastic limit, plasticity index and shear strength.

Laboratory modelling

Oven dried specimens were placed in the shear box and saturated with water. To achieve a B value of at least 0.95 carbon dioxide was first introduced into the samples after which, de-aired water was introduced. All samples were normally consolidated and thereafter, shearing was performed by the incremental loading of shear stress. Shear stress (resistance) is calculated as follows: #

$$\tau = \frac{3}{2\pi} \frac{TR}{(r_2^3 - r_1^3)}$$

Where τ : shear stress, r : radius, θ : angle, T : measured shear force, R : length of the arm from center to torque sensor, r_1 : inner ring radius, r_2 : outer ring radius. Applied normal stress was determined from $\sigma_o = \gamma \cos^2 \theta$, while the initial shear stress was obtained from $\tau_o = \gamma H \sin \theta \cos \theta$ where H is the thickness of the material overlying the sliding surface, γ is the average unit of the soil within the sliding mass, and θ is the slope inclination.

Sample characteristics

Samples from Las Colinas, El Salvador and Stromboli, Italy were taken from the head scarp of the landslides (Fig. 4) while the silica sands used as control specimens are industrial sand materials composed of sub-angular to angular quartz and small amount of feldspar. The grain size distribution and the nature of the pumice samples are shown in Figures 5 and 6 respectively. The Stromboli soils were taken from the Stromboli volcanic monument that is standing 900 m above sea level (Fig.3).

The characteristics of the soils are shown in Table 1. In the Unified Soil Classification System (USCS) a soil is considered well graded if $C_u > 6$ and C_c lies between 1 and 3; otherwise it is poorly graded. Gravel is well graded if $C_u > 4$ and C_c lies between 1 and 3.

Particle size distribution is often considered when choice of fill materials and design of drainage facilities are made because particle gradation exerts some influence on the shear strength and hydraulic properties of soils. Research has also shown that coefficient of uniformity alone cannot be a reliable indicator of soil gradation (Igwe et al, 2012). A soil with high value of coefficient of uniformity (as high as 17.5) may still be a poorly graded soil and needs another component – coefficient of curvature (C_c) to detect that the soil may be a gap graded soil.

Scanning Electron Microscopy (SEM) analysis of a pumice material shows the presence of inter- and intra-particle void spaces (Fig. 7).

SEM is important in the analysis of microstructures which could be intergrowths, particle micro-features such as micro-textures, dissolution characteristics and/or



Figure 2 Las Colinas Landslide, El Salvador

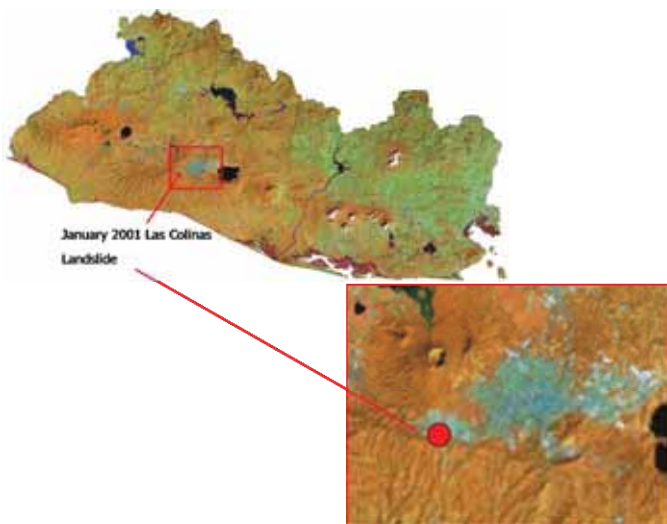


Figure 1 Satellite map of El Salvador showing Las Colinas landslide



Figure 3 Stromboli Landslide, Italy (picture taken by Daniella)

precipitates-coatings. Its high resolution stereo imagery provides a reliable compositional analysis that are better than the results of traditional light microscope.



Figure 4 Sampling locations on the Las Colinas Landslide

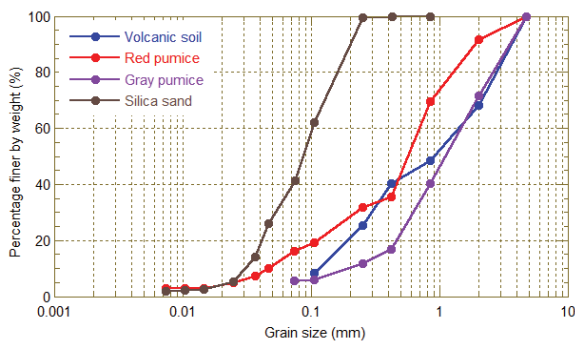


Figure 5 Grain size distribution curves of the soils



Figure 6 Nature of the soils collected at Las Colinas Landslide

Physical model to predict mechanical properties

The slopes were modelled to predict the mechanical properties of the soils in a ring shear apparatus using the equations in Fig. 8. Our model aims to verify two apparently conflicting concepts that liquefaction resistance increases as the grain size becomes coarser due to improved drainage, and also increases as the grain size becomes finer due to increased cohesion. It is widely acknowledged that there is a gap between current

practice of liquefaction potential evaluation and laboratory experiments on the modification of the liquefaction strength of sands containing fines; which is a major draw-back in engineering design.

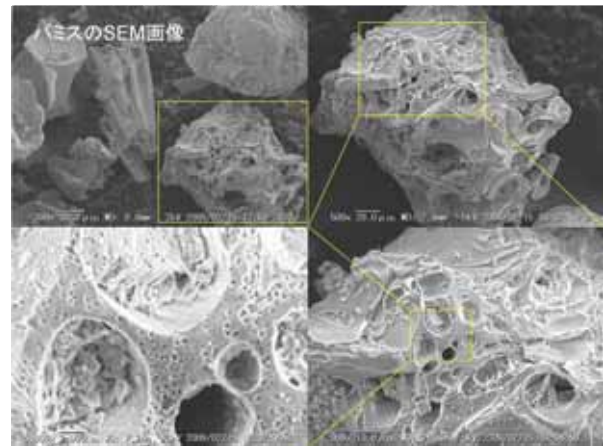


Figure 7 Inter- and intra-voids in a pumice soil revealed by SEM

Table 1 The physical properties of the slope and silica soils

Sample	D ₅₀ (mm)	D ₁₀ (mm)	C _u
Volcanic soil	0.95	0.12	12.5
Red-silty pumice	0.56	0.05	14.0
Gray pumice	1.11	0.21	7.1
WG silica	0.23	0.04	9.0
ING silica	0.11	0.03	4.5
GAP silica	0.42	0.03	17.5
NAG silica	0.09	0.03	3.3

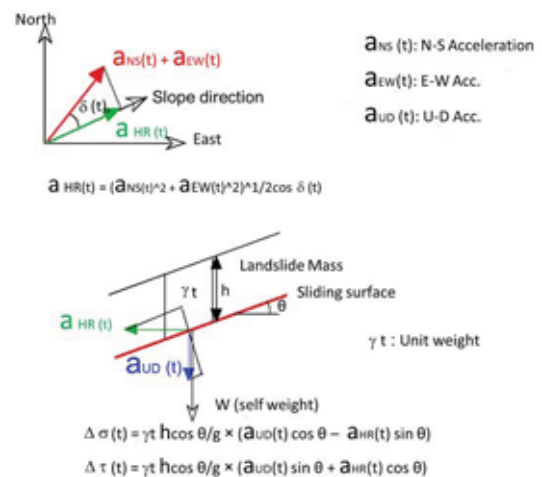


Figure 8 Mathematical illustration of the physical model

Results and interpretations

The pumice soil generated high excess pore pressure at small strains, and by 10 cm shear displacement, pore pressure had almost become equal to the normal stress (Fig 9). The excess pore pressure ratio (u/σ) at residual

state approaches unity. This phenomenon is regarded as liquefaction and is consistent with the physical evidence of liquefaction at site during field investigation. The level of destruction (Fig. 2) appears to support liquefaction as the mechanism of Las Colinas landslide. Liquefied masses do not allow people time enough to evacuate because the soils moving down slope behave like liquids.

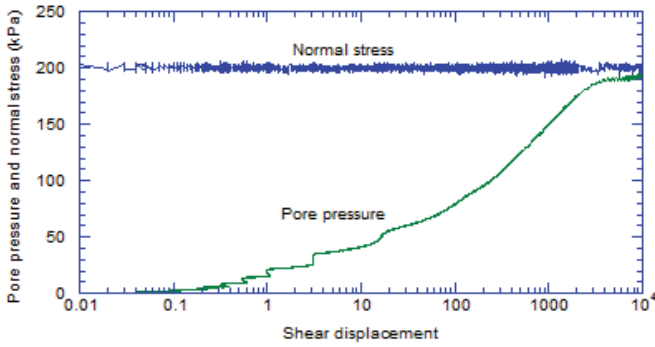


Figure 9 Typical excess pore water generation in the pumice soil

The pumice soil is vesicular and as a consequence, light and crushable. Its high compressibility and crushability are the reasons for high excess pore water generation. The porous structure of pumice is produced during a given volcanic process when the outflow of gases from cooling magma results in hollow voids. The importance of the voids in the shear behavior of pumice and their response to water saturation and undrained loading is the key to proper understanding of the mechanism of deformation. Pumice is generally known for its use in the production of lightweight aggregates. However, results of this research show that it could also be a bad choice as fill or slope material.

In the Stromboli volcanic soil, the stress path is dilatant in nature and excess pore water pressure generation is relatively less rapid (Fig. 10). The residual, phase transformation and peak states of deformation appear to lie on the same line that yielded 13 kPa as the value of cohesion. Yet, only the stress ratios at peak and phase transformation are equal. The higher stress ratio at residual state may be because of soil fabric and cohesion and could be a potential distinguishing factor in analyzing the travel distances of landslides. The residual shear strength is a better parameter for stability analysis because it is not influenced by the level of effective normal stress or even by drainage conditions (Igwe et al. 2012). Limit-equilibrium analyses (the most common stability analyses) assesses forces and moment equilibrium of a slope on an assumed slip plane where shear strength, unit weight, and pore pressure parameters are known quantities and present outcomes as a factor of safety. This kind of analyses assumes that the factor of safety is the same everywhere along the slip plane i.e shear stress distribution along the slip plane is a constant ratio of the shear strength along that plane.

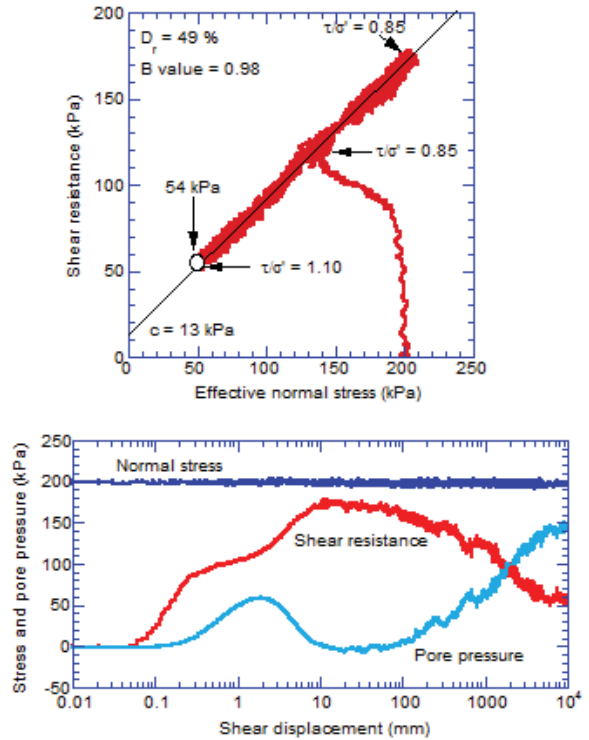


Figure 10 Undrained behaviour of the Stromboli volcanic soil

Silica sand sample at same initial test conditions as the Stromboli volcanic soil deformed also in a dilatant manner. However, excess pore water pressure generation is relatively more rapid (Fig. 11). The residual and phase transformation lie on the same line that passes through the origin of the stress-strain (cohesion is zero). Analyses show, the stress ratios at peak, phase transformation and residual states are equal (about 0.74). This ratio is however lower than that of the volcanic soil and indicates lower resistance to deforming stresses.

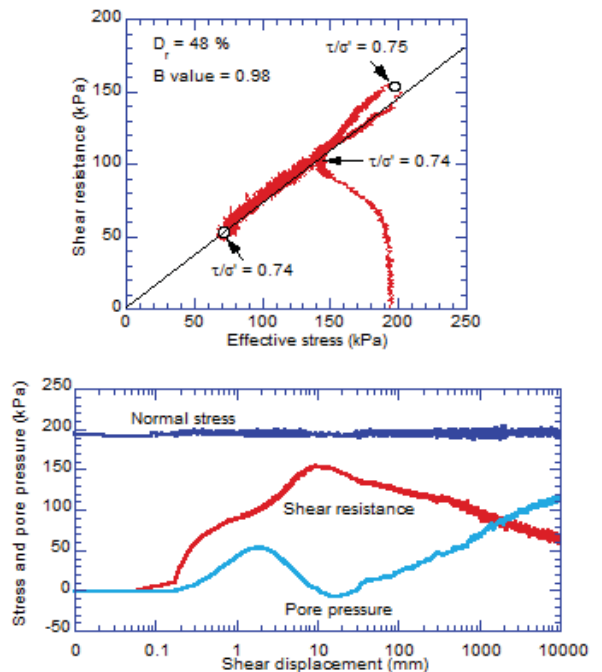


Figure 11 Undrained behaviour of poorly graded silica sand

It appears the coarser the particles the more the capacity to generate excess pore pressure during shearing due to potential grain crushing. Experiments verifying this assertion have been conducted and results presented in Figures 12 and 13. It may be seen that at effective normal stress values of 196 kPa and 290 kPa well graded soils containing coarser particles generate much higher pore pressure after failure than the soils with finer particles. The high post-failure pore pressure is responsible for the low residual strength of well graded materials. Figure 14 shows the undrained behaviour of pumice differs widely from that of the volcanic soil. The residual shear resistance of the volcanic soil is higher than those of silica specimens containing coarser particles.

