Hazard mapping of earthquake-induced landslides of pyroclastic fall deposits

*Masahiro Chigira[1], Takehiko Suzuki[2]

1.Disaster Prevention Research Institute, Kyoto University, 2.Tokyo Metropolitan University

Earthquake-induced landslides of pyroclastic fall deposits are special because they occur on gentle slopes and are highly mobile with long runout distance; even one landslide could have hundreds of fatalities when it occurs in a populated area. We have been examining such landslides induced by 6 earthquakes in Japan and one in Indonesia with field surveys, and here summarize their geological features to establish a methodology of their hazard mapping. Those landslides were induced by the 1923 Kanto earthquake, 1949 Imaichi earthquake, 1968 Tokachi-Oki earthquake, 1978 Izu-Oshima-Kinkai earthquake, 1984 Naganoken-Seibu earthquake, 2011 Tohoku earthquake, and 2009 Padang earthquake, Indonesia. These case histories strongly suggest that pumice deposits and a clay mineral, halloysite, are very susceptible to earthquake shaking. Stratigraphic horizons of sliding zones of previous earthquake-induced landslides of pyroclastic fall deposits are mostly specified for the cases we studied, so their distribution would be the first criteria for the hazard mapping of this type of landslide. Landslides of pyroclastic fall deposits have occurred repeatedly by earthquakes in a certain area until unstable beds are removed, so we need to consider the potential of earthquake-induced landslide is high in an area with buried pumice fall deposits at least where previous earthquakes induced such type of landslides. Another important factor of potential landslide sites is undercutting of pyroclastic fall deposits with mantle bedding. Undercutting could occur by natural erosion as well as artificial cutting, so its condition would change and make new unstable slopes against earthquake shaking.

Keywords: Pyroclastic fall deposits, Landslide, Earthquake, Hazard mapping

Post shear behavior of pyroclastic fall deposits and landsliding phenomena during the 1949 Imaichi earthquake

*Gonghui Wang[1], Masahiro CHIGIRA[1], Takehiko SUZUKI[2]

1.Disaster Prevention Research Institute, Kyoto University, 2.Tokyo Metropolitan University

Landsliding phenomena occurring on pyroclastic fall deposits during earthquake had been widely reported. Some of them are in small scale but very catastrophic due to their rapid