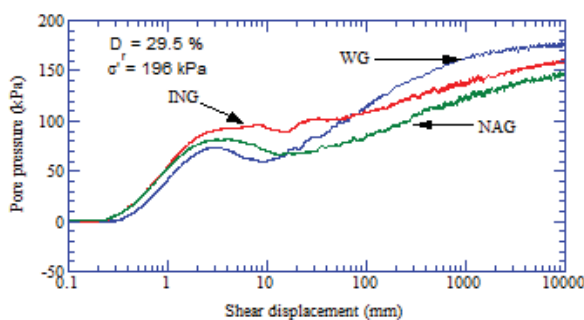


Figure 12 Influence of particle size on pore pressure generation

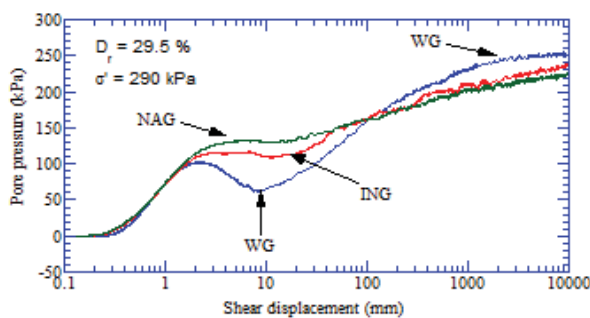


Figure 13 Effect of particle size on pore water pressure generation

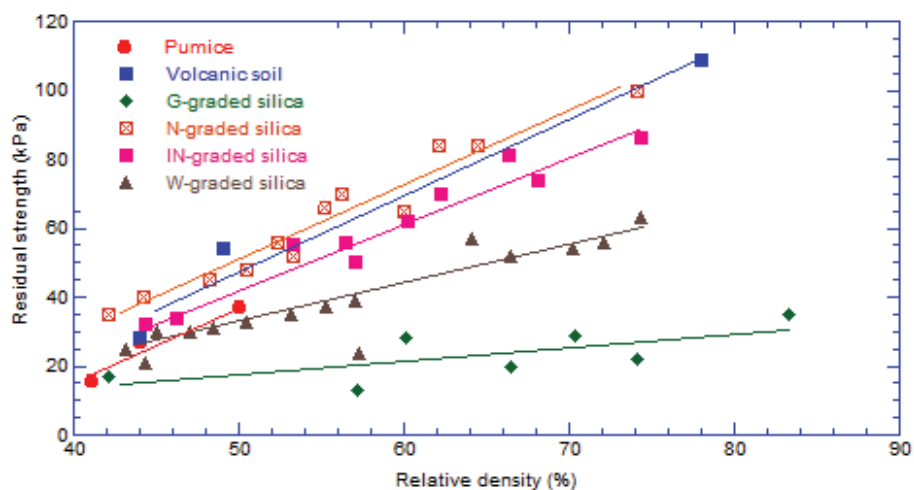


Figure 14 Residual undrained shear strength of the slope soils compared to those of silica sands.

In the volcanic soil the friction angle at peak, phase transformation and residual states is equal (40°). The friction angle at residual state is the most important parameter in predicting the potential travel distance of a landslide. The knowledge that the friction angle at the three defined states is equal is therefore a boost in landslide investigation and mitigation because the friction angle at phase transformation or peak stress could be rapidly and conveniently obtained with a simple direct shear box. It therefore means that the line connecting the three stress states defines a critical or threshold state (Igwe et al, a,b 2012). The critical state parameter, as used in the present research, is the critical or limit value of pore pressure at the failure line (or at the beginning of phase transformation where the resistance of soils drops temporarily at small strains, and regain strength with further shearing at higher strains), above which a soil collapses and liquefies, and below which a soil dilates and regains stability, at least temporarily, if the soil is monotonically loaded in undrained condition. When curves of shear resistance and pore pressure versus shear displacement are made, the critical state parameter could be defined as the least possible dilation a sample of known void ratio can sustain under the same laboratory conditions.

The research further found that for the silica sands the friction angle at peak and residual states is 38° and 36° respectively. These values of friction angle are lower than that of the volcanic soil. This may be because of the high crushability of the silica particles and the resultant high excess pore pressure - a major factor in fast moving landslides. Literature is full with accounts of calamities associated with rapid landslides, which offer people who live at or close to mountainous areas little or no time to evacuate each time disaster looms.

Conclusions

Taking account of all the undrained mechanical properties of the soils we arrive at a new premise that soils with constant stress ratio at peak, phase transformation and residual states may be less resistant to liquefaction, and may travel long distances after a slip. The constant stress ratio phenomenon is more likely to be associated with cohesionless soils than cohesive soils.

The pumice soil generated high excess pore pressure at small strains, and by 10 cm shear displacement, pore pressure had almost become equal to the normal stress. The excess pore pressure ratio (u/σ) at residual state approaches unity. This phenomenon is regarded as liquefaction and is consistent with the physical evidence of liquefaction at site during field investigation. The level of destruction appears to support liquefaction as the mechanism of Las Colinas landslide. Liquefied masses do not allow people time enough to evacuate because the soils moving down slope behave like liquids.

The residual strength of the volcanic soil is nearly same as that of poorly graded, fine silica sand but higher than that of pumice. While the volcanic soil required higher strain to mobilize both peak and residual strength, the pumice soil readily liquefied and rapidly reached low residual state. The residual, phase transformation and peak states of deformation appear to lie on the same line that yielded 13 kPa as the value of cohesion. The friction angle at peak, phase transformation and residual states is equal (40°).

The friction angle at residual state is the most important parameter in predicting the potential travel distance of a landslide. The knowledge that the friction angle at the three defined states is equal is therefore a boost in landslide investigation and mitigation because the friction angle at phase transformation or peak stress could be rapidly and conveniently obtained with a simple direct shear box. It therefore means that the line connecting the three stress states defines a critical or threshold state.

Previous publications by the first author have defined the threshold state. The tendency of loose sands to contract at low stress ratios leads to increase in pore pressure. The medium dense and the dense sands also tended to contract first before dilating. Those publications emphasized that for those sands that showed purely contractive behavior the pore pressure ratio at that collapse point (where liquefaction may be initiated) was greater than unity. For those specimens that showed partial contractive behavior the pore pressure ratio was less than unity. In between these two behaviors were those whose pore pressure ratio was unity. At the point of failure, if the pore pressure ratio is less than 1, the soil will dilate leading to a decrease in pore pressure which is equivalent to the apparent increase in volume usually observed in drained. For specimens with pore pressure ratio greater than unity,

the soils fail without any tendency to dilate which corresponds to volume decrease in drained conditions. In contrast, however those specimens with pore pressure equal to unity show no tendency to either dilate or contract, implying no volume change. Because the volume is constant, shearing and shear displacement progressed without any change in shear resistance, effective stress and pore pressure.

Future work includes defining the exact stage in a stress-strain-void ratio space slides readily transform into flow and to carry out laboratory shear tests on completely undisturbed soils at field densities to increase the applicability of test results to real problems. It is hoped that the laboratory tests will be used with in situ measurements to produce a reliable liquefaction evaluation procedure for sandy soils. The behavior of a completely liquefied material should replicate the high mobility of flow phenomenon similar to real liquids in the field. Successful simulation of complete liquefaction in the laboratory or in the field will improve the understanding of the mechanism of dangerous landslides.

Acknowledgments

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Mechanical-Mathematical Modelling and Monitoring for Landslides

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Abstract Mechanical-mathematical model of high viscous fluid was used for modelling of the matter behavior on landslide slopes. Equation of continuity and approximated Navier-Stokes equation for slow motions in a thin layer of the matter were used. The results of modelling give possibility to define the place of highest velocity on landslide surface, that could be the best place for monitoring post position. Model can be used for comparison of calculated and measured velocities of the matter and gives possibility to investigate some fundamental aspects of the matter movement on landslide slope.

Keywords landslides, modelling, monitoring

Introduction

Landslides process is one of the most widespread and dangerous processes in the urbanized territories. In Moscow the landslips occupy about 3 % of the most valuable territory of the city. In Russia many towns are located near rivers on high coastal sides. There are many churches and historical buildings on high costs of Volga River and Moscow River. The organization of monitoring is necessary for maintenance of normal functioning of city infrastructure in a coastal zone and duly realization of effective protective actions. Last years the landslide process activation took place in Moscow.

Landslide motions is extremely actual and difficult problem which decision is necessary for preservation of valuable historical monuments and modern city constructions. There are near 15 places of deep landslides and many shallow landslides in Moscow (Fig.1).

One of landslide sites is on Vorob'yovy mountains, on a high slope of the right coast of the river Moscow . Within the limits of a considered site there is a historical monument of federal value - «Andreevsky monastery», based in 1648. (Fig.2,3,4).

Also there the complex of buildings of Presidium of the Russian Academy of Sciences, constructed in 70 – 80th years of 20-th century (Fig. 4), bridge with station of underground "Vorob'yovy mountains" and a sports complex are located. Landslide slope (Fig. 5) is in an active condition. In June 2007 a rather big landslide took place there near ski-jump (Fig 6).

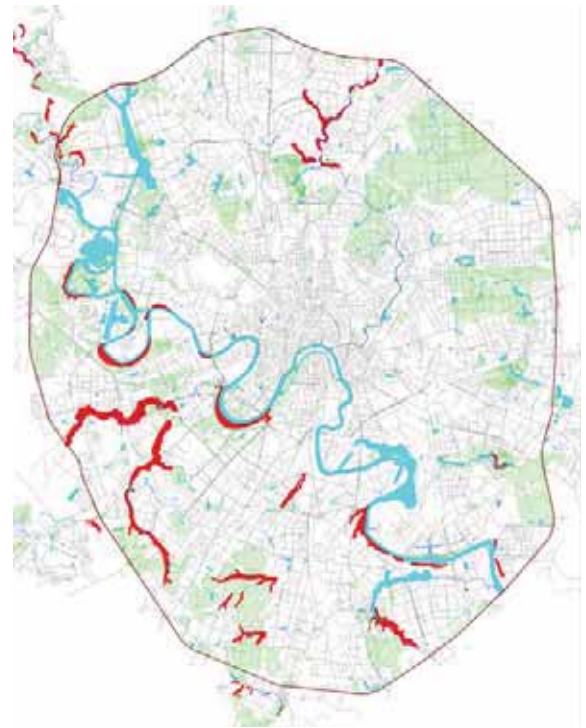


Figure 1. Landslides danger places in Moscow (in red).



Figure 2. Vorob'yovy mountains. Landslide slope.



Figure. 3. Andreevsky monastery and new buildings on landslide slope.



Figure 6. Place of landslide activation near ski jump.



Figure 4. Presidium of RAS, Andreevsky monastery and new buildings on landslide slope.

Another landslide site is in a southeast part of Moscow near museum - reserve "Kolomenskoye"(Fig. 7,8,9). Last serious activation of a landslide has taken place there in 2002.



Figure 7. Museum - reserve "Kolomenskoye". Common view . Landslide slope.

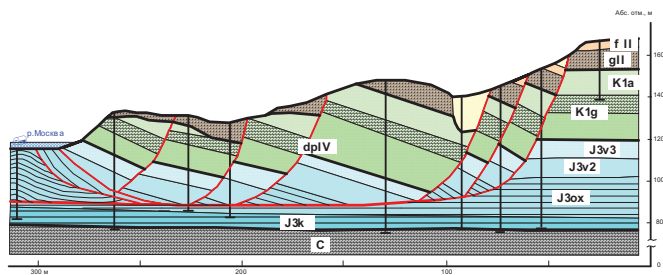


Figure. 5. Schematic cross-section of landslide slope at Vorob'yovy mountains.



Figure 8. Museum - reserve "Kolomenskoye". The church of Beheading of the Honest Head of Iowan Predecessor.

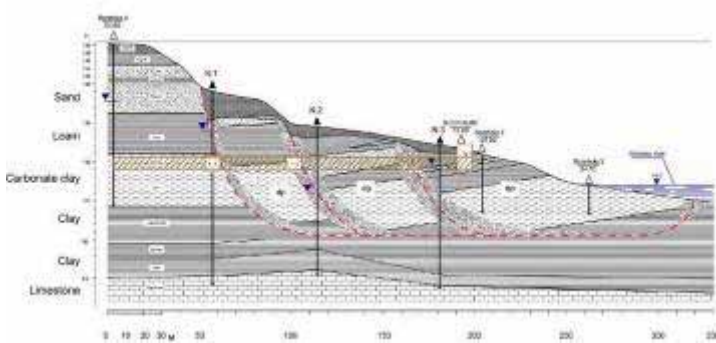


Figure.9. Deep blockslide landslide. Moscow, Kolomenskoye. N.1, N.2, N.3 - extensometers, inclinometers.

Catastrophic activation of the deep blockslide landslide in the area of Khoroshevo on the left-hand shore of the Moskva River at Karamyshevskaya embankment took place in 2006-2007.

Deep landslide activation was in Moskvorechye area in September 2009.

Such complicated situation demands development of new investigations of landslide prone zones. (Osipov et al. 2002, Kutepov et al. 2002, Postoev&Svalova 2005, Svalova&Postoev 2008).

Mechanical-mathematical model for landslide movement

One of the methods of studying of landslide processes is mechanical-mathematical modelling of gravitational movement of the matter on landslide slope. At different stages of the process development the landslide movement can be described by various mechanical and rheological models. At the stage of formation of cracks, losses of stability, break of blocks the models of the elastic medium and model of destruction are applied. During slow movement of soil on the slope the model of high viscous incompressible fluid can be used. Such model allows to calculate velocities of movement in the layer of the matter and to compare them with results of velocity monitoring. Boundary conditions of the problem also depend on concrete situation. So, the condition of sticking is used on the bottom border of the layer in case of slow movement. The condition of sliding or more complex boundary condition is possible on the bottom border, if the process of debris flow, underwater landslip or snow avalanche is considered. The choice of adequate model of the process and statement of initial and boundary conditions are the special mechanical problems.

Our approach is rather close to works of Fathani& Nakamura 2005; Lang&Nakamura 1998; Nakamura& Fathani 2002; Nakamura, Tsunaki & Ishihama 1989; Suzuki 2001; Tsurugaya 2001; De Blasio 2011.

Let's consider movement of landslide masses on the slope as movement of high viscous incompressible fluid described by equation of Navier-Stokes and continuity:

$$\frac{d\vec{v}}{dt} = \vec{F} - \frac{1}{\rho} \text{grad}p + \frac{\mu}{\rho} \Delta\vec{v}$$

$$\text{div } \vec{v} = 0$$

\vec{v} - vector of velocity, F - force of gravity, p - pressure, ρ - density, μ - viscosity, t - time.

Such a model can be successfully used for the lithosphere movements simulation (Svalova 1975) and for soil movements on the slope (Fathani& Nakamura 2005). The problem is to estimate effective viscosity for real matter. It can be done by comparison of calculated and measured velocities of the matter movements.

Let the characteristic horizontal scale of a body of landslip L considerably surpasses its thickness h . We shall count also a landslip extended enough in the plan that allows to consider three-dimensional model as two-dimensional one for sections of landslide bodies. Following works (Svalova 1975, 1992, 1993; Svalova&Sharkov 1992) and applying the method of decomposition on small parameter, it is possible to get the equation of continuity and an approximated equation of the Navier-Stokes in dimensionless form for slow motions in a thin layer:

$$\begin{cases} \frac{\partial P}{\partial X} = \alpha\mu \frac{\partial^2 U}{\partial Z^2} \\ \frac{\partial P}{\partial Z} = -\rho \end{cases}$$

$$\frac{\partial U}{\partial X} + \frac{\partial W}{\partial Z} = 0$$

$$\alpha = \frac{F}{R\left(\frac{h}{L}\right)^3} \quad R = \frac{u_0 L \rho_0}{\mu_0} \quad F = \frac{u_0^2}{gL}$$

P is dimensionless pressure, U,W – dimensionless velocities, F - Frude number, R - Reynolds number, ρ - density, μ - viscosity, ρ₀, μ₀, u₀ - scales of density, viscosity and velocity.

Then it is possible to get the velocities and pressure in the layer:

$$P = \rho(\zeta^* - Z)$$

$$U = U_0 + \frac{\rho}{2\alpha\mu} \frac{\partial \zeta^*}{\partial X} [(\zeta^* - Z)^2 - (\zeta^* - \zeta_0)^2]$$

$$W = W_0 + \frac{\partial U_0}{\partial X} (\zeta_0 - Z) +$$

$$\frac{\rho}{\alpha\mu} \frac{\partial^2 \zeta^*}{\partial X^2} \left[\frac{1}{6}(\zeta^* - Z)^3 + \frac{1}{3}(\zeta^* - \zeta_0)^3 -$$

$$\frac{1}{2}(\zeta^* - Z)(\zeta^* - \zeta_0)^2 \right] +$$

$$\frac{\rho}{2\alpha\mu} \left(\frac{\partial \zeta^*}{\partial X} \right)^2 (Z - \zeta_0)^2 + \frac{\rho}{\alpha\mu} \frac{\partial \zeta^*}{\partial X} \frac{\partial \zeta_0}{\partial X} \zeta_0 (\zeta^* - \zeta_0)$$

ζ₀ - the bottom border of the layer,

ζ* - the top border.

Let on the bottom border the condition of sticking is satisfied:

$$U_0 = W_0 = 0$$

The discharge of matter along the layer is:

$$Q = \int_{\zeta_0}^{\zeta^*} U dZ = -\frac{\rho}{3\alpha\mu} \frac{\partial \zeta^*}{\partial X} (\zeta^* - \zeta_0)^3$$

Since Q=const lengthways X, then:

$$\frac{\partial Q}{\partial X} = 0$$

$$\frac{\partial^2 \zeta^*}{\partial X^2} (\zeta^* - \zeta_0)^3 + \frac{9\alpha\mu Q}{\rho} \left[\frac{3\alpha\mu Q}{\rho} + (\zeta^* - \zeta_0)^3 \frac{\partial \zeta_0}{\partial X} \right] = 0$$

The condition of convexity of upper boundary is:

$$\frac{\partial^2 \zeta^*}{\partial X^2} < 0 \Rightarrow$$

$$\frac{3\alpha\mu Q}{\rho} > -(\zeta^* - \zeta_0)^3 \frac{\partial \zeta_0}{\partial X}$$

This condition enables to analyze the form of the surface of moving matter (Fig. 10).

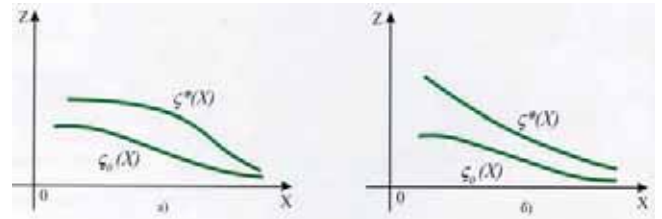


Figure 10. Sketches of dimensionless landslide surface. Various possible forms of landslide ground surfaces: a) - convex, b) - concave.

Structure of clinoforms (convex) can arise, if:

1. Q is large, that is flux is high
2. μ is large. It means that matter spreads bad and can support big angle
3. ρ is small. It means that matter has large specific volume and is friable
4. grad ζ₀ is small, that is angle of lower boundary is small
5. (ζ* - ζ₀) is small, that is thickness of sedimentary layer is small. Under fixed Q it means that velocity of flux is high and formation of clinoformes and even overturning of rockes are possible.

All these conditions seem to be natural enough for explanation of formation of structures such as inflows and clinofolds of sedimentary cover that confirms correctness of the model.

It is important to define the place of maximal velocity on the slope. An optimum place for location of monitoring post is the point of maximal speeds of movement of landslide masses.

Let's consider the massif of sedimentary rocks with the top border ζ^* representing landslide slope. The bottom border ζ_0 is compatible with an axis X. The maximum of horizontal speed U is reached on the top border ζ^* of the massif according to condition:

$$\frac{\partial U}{\partial Z} = -\frac{\rho}{\alpha\mu} \frac{\partial \zeta^*}{\partial X} (\zeta^* - Z) = 0 \Rightarrow Z = \zeta^*$$

Point of the maximal horizontal speed on the surface ζ^* can be found from condition of equality to zero of the first derivative:

$$\frac{\partial U}{\partial X} = 0, \text{ where } U = -\frac{\rho}{2\alpha\mu} \frac{\partial \zeta^*}{\partial X} (\zeta^*)^2$$

From here it is easy to receive the condition:

$$\frac{\partial^2 \zeta^*}{\partial X^2} \zeta^* + 2\left(\frac{\partial \zeta^*}{\partial X}\right)^2 = 0 \quad (1)$$

It is necessary to stress, that $\zeta^*(X)$ is known function - the surface of landslide slope. And the received condition allows to find a point on a slope where speed of movement is maximal.

Let's consider for illustration of the received decision the surface of landslide as (Fig. 11):

$$\zeta^*(X) = -thX + 1$$

It reflexes roughly the form of landslide surface (Fig. 5, 9).

Then the condition (1) gives:

$$th^2 X - thX - 1 = 0$$

Whence we receive $thX = \frac{1 - \sqrt{5}}{2}$ and

$$\zeta^* = \frac{1 + \sqrt{5}}{2} \approx 1,62$$

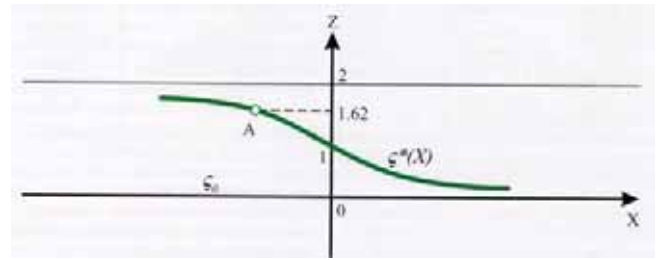


Fig. 11. Sketch of dimensionless slope surface. Point A is the point of maximal horizontal speed of movement of masses on the ground surface of the slope.

Such position of the point of the maximal horizontal speed seems to be real, and more exact data on the structure of landslide and its surface will enable to define such point on a concrete slope. The point of maximum of speed on a slope defines the place of possible failure of a landslide in case of achievement of limiting pressure in massif of rocks.

There could be several points of local maximum of speed on a slope, that characterizes an opportunity of failure of a landslide on each terrace of a slope.

The places of minimum speed can be used for building constructions and oil-gas pipelines. Model velocities of matter can be compared with real velocities, that gives possibility to define the real mechanical parameters of media.

Conclusions

Landslides process is one of the most widespread and dangerous processes in the urbanized territories. The landslide process activation took place in Moscow last years. Such complicated situation demands development of new investigations of landslide prone zones.

Mechanical-mathematical model of high viscous fluid is elaborated for simulation of matter movement on landslide slopes. The results of modelling give possibility to define the place of highest velocity on landslide surface, which could be the best place for monitoring post position. Model can be used for comparison of calculated and measured velocities and estimation of effective viscosity of real matter, that is subject of future research. The results of modelling give possibility to investigate some fundamental aspects of landslide matter movement.

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A Comparative Analysis of Landslide Susceptibility by WAA and SINMAP Model

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Abstract: In order to analyze susceptibilities to shallow landslide occurrence, a modeling of overburden soil depth and rainstorm occurrence is necessary, since both of them are controlling factors in the recurrence interval of shallow landsliding. Landslide hazard zoning mapping is a tool and one way solution to mitigate the landslide disaster. Shallow landslides are one of the most common types of failures occurring frequently in steep slopes, overburden soil, landscapes in different climatic zones. As for the effect of topography that slope angle, slope drainage, vicinity of road and infrastructure, overburden soil depth and geology are important factors for recurrence of shallow landsliding. Data, although insufficient in number, stimulated the debate about the effect of geology and topography on the susceptibility to shallow landsliding. An Analytical Hierarchical Process is applied in order to derive the weights associated with attribute map layers. And based on these weights, GIS datasets are combined by weighted Average Analysis (WAA) and the landslide susceptibility map of the study area created. The resulting information was compared with the landslide susceptibility map derived through the SINMAP model. Both outputs are useful for a better understanding of landslide susceptibility comparatively to a sensitive landslide disaster event and their origins and prioritization of efforts for the reduction and mitigation of future landslide hazards. Sensitivity of the both approaches was fine tuned with the overburden soil strength parameters, geomorphological evidences and field verification techniques.

that extrinsic variables such as human interference in the hill slope areas for construction of roads, urban expansion along the hill slopes, non engineered constructions, deforestation contributes landslide causative factors. A post-storm hazard assessment was conducted by Sri Lanka in 2003, due to torrential rains accompanied by heavy winds had left an estimated 247 dead and over 200,000 families displaced during the month of May 2003. GIS mapping technique is ideally suitable for overall evaluation of regional effects and interpretation of landslide susceptibility analysis which can be interpreted even inaccessible mountainous regions where majority of old landslides were identified.

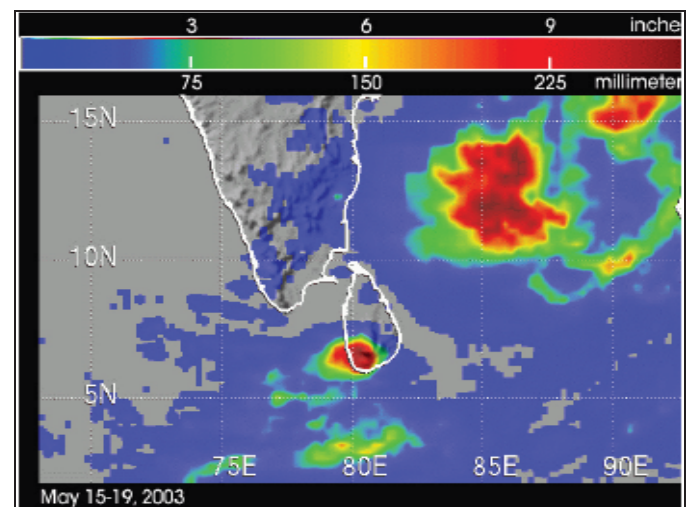


Figure 1: Rainfall patterns from TRIMM satellite observations during 15-19 May 2003.

Keywords: Landslides, AHP, Susceptibility, SINMAP

Introduction

Landslides are one of the major natural hazards that account each year for enormous property damage in terms of both direct and indirect cost. Landslides are defined as movement of a mass of rock, debris or earth down slope, due to gravitational pull, can be triggered by a variety of extrinsic factors such as intense rainfall, earthquake, seismicity, change of ground water, storm waves which causes rapid stream erosion and decrease in shear strength of slope forming materials. In addition to

Sri Lankan Content

Landslide take place on slopes and generally but not always, on steep slopes, where there is already some degree of instability (Cooray, 1994). Hence landslides are commonest in the central hill country of Sri Lanka, which is generally considered to be land over 300m above MSL (Cooray, 1994). The hill country extends from the parallel hill ranges of the Ratnapura and Rakwana areas in the south-west to the Knuckles Massif in the north-east, and includes all the land in between. The areas worst affected by the landslides, and areas where they were commonest

until recent years, were N'eliya, Kegoll, Badulla, Ratnapura, Matale and Kandy (Tissera, NBRO, 1994). Many studies have been conducted to pinpoint the correlation between rainfall and landslide occurrence, in different geological and climatic environments.

In Sri Lanka, Landslides, which are often triggered by intense rains, are responsible for about 3000 casualties and considerable losses to road and infrastructure approximately covering about 10,000 sq km of the hill country(Tissera, NBRO, 1994). Between 1964 and 1991, floods and landslides are reported to have killed about 750 people and to have left about 1.3 million homeless. Sri Lanka is a small tropical island country off India's southern coast with only 18.6 million inhabitants.

In late 80's when information was scanty, the landslide triggering threshold was placed at 200mm of rainfall in a 72 hour period, provided rain in the area continued (Bhandari, et al., 1992) .

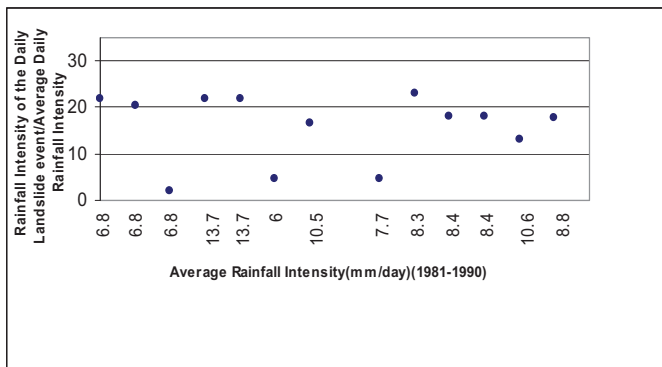


Figure 2: Ratio of the rainfall intensity of the daily landslide event to average daily rainfall of intensity over average daily rainfall intensity (Bhandari & Dias, 1996).

This is mainly because of the preliminary loss of metric suction, intensive rate of water penetration as well as percolation of rainwater and lack of slope protection ingredients in the event of heavy rains (Dias,et.al.,1997). Some of the dynamic appears to be related to the difficulties in modeling of unsaturated boundary condition and the flow through the unsaturated soil (Dias, et.al., 2001).

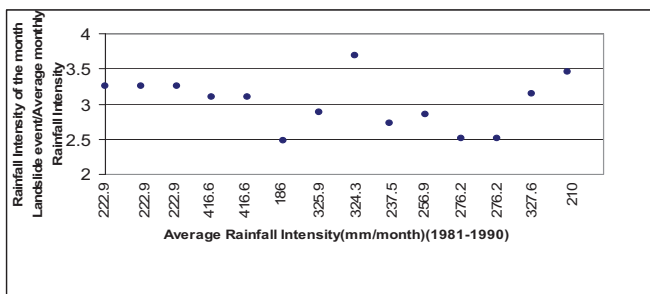


Figure 3: Ratio of the rainfall intensity of the month of the landslide event and average monthly rainfall of the place over average monthly rainfall intensity (Bhandari & Dias, 1996).

The criterion did work only partially, in case of reactivation of recent, seasonally active landslides. A relationship of rainfall records of a very large number of landslides conveys that 24hour rainfall associated with a landslide event was generally 2 to 23 times higher than average daily rainfall of that particular location (Bhandari & Dias, 1996). The month in which a particular landslide event fell attracted 2.5 to 3 times the average monthly rainfall and annual rainfall in the year of a landslide event was found to be 22% to 50% higher than the annual rainfall average (Bhandari & Dias, 1996).

Geologically, Sri Lanka is considered to be of low seismicity (Vitanage, 1994). As in the case of Indian Deccan Plateau around Koyan and Latur, Maharashtra State in India, the most scientists including geologist and engineers in Sri Lanka believed Sri Lanka as an area least likely to be subject to earthquake than predicted to date.

Shallow Landslides and Model Approach

Landslides result from independent or combined effect of spatio-temporal intrinsic and extrinsic variables, including hydrology (rainfall, evapotranspiration and ground water), topography (slopes and ground setting), geology (soil and rock), land use (vegetation surcharge, root strength) and human activities including excavation, trenching and backfilling. Relatively static environmental factors (i.e. elevation, slope, aspect and topographic curvatures) exhibits negligible changes in their state through time, and differ from dynamic factors such as climatic or human activities which tends to alter landslide susceptibility through time. The spatio-temporal differences do exist in both environments. To predict the spatial and temporal pattern of the areas susceptible to landslide, a distribution approach is needed that incorporates varying precipitation intensity, soil depth, vegetation (species, age, density) and root strength.

Over the past several years, a variety of entities have developed GIS-based models for the evaluation of shallow and rapid slope stability using static base slope stability models which includes deterministic assessments and probabilistic approach or both compiled together for the output results. These models, however, have not been rigorously compared or adapted for state-wide application to management and regulation of up country development programme in Sri Lanka. For image interpretation and field mapping of landslides, the use of checklists for standardized data collection is an important, but also time-consuming component (Van Westen, 1993).

Landslide hazard assessment, as defined by Varnes (1984), aims at improving the knowledge of processes that lead to slope instability and, in addition, at identifying the locations where and when landslides or potentially instable slopes may occur. According to Carrara et al. (1998) approaches for landslide hazard assessment can generally be grouped into two main

categories: the direct, qualitative method that relies on the ability of the investigator to estimate actual and potential slope failures and indirect, quantitative methods that produce numerical estimates (probabilities) of the occurrence of landslide in any hazard zone. The choice of the method mainly depends on the spatial scale (Van Westen, 2000) and, thus, the data availability. To assess landslide susceptibility on a regional scale, multivariate statistical approaches were commonly used in the last decades.

SINMAP Model Approach

The shallow landslide usually obeys the infinite slope failure condition which explains the validity. Several shallow landslide models have been developed on the basis of the infinite slope equation. The mathematical models developed by Montgomery and Dietrich (1994), Pack et al. (1998) available for studying shallow landslides, take into account the infinite plane slope stability model coupled with a steady state topographic hydrologic model.

The stability index (SI) is defined as the probability that a location is stable, calculated by considering the most and least favourable situations (i.e. either lower or upper bounds) and the probability that a certain factor of safety may be attained. The factor of safety calculation (FS) in SINMAP is based on the infinite slope form of the Mohr-Coulomb failure law as expressed by the ratio of stabilizing forces (shear strength) to destabilizing forces (shear stress) on a failure plane parallel to the ground surface (Hammond et al., 1992).

$$FS = \frac{C_r + C_s + \cos^2 \alpha [\gamma_s (D - D_w) + (\gamma_s - \gamma_w) D_w] \tan \phi}{\sin \alpha \cos \alpha [\gamma_s D]}$$

The specific catchment area is defined by the ratio of the area that drains into the grid cell to the contour length across the grid cell. For steady saturated flow, lateral subsurface flow may be expressed by the transmissivity (T) along slope (Pack et al., 1999):

$$T \sin \alpha b = K_s D_w \cos \alpha \sin \alpha b$$

where, T is assumed to be constant with depth, b is the flow length, and K_s is saturated hydraulic conductivity. The capacity for subsurface lateral flow is defined by the product of recharge and contributing area:

$$Ra = K_s D \cos \alpha \sin \alpha b$$

where, D is the vertical thickness of soil. Combining 2a and 2b yields an expression for the thickness of the water table:

$$D_w = D \frac{R}{T} \frac{a}{b \sin \alpha}$$

where

- $C = (C_r + C_s) / (h r_s g)$ is the combined (root and soil) cohesion made dimensionless relative to the perpendicular soil thickness.
- $h = D \cos \alpha$ soil thickness, perpendicular to the slope.
- C_r - root cohesion [N/m^2]
- C_s - soil cohesion [N/m^2]
- D - the vertical soil depth [m]
- α - slope angle
- r_s - wet soil density [Kg/m^3]
- g - the gravitational acceleration (9.81 m/s^2)
- R - recharge rate (m/hour)
- T - transmissivity (m^2/hour)
- a - specific catchment area (m^2)
- r_w - the density of the water [Kg/m^3]
- ϕ - the internal friction angle of the soil [deg]

In the FS formula, terrain stability model SINMAP can compute all variables from the topography, except for combined cohesion; C , tan of effective angle of internal friction of soil; $\tan(\phi)$ and wetness index, T/R . The digital elevation model (DEM) and appropriate soil parameters were the fundamental input parameters for the model. For the purpose of detailed calibration of the model, initially the Kalawana division divided in to 10 number of sub watersheds using hydrology extension of the ArcView 3.2. The analysis was further extended by sub dividing to more sub watersheds in old landslide proven areas. The evaluation of the T/R ratio and the combined cohesion (i.e. soil cohesion and the root cohesion) was determined considering supportive landuse pattern of a watershed. The uncertainty of these parameters is incorporated through the use of uniform probability distributions with lower and upper bounds.

Model uses the following assumptions:

1. Shallow lateral subsurface flow follows topographic gradients.

This implies that the contributing area to groundwater flow at any point is given by the specific catchment area (a) defined from the surface topography. To calculate this, the upslope area of each grid cell is taken as its own area and then the area from upslope neighbours that have some fraction draining to it is added. Specific catchment area is then upslope area per unit contour length.

Slope steepness is a major contributing factor to the occurrence of landslides closely related to many other factors including the soil thickness, climate, hydrology, lithology, structure and geomorphic history.

2. Lateral discharge at each point is in equilibrium with steady state recharge R [m/hour].

The sensitivity of clays, the ratio of peak to remoulded strength, is an important factor influencing the behaviour residual soils. The Kalawana area silty sand to clayey sand had only slight to medium sensitivity of soil, and exhibited limited mobility near the toe of the landslide where they flowed. In contrast some cases with high sensitivity (are subject to sudden collapse and mobilization into very rapidly moving landslides.

3. The capacity for lateral flux at each point is $T \cdot h$, where T is the soil transmissivity [m^2 /hour], i.e. hydraulic conductivity [m/hour] times soil thickness, h [m].

High pore water pressure reduces shear strength and is a major mechanism responsible for triggering landslides. Landslides in fine-grained soils triggered by elevated pore-water pressures during heavy precipitation and landslide movement, water rapidly flowed from the main scarp forming ponds on the body of the landslide.

Evaluation of Results

Results from the factor of safety calculations are expressed by a stability index based on values of FS ranging from 0 to > 1.5 . The stability index (SI) is defined as the probability that a location is stable assuming uniform distribution of the soil parameters over their range of values. The classification is divided into 6 classes. Classes 1-3 are for regions that according to the model should not fail with the most conservative parameters in the specified range. These areas have $SI > 1.5$ and $FS > 1.0$. For classes 4-5, the calculated FS is < 1.0 , yet the probability of failure is less than and greater than 50%, respectively. These two classes define a lower and upper limit for ground failure and have SI values 1.0-1.5 and 0-1.0, respectively. Class 6 is unconditionally unstable meaning that the probability of failure within the specified range of parameters is greatest (assumed $> 90\%$ probability). In this case, FS is < 1.0 and $SI = 0$.

Slope Dynamics

Understanding of factors which influence slope stability should be firmly based on the principles of effective stress and the influence of strains and deformations on shear strength. Moreover, the importance of geology, geological history and geological modeling can hardly be overstated (Fookes 1997; Fookes *et al.* 2000; Hutchinson 2001). Conventional stability analyses play a useful but limited role in assessing and managing slopes. For a discussion of

the merits and limitations of conventional deterministic and probabilistic analyses, the more explanations are given in Chowdhury (2000), Duncan (2000) and Chowdhury & Flentje (1999).

Landslide dynamics gets remarkably modulated by interplay of several factors and all related scientific studies must therefore necessarily attempt to co-related cause-effect relationship. (Bhandari & Dias, 1996). Since the advantage of slope movement and piezometric measurements may not always be available, it may often be helpful to co-related rainfall intensities with possible initiation of Riedel shears and other slope surface features particularly in the areas known to be a landslide (Dias & Bhandari, 1996).

Many of the relatively large landslides have their main or lowest slip surface located at or near the interface between soil intact or colluvium and bedrock. This is particularly the case for relatively deep-seated landslides that move very slowly and intermittently and require subsurface monitoring with inclinometers (Chowdhury & Flentje 1998) for the accurate evaluation of stability. Typical average rates of movement range from 0.1 mm per day up to 15.6 mm per day. According to the WP/WLI (Working Party on World Landslide Inventory), 1995, these correspond to velocity ranges from extremely slow to slow. These flows usually begin when the pore pressures in a fine-grained mass increase until enough of the weight of the material is supported by pore water to significantly decrease the internal shearing strength of the material. This thereby creates a bulging lobe which advances with a slow, rolling motion.

This is mainly because of the preliminary loss of metric suction, intensive rate of water penetration as well as percolation of rainwater and lack of slope protection ingredients in the event of heavy rains (Dias, 1997). Some of the dynamic appears to be related to the difficulties in modeling of unsaturated boundary condition and the flow through the unsaturated soil (Dias, et.al., 2001).

Deterministic, or physically based, models are based on physical laws of conservation of mass, energy or momentum. The parameters used in these models can be determined in the field or in the laboratory. Most deterministic models are site-specific and do not take into account the spatial distribution of the input parameters. Models which take into account the spatial distribution of input parameters are called 'distributed models' (Van Westen, 1994). Deterministic distributed models require maps which give the spatial distribution of the input data. The application of deterministic models for the zonation of landslide hazard in larger areas, however, has never seen a more extensive development, due to the regional variability of geotechnical variables such as cohesion, angle of internal friction, thickness of layers, or depth to groundwater. Furthermore, the calculation of safety factors over larger areas involves an extremely large number of calculations, which could not be executed without the use of GIS.

Weighted Average Analysis (Factor Overlay Model) Approach

Landslide susceptible analysis requires validity and prominence of individual factors responsible for the slope instability and that could be used in place of weighted average analysis.

Therefore, in the second method of approach, a number of factor maps were used for the study. These were slope map derived from the DEM, bedrock geology map, landuse map derived from the aerial photos, soil map derived from the average combined cohesion concept (i.e. root cohesion and soil cohesion), derived map of road buffer from slopes, rainfall map and stream density map. Rainfall is the most triggering factor in most slope instability problems in hill slopes. Therefore, hydrological parameters (rainfall and stream density) were considered to obtain reasonably accurate weight for the analysis. Three day cumulative rainfall distribution pattern in a particular watershed and total number of 1st order streams in the watershed were considered. The evaluation of weighted average was made through the Analytical Hierarchy Process (AHP) (Lane, E.F. & Verdini, W.A., 1989).

Factor Prioritizing and Weighted Average Analysis

The Analytic Hierarchy Process - AHP - is a mathematically based process that can be used to prioritize requirements. Its applicability is in the latter portions of the requirements phase, after the requirements are elicited. The requirements will likely have to be organized using a hierarchy such that not just the requirements can be categorized but such that their respective categories can be prioritized as well.

Factor prioritize requirements was made using Analytical Hierarchy Process (AHP) for the Kalawana watershed. In this method, at first for the reason of determining different factors preference and conversion they into quantitative values, is used from valued judgements. In this case, the preference of a factor as compared with the other factor is taken into as a table 1, and then these judgements are changed into quantitative values from 1 to 9.

The areas with highest landslide susceptibility were chosen to be studied in detail from the point view of slopes and directions of slopes. Next prominence was considered as soil properties. The combined cohesion (root cohesion and soil cohesion) and the effective angle of internal friction has considered for the interpretation of weighted average analysis. All other factor such as bedrock geology, landuse, hydrology 1(rainfall), hydrology 2(1st order streams) and road buffer considered as decreasing tendency for the landslide susceptibility quantification assessment. The creation of a digital terrain model showed to be very important for a relevant landslide susceptibility analysis made in larger scale than 1 : 50 000.

Table 1: The preference of factors and conversion they into quantitative values

Preference of a factor as compared with the other	Numerical value
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Intervals between preferences	2,4,6,8

After the valuing of area with regard to seven factors, at present, the values of seven factors classes X are multiplied by derived individual weights for each factor (w₁.....w₇) and then are summed together. Then the total value M₁ for each pixel and the regional model will be derived:

$$M_1 = w_1X_1 + w_2X_2 + w_3X_3 + w_4X_4 + w_5X_5 + w_6X_6 + w_7X_7$$

And with replacing the combined weights (w₁.....w₇) that had been earned previously, the final model was derived:

$$M = w_1X_1 + w_2X_2 + w_3X_3 + w_4X_4 + w_5X_5 + w_6X_6 + w_7X_7$$

Where: M = Susceptibility coefficient

X₁...X₇ = orderly are related to slope, soil, geology, landuse, hydrology 1(rainfall), hydrology 2(1st order streams) and road buffer and, w₁.... w₇ = are the weights related to each X₁.... X₇ factors. M variations from 0 to 1, thereafter 5 number of susceptibility classes were assigned as high values attain high susceptibility landslides.

Study Area

The selected study area mainly belongs to the Kalawana administrative division which belongs to the Sabaragamuwa Province in Sri Lanka. It runs from 6°35'30" To 6°22'20" northern latitude and from 80°38'25" To 80°17'23" eastern longitude.

Klawana is located in the south-western part of Sri Lanka in the province of Sabaragamuwa, the so-called wet zone. A Kalawana main watershed is the area drained by three major tributaries namely Delgoda Ganga, Koswatta Ganga and the Wewa Ganga as shown in the Fig. 4.

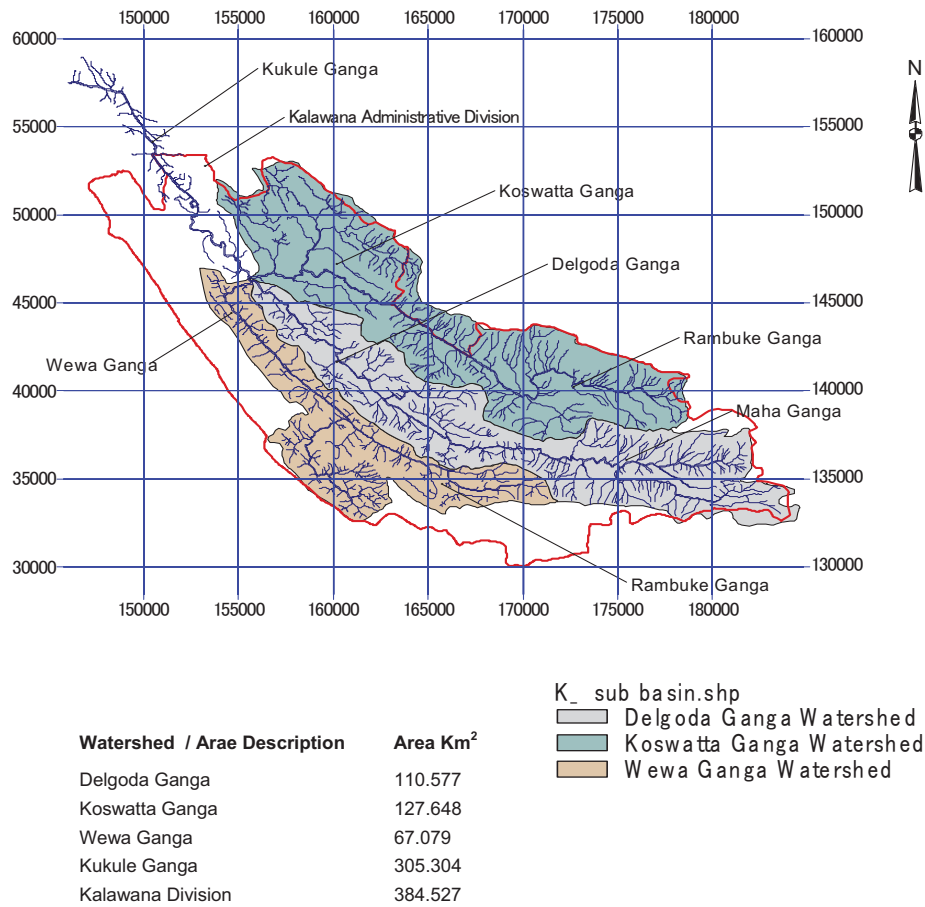


Figure 4: Overall sanction of the study which includes major sub watersheds of the Kukule Ganga main watershed. Three major tributaries are situated within the Kalawana Administrative Division of the Ratnapura District.

Table 2: Landuse Characteristics of the Kalawana Division of Sri Lanka

Landuse	Area km ²	% Area
Rivers	6.20	2.03
Tank	0.04	0.01
Built up Land	0.02	0.01
Homesteads	17.54	5.75
Tea	21.88	7.17
Rubber	6.13	2.01
Coconut	0.04	0.01
Paddy	10.08	3.30
Spars used	86.64	28.39
Other Crop Land	0.95	0.31
Dense Forest	105.93	34.72
Open Forest	20.78	6.81
Forest Plantatio	9.47	3.10
Scrub Land	13.13	4.30
Grass Land	6.11	2.00
Barren Land	0.18	0.06
Rock Outcrop	0.01	0.00

Table 3: Resorce Profile of the Kalawan Divison (DSO, Ratnapura, 2002)

Description	Record with units
Area of Kalawana Administrative Division	385 (Sq km)
Major City Areas	Kalawana, Weddagala & Pothupitiya
Total Population	48201
Building Units	
Housing Units	9673
Total Number of Building Units	10450
Agricultural holdings	
TotHld - Total number of agricultural holdings	9889
Major Hydropower Development Projects	
KUKULE GANGA (High) HP	122 MW
PENTAX (Mini) HP	3.2 MW
ZYREX (Mini) HP	10.0 MW
WESWIN (Mini) HP	2.8 MW

Study Objectives and Method of Approach

The main objective of the study is to identify the area susceptible to landslides with the use of a GIS database. The specific objectives are fall in to two major categories. One, is to use deterministic slope stability model – SINMAP (Stability Index MAP) with due consideration of intrinsic triggering factors of slopes in the region. Secondly, number of extrinsic triggering factors also creates instability of slopes which is difficult to address in analytical modelling. Therefore, Weight Average Analysis(Factor overlay approach) Method was used to incorporate a number of intrinsic and extrinsic factors for the evaluation of areas susceptible to landslides. The schematic diagrams of the approach methodologies are given below in Fig 5 and Fig 6 below.

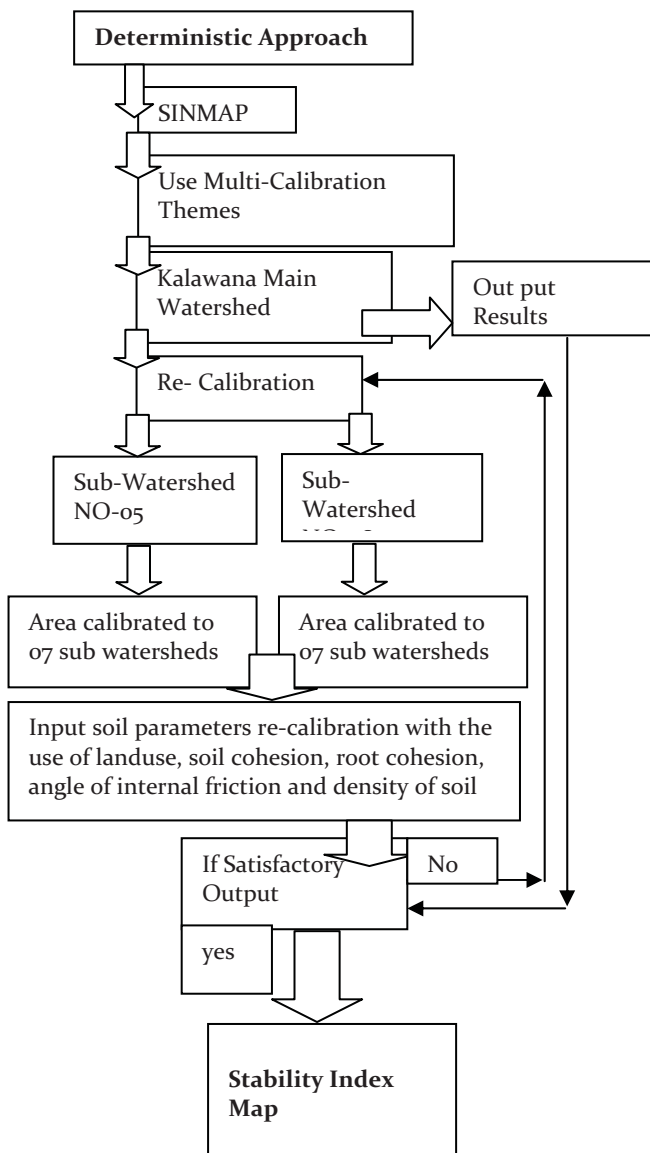


Figure 5: Method 1 : SINMAP model approach for the Landslide Susceptibility Assessment

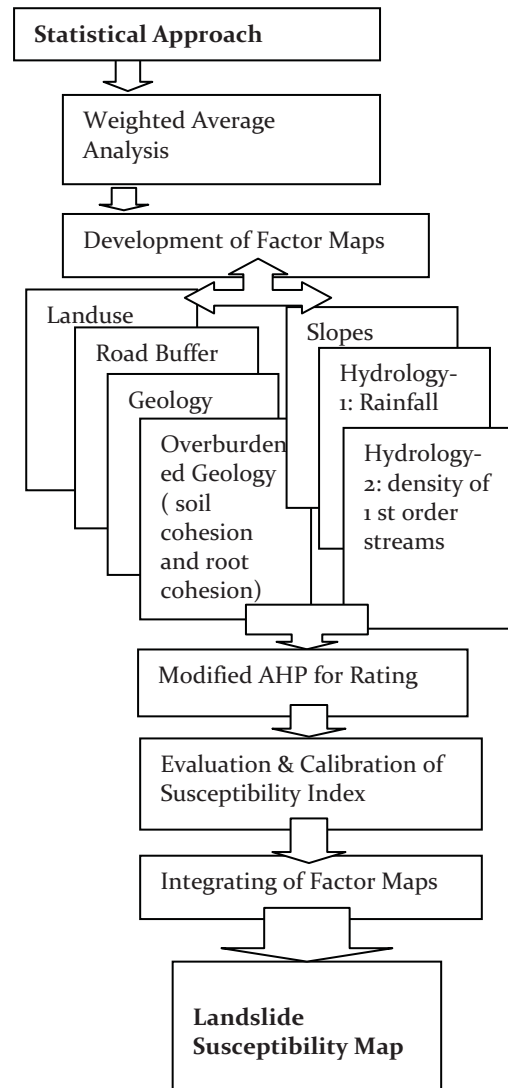


Figure 6: Method 2 : Weighted Average Analysis (Factor Overlay Approach) model approach for the Landslide Susceptibility Assessment

Evaluation of Sensitivity

Steps 1

Kalawana main watershed disintegrated in to ten number of sub watersheds as in the Fig. 7 according to the pattern of stream hydrology and the morphology. It is assumed that each subdivision is showing uniformity of parameters within its own extent. Therefore, stability attributes also showing uniformity within the sub watershed.

Steps 2

In order to evaluate the sensitivity of the both approaches major watershed further expended and evaluated by two separate sub watersheds within the main watershed as in the Fig. 8 and Fig 9.

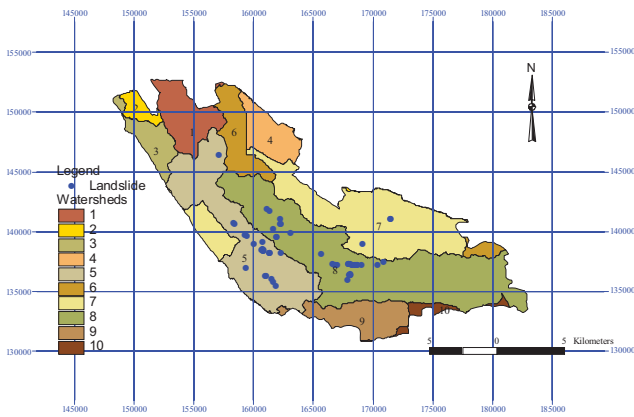


Figure 7: Step 1 analysis: 10 number of sub-watersheds developed by the Hydrology extension of ArcView 3.2 of the Kalawana main watershed

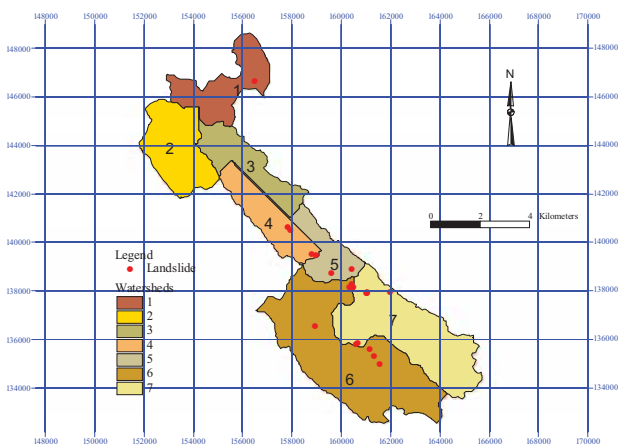


Figure 8: Further sub dividing in to 7 number of sub watersheds of the No. 05 of Kalawana main watershed.

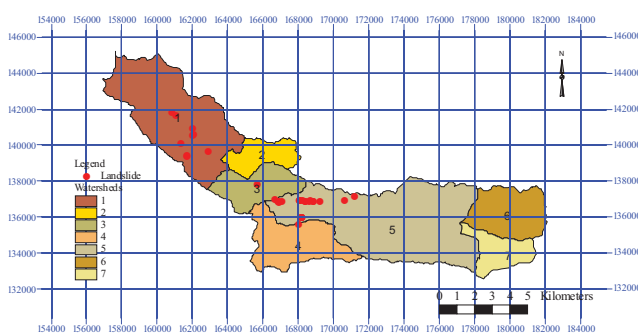


Figure 9: Further sub dividing in to 8 number of sub watersheds of the No. 07 of Kalawana main watershed.

Field Survey & Laboratory Findings

Laboratory tests of soil revealed that liquid limits were in between 27% to 44%. Water content and the plasticity index decreases with the depth. The fine content of soils ranges from 4% to 60%. The dry density increases marginally with depth due to in-situ and completely

weathered rock with an average value of 1.5-1.6 and 1.89 Mg/m³, respectively. The specific gravity of the soil averages from 2.6 to 2.9. Laboratory test for shear strength showed an average effective cohesion, C' , of 6.5 kPa to 15.5 kPa with effective angle of internal friction, ϕ' from 26° to 35°. At shear boundary effective cohesion, $C' = 0$ kPa and effective angle of internal friction, $\phi' = 22^\circ$.



Figure 10: Identification of residual soils formations tested at the CECB Laboratory during the field investigation works



Figure 11: Identification of leaching of minerals in soils at boundaries of the shear

Table 4: Cohesion Parameters for the different Landuse areas in Kalawana Division

Landuse Pattern as at 2003	Soil Cohesion kPa	Root Cohesion with soil moisture kPa
Dense Forest	15.5	12
Forest	12	10
Homestead & Barren	2	2
Paddy	2	0
Plantations	6.5	4
Scrub & Grass	5	4
Water Features	0	0

Table 5: Laboratory measured value of K (or k) saturated hydraulic conductivity (Using Hezen formula) for various residual residual soils

Type of Residual formations	Category	Saturated Hydraulic Conductivity, K (10^3 m/yr)
Clay	Type 5	<0.0001
Silt, clayey	Type 3	0.1 - 0.4
Silt, slightly sandy clay	Type 2	0.5
Silt, moderately sandy	Type 2	0.8 - 0.9
Silt, very sandy	Type 4	1.0 -1.3
Sandy silt	Type 1	1.3
Silty sand	Type 1	1.4

Table 6 : Recommended Effective Shear strength Parameters for the evaluation of landslide Susceptibility using SINMAP

Soil Type	Moist Unit Weight kN/m ³	Saturated Unit Weight kN/m ³	Cohesion Intercept kPa	Angle of Internal Friction Deg.
Type 1 SM	16.5	18.5	5.0	34.0
Type 2 SM	18.5	20.0	6.5	26.0
Type 3 SM	18.5	20.0	0.0	21.0
Type 4 SM	16.5	18.5	15.5	29.2
Type 5 SM / CL	18.5	20.0	6.5	26.0

Results & Discussion

WAA (Weighted Average Analysis)

The state-of-nature attribute maps are well defined under the weighted average technique which explores sensitivity of the geomorphological input parameters such as road buffer, rainfall zones, stream order and overburden geology for the overall assessment. From the resulting weights in the Table 7, the most important influential types of factor maps related with landslide were recognized. Based on the weights assignment landslide susceptibility were categories as no-susceptibility to very-high susceptibility. The final weights of the resulting map ranged from 0.036 to 0.585 or 1. The hazard map was grouped into five simplified categories based on the histogram of the final weight map and sensitivity is shown in the Table 8.

Table 7: Landslide Susceptibility Reclassified Result - Std deviation 1/2 , reduced to 5 classes

Class	Class Lable	Classification	Count
1	0.036-0.146	No Susceptibility	1461669.0000
2	1.146-0.256	Low Susceptibility	719978.0000
3	0.256-0.365	Moderately Susceptibility	861153.0000
4	0.365-0.475	High Susceptibility	615242.0000
5	0.475-0.585 and over	Very High Susceptibility	122367.0000
		total	3780409

Table 8: No of old landslides recorded in the overall analysis

SESCEPTIBILITY	NO OF LANDSLIDES
No Susceptibility	4
Low Susceptibility	2
Moderately Susceptibility	12
High Susceptibility	6
Very High Susceptibility	15
Total	39

With regard to this analysis the Kalawana watershed has been divided to five susceptibility classes:

- 1- 0 M 0.146 No Susceptibility
- 2 0.146 < M 0.256 Low Susceptibility
- 3- 0.256 < M 0.365 Moderately Susceptibility
- 4- 0.365 < M 0.475 High Susceptibility
- 5- 0.475 < M 1 Very High Susceptibility

SINMAP

The analysis fairly well defines the areas that intuitively appear to be susceptible to landslides. It was noted that few landslides occurred on slope that would not normally be recognized as susceptible to landslides. This means that methodology misled classifying several of these sites as being landslide-prone due to the site-specific conditions and inaccurate input parameters. The wetness index is indicated more inaccuracy during preliminary modelling of the area and therefore, re-calibration was made by further subdividing of landslide proven watershed areas of the main Kalawana watershed. The output results were shown in the Table 9 and 10 before and after recalibration. The overall results are shown in the Table 11.

Table 9: Comparisons of SINMAP results of the model after re- calibration of the watershed number 5 of the main watershed (Kalawana Division)

Stability Index (SI) and Class of stability against landslides occurrence	Results of SI of the sub watershed number 05 of Kalawana main watershed before re-calibration of results			Results of the SI after re-calibration of watershed number 05 in to further 07 sub watersheds		
	% Area fall in the stability class	No. of Landslides fall in the category	Density of Landslides LS/km ²	% Area fall in the stability class	No. of Landslides fall in the category	Density of Landslides LS/km ²
Stable	50.1%	4	0.2%	45.6%	4	0.1%
Moderately Stable	7.9%	1	0.5%	6.4%	0	0.0%
Quasi-stable	12.6%	7	0.2%	10.4%	2	0.3%
Lower Threshold	28.1%	3	0.2%	35.0%	8	0.4%
Upper Threshold	1.3%	1	1.4%	2.8%	2	1.3%
Total		16	0.2%		16	0.2%

Table 10: Comparisons of SINMAP results of the model after re- calibration of the watershed number 08 of the main watershed (Kalawana Division)

Stability Index (SI) and Class of stability against landslides occurrence	Results of the SI of sub watershed number 08 of Kalawana main watershed before re-calibration of results			Results of the SI after re-calibration of watershed number 08 in to further 07 sub watersheds		
	% Area fall in the stability class	No. of Landslides fall in the category	Density of Landslides LS/km ²	% Area fall in the stability class	No. of Landslides fall in the category	Density of Landslides LS/km ²
Stable	45.6%	3	0.1%	40.1%	2	0.04%
Moderately Stable	9.1%	2	0.2%	7.4%	0	0.0%
Quasi-stable	12.9%	1	0.1%	11.2%	5	0.4%
Lower Threshold	29.1%	16	0.5%	35.4%	12	0.3%
Upper Threshold	3.1%	0	0.0%	5.0%	3	0.5%
Total		22	0.2%		22	0.2%

Table 11: Overall Results of the Landslide Susceptibility Analysis of the Kalawana Division

RESULTS WAA - Use of Weighted Average Analysis method of assessment model SINMAP- Use of terrain stability model of Stability Index Mapping (SINMAP)	% Area fall in the equivalent stability class according to the susceptibility criteria					
	Sub-watershed number 05 of main watershed		Sub-Watershed number 08 of main watershed		Overall results of the Kalawana Main Watershed	
	WAA	SINMAP	WAA	SINMAP	WAA	SINMAP
No Susceptibility	46.45	45.6	22.07	40.1	38.67	52.49
Low Susceptibility	8.09	6.4	25.53	7.4	18.99	8.90
Moderately Susceptibility	26.29	10.4	25.44	11.2	22.80	12.11
High Susceptibility	15.78	35.0	21.04	35.4	16.30	24.11
Very High Susceptibility	3.39	2.8	5.91	5.0	3.24	2.19

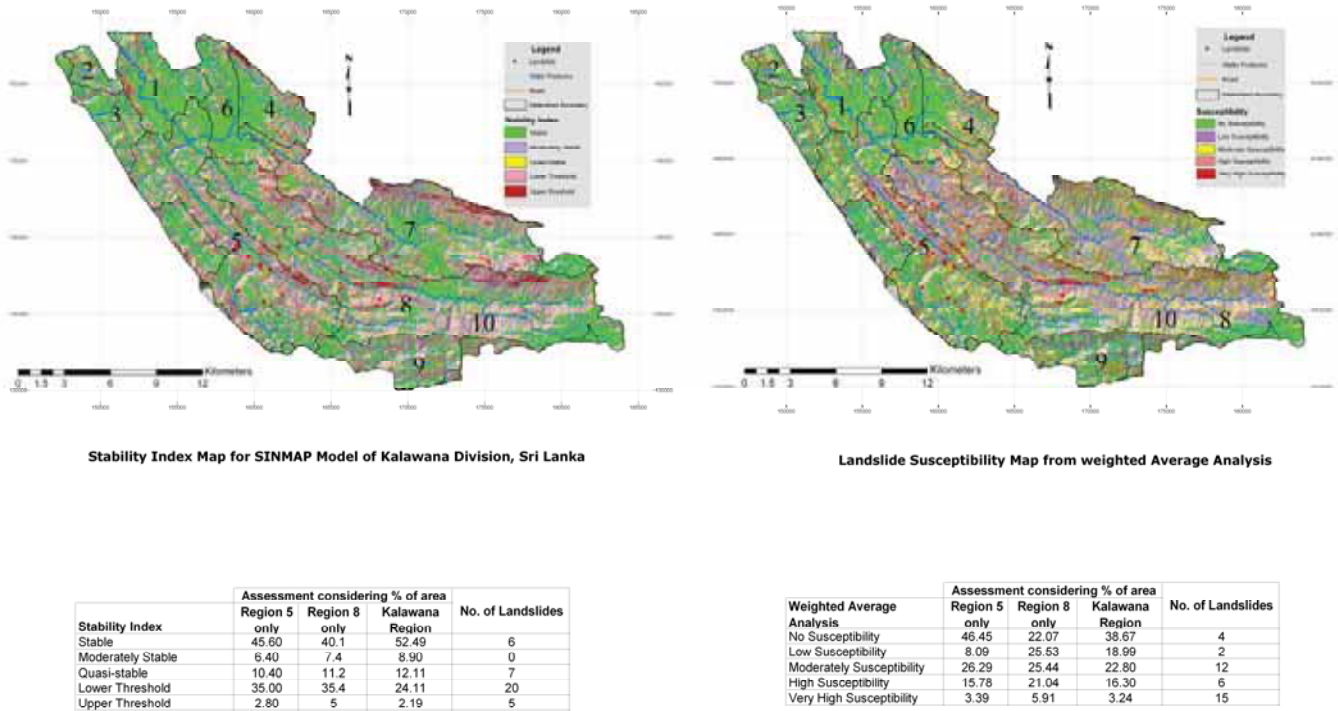


Figure 12: Overall Evaluation of Results of the Landslide Susceptibility Analysis of the Kalawana Division, Ratnapura District, Sri Lanka

Conclusion and Recommendations

The above finding indicates the variability of conceptual models and their relative importance with the input databases. The detailed and comprehensive geographical information databases are required to obtain the statistical interpretation and calibration of the model. Similarly, soil saturation conditions and the validity of wetness indices within a watershed also create another avenue to calibrate the analytical model with the inputs of other soil parameters.

Space technology using satellite and aerial remote sensing plays a very important role in terrain mapping and scientific assessment of the ground conditions. This technology is ideally suitable for inaccessible mountainous regions where majority of old landslides were identified. By using multi-temporal satellite data the areas of landslide every year can be compared with other prediction variables such as altitude, slope, nearness to settlements, road access and grave sites, and the areas most susceptible to landslide in a particular year can be flagged for extra precautionary measures to be taken. One of the critical observations of the study is a lack of complete data base of recent occurrences of old landslides on May, 2003. Only 39 landslides were used out of 78 case records at Kalawana to calibrate models due to inaccessibility at field. Therefore, multi-temporal satellite data may be only solution to overcome such

problems and acquire more geographical information. In landslide study high spatial resolution satellite photo images are recommended. The satellite imagery data allowed generation of high-resolution Digital Elevation Models (DEM). The derived relief parameters can be analyzed in a GIS together with other information obtained from remote sensing data, thematic maps and field observation for a spatially differentiated terrain properties as a basis for further assessment of landslide hazard.

The further study should not be restricted to ALOS, LANDSAT TM and IKONOS data, but there would appear to be great potential in using this and other remotely sensed data, such as airborne radiometrics (Cranfield, 2003, pers. comm.) to map specific ground conditions including the identification of areas of alteration and deep weathering that may be additional predisposing factors for landslides. In the longer-term, such work will serve to inform relevant sectors of local government of the potential risks associated with major land development projects.

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Experimental researches on technical state, design and operation of reinforced concrete anti-landslide structures for seismic dangerous of UKRAINE

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Abstract Intensification of seismic activity in Vranche zone and Black Sea region and on our planet also led to increasing of seismic danger level and, as result, to increasing of relevant landslide provoking factor. Considerable landslide and landslide danger intensification has been a result of these events in seismic dangerous regions of Ukraine (Chernivtsi, Odessa and Crimea Autonomy Republic).

Experimental and analytic researches on technical state of reinforced concrete (RC) anti-landslide structures were carried out by non-destructive methods. Analysis of that state change under influence of constant seismic loads in seismic dangerous regions of Ukraine is carried out too. The results of visual and instrumental surveys are presented in paper.

Keywords: Anti-landslide structure, reinforced concrete, seismic action, water-draining gallery

Introduction

More than 23 thousands of landslides have place today in Ukraine. They are distributed irregular on it territory. More then 9% of Chernivtsi region is affected by landslides. That region is situated on joint of East-European platform edge and Carpathians geosynclinal area. Bukovina territory is affected to tectonic processes and it seismicity is testifying that fact. Local seismic station records 110...130 seismic events early approximately; 70-80% from them are in radius less then 100 km with intensity 2...4 points. The vertical displacements of Earth's crust in Chernivtsi area reach up to 4 mm/year according to data of Ukrainian Geophysical Institute.

Chernivtsi region belongs also to area with intensive pouring rain action. Note: more then 100 mm of water per some hours (sometime 222 mm per some hours) can fall during some rains in Chernivtsi. Therefore the drain galleries are the effective anti-landslide structures on Chernivtsi territory.

Many scientists from all over the world were engaged in the researches and designing of anti-landslide

structures, monitoring and analysis of RC and buildings stress-strain state under influence of extreme loads (seismic factors, pouring rains, vibration etc.) [1-6]. For example, the issues of environmental influence to viaduct state are considered in paper [2] and the issues of designing of the protection systems against extreme events are analyses in report [3]. In the scientific works [4-6] the authors pay attention to the peculiarities of stress-strain state of the RC structures under influence of sign-changing seismic and dynamic loads.

2 Visual and instrumental surveys of water-drain gallery in Chernivtsi

Two-level water-conducting gallery (see fig. 1) for drain of landslide slope in Chernivtsi (fig. 2) is constructed as 2,5 m concrete tunnel with length 1363,68 m.

Gallery was constructed beginning from 1975 and it was erected in 1978. It depth is 25 ... 35 m. Sixty dewatering wells and alone ventilation shaft are provided into water-conducting gallery. These wells have diameter 120 ... 260 mm and they are salted-up practically all.

Research task – selective determination of the concrete compressive strength and parameters of work reinforcing for RC framework ring and water-conducting gallery portals between streets in Chernivtsi.

Methods and test means – Concrete strength determination was carried out by ultrasonic methods according to Ukrainian normative document DSTU B B.2.7-226:2009 «Concretes. Ultrasonic method for strength determination». The parameters of work reinforcing for RC were determined by magnetic method according to Ukrainian normative document DSTU B V.2. 6-4-95 «Magnetic method for determination of concrete protective layer thickness and reinforcement



Fig. 1

arrangement». Ultrasonic tests for concrete were carried out by certified device UK-14PM together with device UPP for surface sounding with measurement base 120 mm.

Essence of ultrasonic method is in correlation dependence between concrete compression strength and velocity (time) for propagation of ultrasonic wave into concrete. Concrete strength is determining according to beforehand prescribed calibration dependence between these parameters. Measurements of ultrasonic wave into tunnel structural RC elements was carried out by method of surface sounding. Transition from velocity of surface sounding to velocity of through sounding was implemented taking into account the transition coefficient K_{Π} ($K_{\Pi} = 1,74$ for applied device).

Gallery consists from two parts disposed in different levels: upper gallery with length ~1060 m and exit to the first street lower gallery with length ~ 260 m and exit to the other street. Both galleries are connected by vertical well with height ~ 12 m. Gallery framework has annual contour and made from precast reinforced concrete rings. Every ring is produced from four tubings elements with ribbed internal surface. Gallery exits are formed as monolithic RC portals (they are filled with pebble) acting as retaining walls.

The gallery framework concrete strength tests were carried out on the sections of side and upper tubings without visible defects (lower tubing is covered by water and slime). Every tenth framework ring was inspected (beginning from the first entry up to 330-th ring) and then was inspected every 30-th ring (due to similarity of device reading, i.e. concrete homogeneity). The tests of portal concrete were carried out on defect-free sections of structure external surface on height from 0,5 m to 2 m. Six measurements were carried out on every section. The tests of the second portal were impossible because of destruction of surface concrete layer.

Calibration dependency “time – strength” prescribed for applied device according to statistic data on the results of comparative ultrasonic and mechanical tests for concrete B 15...B35 grade specimen was used for determination of concrete strength in the test places. Continuous numbering for rings is done from the first entrance into gallery for upper and lower levels separately.

Statistic processing of the test results was carried out for determination of the relevant concrete grade on strength. For that purpose the average values of compression strength $f_{m(n)v}$ were calculated separately on the values of concrete strength in the tested rings

from upper and lower gallery parts and monolithic RC

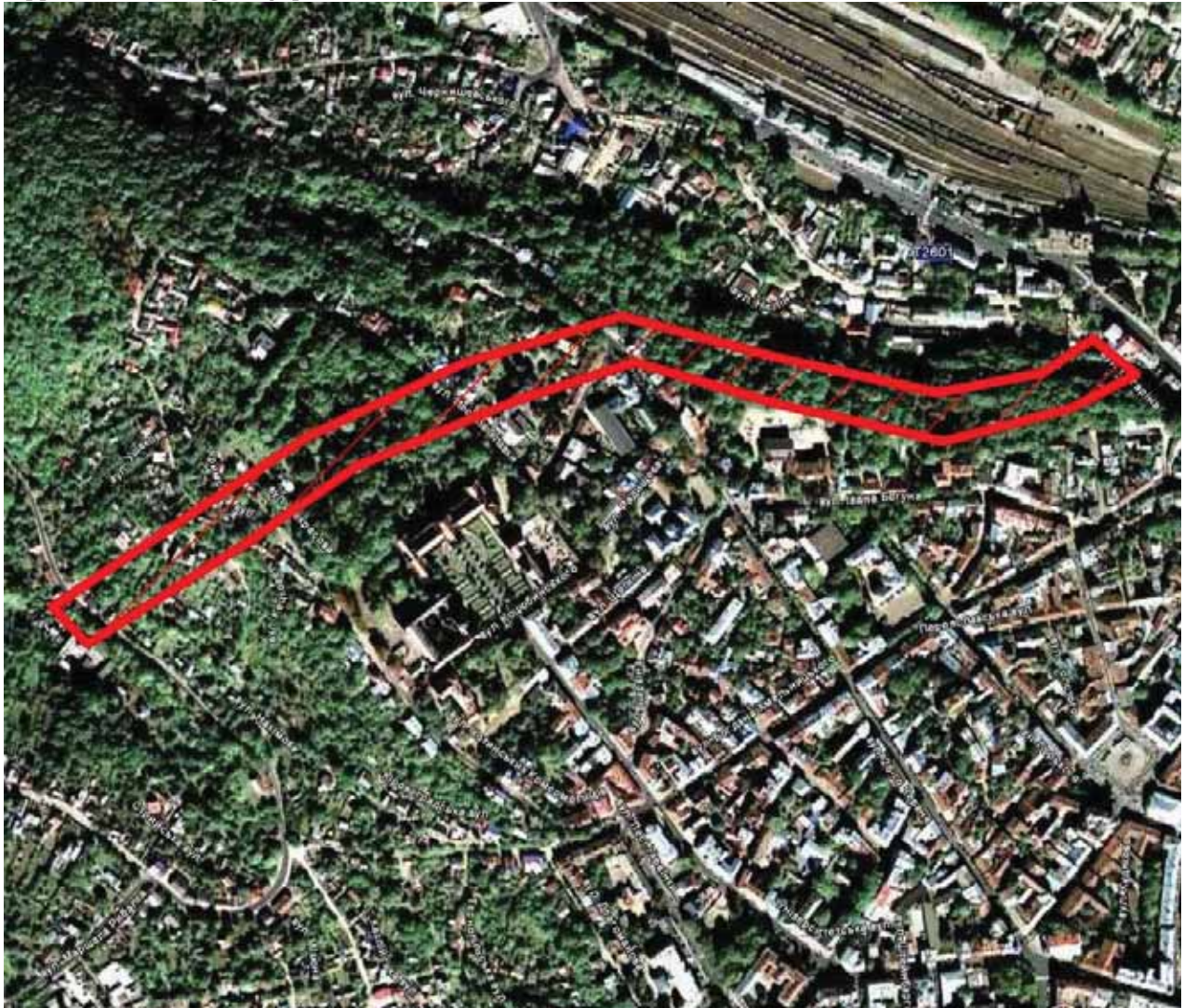


Fig. 2

portal.

Results of the measurement and concrete strength in the test places are presented in tables 1 and 2.

Transverse cracks in the central part of tubings of rings №№ 110, 720, 1110 (it is 5% from all inspected tubings in upper gallery level, see fig. 3, fig 4) were detected during ultrasonic sounding of RC framework of the upper and lower gallery levels. Concrete strength in these tubings is not worse then in other inspected tubings. So we can suppose, a same percent of the upper tubings with cracks would be presented into non-inspected gallery rings. Crack into portal concrete above the first entrance into gallery was detected too.

Table 1 Average results of concrete strength assessment

Table 1 Average results of concrete strength assessment

Disposition of structures	Average strength, $f_{m(n)v}$, MPa	Relevant concrete grade corresponding to compression strength
Upper gallery part (the first exit)	40,8(415)	B30
Lower gallery part (the second exit)	42,3 (431)	B30
Portal (retaining wall) of the first exit	33,0 (337)	B25

Table 2 Results of concrete strength assessment along water-conducting gallery

	Tunnel beginning						
Ring №	1	10	20	30	40	50	60
Concrete strength in side rings, MPa	36,7	35,9	36,9	38,2	39,7	38,0	38,7
Concrete grade of side rings	B25	B25	B25	B25	B25	B25	B25
Concrete average strength (MPa) and concrete grade of side rings	37,7 (B25)						
Ring №	1	10	20	30	40	50	60
Concrete strength in upper rings, MPa	35,4	36,7	35,8	35,7	35,6	37,6	36,9
Concrete grade of upper rings	B25	B25	B25	B25	B25	B25	B25
Concrete average strength (MPa) and concrete grade of upper rings	36,2 (B25)						
	Tunnel middle						
Ring №	90	330	510	720	930	1140	1350
Concrete strength in side rings, MPa	41,7	41,4	41,5	41,3	42,1	40,5	41,1
Concrete grade of side rings	B30	B30	B30	B30	B30	B30	B30
Concrete average strength (MPa) and concrete grade of side rings	41,4 (B30)						
№ кільця	80	290	510	720	930	1140	1350
Concrete strength in upper rings, MPa	40,5	42,1	39,5	41,4	40,8	39,2	40,2
Concrete grade of upper rings	B30	B30	B30	B30	B30	B30	B30
Concrete average strength (MPa) and concrete grade of upper rings	40,5 (B30)						
	Tunnel end (lower level)						
Ring №	1	15	45	75	105	135	165
Concrete strength in side rings, MPa	42,0	41,3	43,8	42,2	44,5	43,1	41,0
Concrete grade of side rings	B30	B30	B30	B30	B30	B30	B30
Concrete average strength (MPa) and concrete grade of side rings	42,6 (B30)						
Ring №	1	15	45	75	105	135	165
Concrete strength in upper rings, MPa	42,2	44,2	41,7	42,2	42,1	43,8	43,9
Concrete grade of upper rings	B30	B30	B30	B30	B30	B30	B30
Concrete average strength (MPa) and concrete grade of upper rings	42,9 (B30)						



Fig. 3



Fig. 4 Iurii Kaliukh & C⁰

Technical Cooperation Project to Develop Landslide Risk Assessment Technology along Transport Arteries in Vietnam

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Abstract: Like other South-East Asia countries, Vietnam is the country with mountainous terrain, complicated geological structure and high rainfall, and as the result landslides occur regularly and seriously on mountainous road network in rainy season. Due to difficulties of economic, lack of the deep knowledge about the phenomena, the activities to prevent and mitigate landslides are not effective. The ODA Project of research cooperation between Japanese and Vietnamese researchers in the years of 2011 to 2012 will not only help Vietnam in education of human resources, research equipment and development a standard system on landslide investigation, monitoring, forecast and early warning but also contribute to disaster prevention and reduction in the future of Vietnam. It can consider this project as a success of a new landslide - training tool in the cooperation with Asia members of International Consortium on Landslides (ICL), especially South-East Asia countries.

Keywords Technical Cooperation, Landslide, Risk Assessment, Transport, Vietnam

Landslides Situation along Transport Arteries in Vietnam

Vietnam is located on the Indo-Chinese Peninsula belonging to the South-East Asia, with the population is 90 million people. The topography of Vietnam is varied depending on the natural areas. Overall, Vietnam is composed of three geographic domain extends from North to South. In which, the North has mountainous terrain concentrated in the Northwest and the Northeast, plus the Red River Delta; the Central has a strip of coastal plain and high mountains called Truong Son mountain range adjoins Laos; and the South's major terrain is the Mekong Delta. The average annual rainfall throughout the country is from 1,200 to 3,000 mm and can reach to 4,000-4500 mm/year in some particular areas in the Central. The average sunshine duration is 1,500 and 3,000 hours/year and the average temperature fluctuate from 5°C to 37°C. Particularly, sometimes the temperature drops to 0° C (at Sa-Pa) or increases to 40-45 ° C (for instant, in Hanoi, Ha Tinh, Quang Binh). Vietnam usually has to deal with typhoons and floods every year, with an average of 7 to 10 typhoons/ year.

In such natural conditions, landslide is one of the most popular natural phenomena occurring on road

network in rainy season in Vietnam, while it is located in extreme climate areas where are impacted by heavy rain, high terrain, strong cleavage and complex geological structure.

Landslide is always one of the most dangerous and damaged natural disaster for transport in Vietnam. It becomes one of natural disasters disturb the most for people life, socio-economic development in Vietnam in rainy season. How to do landslide mitigation and restoration to exiting road and also to the new designed road is the Question. In accordance with the statistics up to 2010 of Vietnam Ministry of Transport (MOT), total length of highways in Vietnam is about 17,500 km, it takes about 8% total length of the country's road network. In which, 3/4 total length of highways is in mountainous terrain. The landslide regular areas concentrate on the routes of north-western mountains and of the Central in Vietnam, with a total length of landslide regular highways over 3,000 km. The annual average volume of landslides caused by typhoons on road network is from 300,000 m³ to 600,000 m³ depends on the number of typhoons hit the land and typhoon intensity. Particularly, the volume of landslides was over 1 million m³/ year during the rainy season of 1999 – 2000.

As statistics of Institute of Transport Science and Technology of Vietnam (ITST) had indicated that there were 400 new landslides appeared in 2005-2008 along new Ho Chi Minh route. To prevent the landslides, over 150 km of retaining wall on this road had been built , but till now, it is seen that landslides have not been controlled on this route. The occurrence of landslides affect to the economic development, interrupt continuous traffic, threaten to property and lives of people and over head, We are being passive to face with this phenomenon.

For more insight into the phenomenon of landslides in general as well as to control and mitigate the loss of this natural phenomenon to the under-operated traffic system as well as the new projects in a mountainous area, ITST has coordinated with the ICL to make a propose of a technical cooperation project and has been the Japanese government approved and supported. This project also gets concern of scientists and professionals in Vietnam. The name of project is "Development of Landslides Risk Assessment Technology along Transport Arteries in Vietnam. Overall objective of project is to socially implement the developed landslide risk assessment technology and early warning system will contribute to

the safety ensuring of transportation arteries and residents in mountainous communities in Vietnam.

Overview of the Technical Cooperation Project

There are two objectives of Project that are desired including short-term and long-term objectives. The short-term/directly objective is to develop the landslide risk assessment technology to reduce disasters caused by landslides on transport arteries throughout the joint research based on experimental technology from Japan and human resources development to effectively technology implementation in Vietnam. The long-term/indirect objective of the project is to socialize developed landslide risk assessment technology and early warning system to not only ensures transport arteries operation but also mountainous resident areas in Vietnam.

The technical cooperation project is planned for five years from 2012 to 2016 with four components corresponding to four working groups (WG). They are the WG₁ for integrated research, education, development of human resources, announcement and information spread; WG₂ for wide-area landslide mapping and identification of landslide risk area; WG₃ for development of landslide risk assessment technology based on soil testing and computer simulation; and WG₄ as Risk for evaluation and development of early warning system based on landslide monitoring.

Development of Landslide Risk Assessment Technology and Education

Major outputs of the project are (1) the application guidelines of landslide-risk-assessment technology developed by activities of WG₂, WG₃ and WG₄; (2) the staffs' education and capacity enhancement by the project; (3) publishing reports and papers on landslide-risk-assessment technology; and (4) spreading information and outputs of the project.

The main activities of WG₁ include:

(1) Preparation of integrated guidelines for the application of developed landslide-risk-assessment technology based on the activities of WG₂, WG₃ and WG₄;

(2) Education and human resources development throughout the training courses of Master (for 2 years) or Doctor (for 3 years) at Kyoto University, Tohoku Gakuin University, University of Shimane Prefecture, Shizuoka University and Gunma University with an accumulate duration of 12 years;

(3) Organization study tours in Japan for 2 – 3 weeks to researchers and engineers work in the project;

(4) Lecturing and awareness spread on landslide risk assessment technology for those who concern in Hanoi and study sites of the project;

(5) Holding workshops and seminars in Vietnam and Japan to spread project results, as well as publications.

Wide-area Landslide Mapping and Landslide Risk Identification

The major outputs of WG₂ activities are (1) identification of terrain changes in survey area by terrain characters identification, terrain specific knowledge of slope and geological structure forecast for respective area; and (2) identification of landslide scale and moving direction as well as geological structure evaluation, forecast of landslide's origin and process in the future and landslide mapping.

There are four proposed activities of WG₂, including:

(1) Identification of previous landslide sites from air and satellite photos;

(2) Identification of the precursor stage of landslides by the pattern analysis of digital surface model (DSM) of forest cover and others;

(3) Formation of landslide risk map based on detailed field investigation and analytical model such as Analytical Hierarchy Process method (AHP); and

(4) Development of the technology to visualize the feature of landslide.

Soil Testing – Computer Simulation of Landslide Initiation and Motion

Simulation of landslide development process is implemented in the lab and that can be active through WG₃ activities. They are:

(1) Development of untrained dynamic-loading ring shear apparatus; and

(2) Elucidation of the initiation mechanism and the dynamics of post-failure motion of the targeted landslides and development of hazard assessment technology of the precursor stage of landslides.

Landslide Monitoring and Development of Early Warning System

Major outputs of WG₄ are desired including 2 items: (1) Landslide condition to which conclusion on signals and warning about beginning and ending of landslide based on monitoring of moving speed, water column pressure and rainfall and (2) Condition of surface deformation to which Condition of surface deformation based on the measurement of moving speed over time, the depth of the sliding surface, the relationship between shear strain and the factors made sliding surface (including pore water pressure with the location of surface and pore water ultimate pressure related to instance and rainfall).

The main activities of WG₄ include:

(1) Selection of pilot area for landslide monitoring based on the field investigation;

(2) Drilling at site for Samples to make test of mechanical and physical indicators of soil; Slide surface assessment, measurement of groundwater table, and

installation of groundwater monitoring equipments;

(3) Development of the integrated automatic monitoring system for rainfall-groundwater-slope movement; and

(4) Establishment of early warning system suitable for the region based on the landslide experiment on natural slopes with artificial rains.

The Importance of the Project to Vietnam

The landslide risk assessment technology developed throughout the project is purposed to reduce disasters caused by landslides on transport arteries is developed by joint research based on experimental technology from Japan and human resources development to effectively use the technology in implementation in Vietnam. The landslide risk assessment technology, including zoning of areas at landslide risk, monitoring of sliding block movement and simulation of the landslide formation and development, is a key platform in the landslide risk assessment and management system. This technology is the basis for the system to predict the risk level, decide whether or not and make the reasonable control measures to minimize for the unacceptable risk level. The evaluation which supplied by the system will help the management to have full awareness on landslide risks of and make appropriate decisions, including budget distribution planning for landslide treatment before the disaster actually occurred, thus it contribute to reducing the loss of human, economic and other negative impacts on society caused by landslides.

The technical cooperation project is a good opportunity for Vietnamese scientists to access to advanced technologies from Japan and enhance technical human resources to protect infrastructure systems. That is the basic step to contribute in socialization of development of landslide-risk-assessment technology and early warning system to ensure transport arteries and mountainous resident areas in Vietnam in the future.

Conclusion

Vietnam is the country on the coastal area of Pacific Ocean. Due mountainous terrain, complicated geological structure and high rainfall, landslides occur regularly and seriously on mountainous road network in rainy season. Though Vietnamese economic condition recent years is difficult, the Vietnamese government have paid attention and investment to landslide researches, contributing to landslide restoration, mitigation and prevention on road network but it seem insufficient. In such situation, the ODA Project by Japanese government in the years of 2011-2016 will help Vietnam in human recourses education, in equipments and standard system on landslide investigation, monitoring, forecast and early warning, contributing to disaster prevention and reduction of Vietnam in the future. Beside this, the contend as well as aplying method of the project is considered as a success of a new landslide teaching tool in cooperation with Asia

members of ICL, especially South-East Asia countries including.

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Identification of rainfall-induced shallow landslides on mountain terrain

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Abstract Rainfall-induced Landslide is a major hazard that often occurs in mountain terrain of the world during or after heavy storm. Identification of landslide susceptible area on steep, mountain terrain is essential for forest management. TRIGRS model was used to simulate the landslides that occurred in Mt. Umyeon on July 27, 2011. Model parameters were derived from field investigation and the previous research. Model performance was also evaluated by comparing the simulation results.

Keywords Landslides, TRIGRS, Mt. Umyeon, Mountain Terrain

Introduction

Rainfall-induced Landslide is a major hazard that often occurs in mountain terrain of the world during or after heavy storm. It poses significant threats to human and property by slope failure and associated debris flow. Landslides are responsible for about 17 per cent of all fatalities from natural hazard around the world (Cred, 2006). Landslide is characterized by the shear failure of slope plane that occurs along the shear plane in steep terrain. The failure can be developed when the shear stress exceeds the resistance of soils by either natural or anthropogenic causes. Intense rainfall is a major trigger factor of shallow slope failure in mountain areas of Korea. A recent example of landslide is the Mt. Umyeon landslides in Seoul, which were triggered by the July 27, 2011 storm event.

Predicting landslide prone area is essential for forest management. Recently, a variety of approaches have been developed to assess slope instability and to identify landslide susceptible areas. Empirical or statistical techniques generally are applicable to predict landslide susceptibility at regional scale, while process-based approaches are used at local scale. A process-based model can calculate the index of stability, a well-known safety factor, based on geotechnical mechanism that control slope failure. Statistical approach can assess qualitatively to landslide propensity by measuring the correlation of dependent variables that have led to landslide occurrence in the past. This qualitative analysis is empirical in nature and hence there are limitations to extrapolation beyond

the applied site that employed to collect data (Dietrich et al. 2001). However, deterministic approaches provide the quantitative and direct judgment for detection landslide prone areas, resulting in the calculation of factor of safety

A number of process-based models have been developed during last few decades. Some are SHALlow Landsliding STABility (SHALSTAB, Montgomery and Dietrich, 1994), Stability Index MAPping (SINMAP, Pack et al. 1998), Transient Rainfall Infiltration and Grid-based Regional Slope-stability analysis (TRIGRS, Baum et al., 2005). There are meaningful differences in model structure and methodology between models. But, each model has advantages and limitations in simulating landslide initiation and development.

Most of process-based approaches do not capable of simulating the magnitude and location of failure that might occur on a watershed scale. And, these approaches cannot be used to directly for assess the consequences of slope failure such as the timing and volume of landslide generated sediment unless the models incorporated with run out model. It provides the best quantitative information on landslide hazard that can be used directly in the design of engineering works, or in the quantification of risk. Detection of unstable slope can be achieved by computing a safety factor for a given area. The models require a large amount of detailed data, such as soil thickness, soil strength, slope geometry, and hydraulic properties of soils, which are typically derived from laboratory tests and field measurement.

In this study we employed TRIGRS model as the model environment to predict temporal and spatial development of landslide. TRIGRS was widely applied around world, for example, United States (Baum et al. 2005), Switzerland (Cannata et al., 2010), Italy (Salciarini et al. 2006), as well as Korea (Kim et al. 2010). Comparative analysis was conducted to evaluate model performance in terms of landslide prediction.

The 2011 Mt. Umyeon landslides

Site description

Umyeon mountain is located in downtown of Seoul, Korea. The height of mountain is about 312.6 m above the sea level, and has steeper slope. It has a main ridge formed from the northeast to the southwest, including six

valleys perpendicular to the main ridge. Most of the area consists of lacustrine biotite gneiss. The water ground seems to be high because six mineral springs are located at the altitude of 220 to 250 meters on the slope

More than 80 percent of the area is covered by a broadleaved forest, which are dominated with Mongolian oak (*Quercus mongolica* Fisch. Ex Ledeb.), Sawthooth oak (*Quercus acutissima* Carruth.), and Asian black birch (*Betula davurica* Pall.). Coniferous trees, such as Korean pine, needlew fir, and Rigida pine have been planted around 1960–1970s and partially present around the foot of the mountain.

Tree root characteristics around landslide initiation spots were thought to have a heart-shaped or tap-root. Root system appears to distribute in all direction and penetrate into deep soil layer. It affects positively in development of landslide on forests.



Photo 1. The 2011 Mt. Umyeon Landslides, Seoul, Korea.

Landslides inventories

A field survey showed that a total of 140 slope failures and associated 33 debris flows developed in Mt. Umyeon on July 27, 2011, as shown in Figure 1. These landslides occurred mainly between 15° and 40° slope and most frequently in 29°.

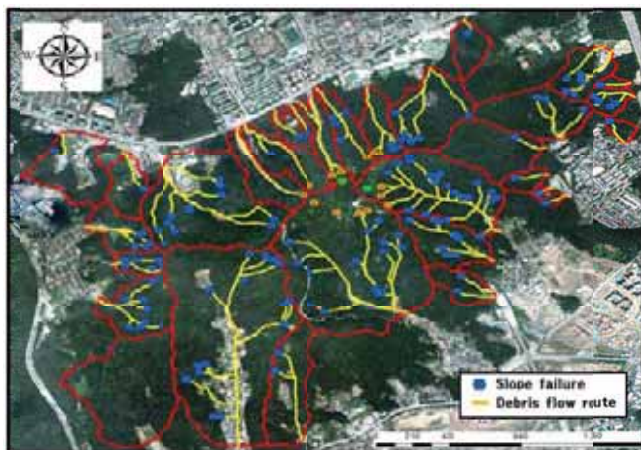


Figure 1. Mt. Umyeon Landslides on July 27, 2011.

Heavy rainfall associated with the passage of the Typhoon Kompasu in 2010 caused a few landslides on Mt. Umyeon, but these slope failures were not strongly related to the 2011 landslides. In 2011, Typhoon Meari hit to Korea during June 22–27, 2011, and produced much more rainfall around Seoul.

A field survey showed that the distance of debris movement ranged from 98 to 1,365 m, with an average of 448.8 m. The averaged volume of landslides was estimated to be about 116.7 m³, ranging from 1.1 to 1,914.8 m³ (KSCE, 2012, unpublished).

Modelling Landslide Initiation

TRIGRS model

Forest hillslopes are characterized by steep topography, shallow forest soil, and vegetation, which have different hydrologic and geo-mechanical conditions both in function of space and time. TRIGRS model (Baum et al., 2002) was implemented in this study as a core of modelling framework, because the model has been widely applied for simulating the timing and distribution of shallow landslides in mountain areas (Kim et al., 2010).

TRIGRS is a computer program to simulate infiltration, subsurface flow of storm water, runoff, and slope stability in order to calculate the effects of rainfall characteristics on the stability of slopes over large areas (Baum et al., 2002). It was originally developed based on the hydrological, geotechnical method proposed by Iverson (2000) to simulate transient pore pressure, responding to vertical infiltration. Baum et al. (2002) have extended Iverson's method by adding a solution for an impermeable boundary at a certain soil depth to predict shallow landslide in time and location that occurs when the soil is wet enough. They extended the model by adding a simple runoff routing technique to transport the excess water where rainfall exceeds the infiltration capacity of the soil.

In TRIGRS, failure of an infinite slope is modelled by the ratio of resisting basal Coulomb friction to gravitationally induced downslope basal driving stress.

The model requires the cell-based input data, such as rainfall intensity, slope, soil depth, initial groundwater table, hydraulic conductivity, hydraulic diffusivity, cohesion and internal friction angle for effective stress, and unit weight of soil

Rainfall input

Rainfall was considered as the most influencing factor for landslide occurrence. The site was subjected to the extreme storm occurring over July 26–27, 2011, with a total rainfall of 364.5 mm and maximum 1-hr rainfall of 68.5 mm/hr, measured at the Seocho station (Figure 2). A total of 140 landslides were triggered by the severe storm event, as shown in Figure 1.

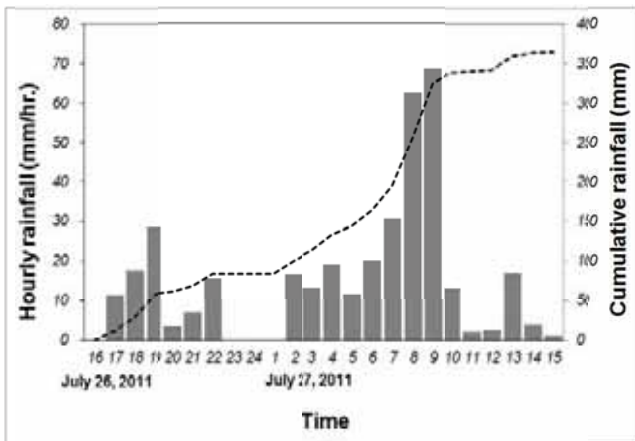


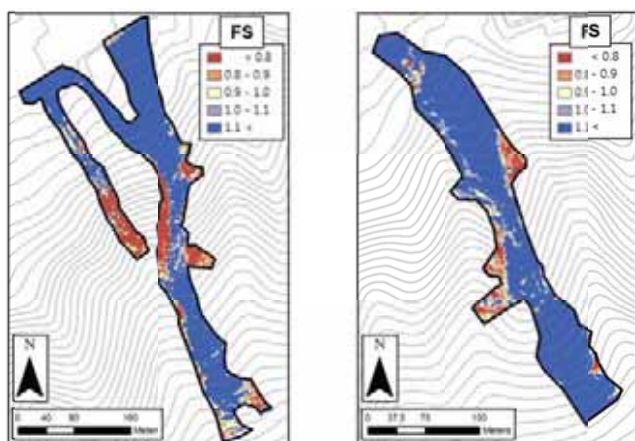
Figure 2. Hourly rainfall data over the storm.

In addition, high resolution DEM data, soil information that derived from comprehensive field measurements, and soil depth data were used as input of model application.

Model performance

TRIGRS model was applied to evaluate model performance by assessing the effect of transient rainfall infiltration on the landslide triggering over the study site. The model was employed to figure out the pore pressure variation and associated stability for each grid cell during the extreme storm condition on the July 26-27, 2011.

Simulated values of Factor of Safety (FS) for each grid are depicted in Figure 3. Figure 3 presents the change of FS values simulated by TRIGRS model after rainfall. The FS values were also compared against the landslide sites that were triggered by the storm on the July 27, 2011.



(a) The Raemian area (b) The Dukwoam valley
Figure 3. Landslides simulation over July 26-27, 2011.

Conclusion

Rainfall-induced landslide is a major hazard in all geographical regions of the world. In this study, modelling effort has done to quantitatively examine the geo-engineering processes of landslide development in

mountain terrain. Transient Rainfall Infiltration and Grid-based Regional Slope-stability (TRIGRS) model was employed in this study as the modelling framework. TRIGRS was originally developed to assess time-dependent rainfall infiltration and slope stability.

Landslide simulation has conducted to explore the timing and location of unstable slope. The Mt. Umyeon in Seoul, Korea, damaged by an extreme storm on July 27, 2011, was selected for simulation. In the selected area, the storm with total rainfall amount of 307 mm caused 140 shallow and translated landslides during or after the storm.

Results of modelling efforts demonstrate that the TRIGRS model has the potential to simulate well the landslide initiation and development induced by heavy rainfall. However, model performance is strongly related to spatiotemporal variation of information, such as rainfall, soil, and geology. Future work is also needed to consider the effect of vegetation on landslide occurrence.

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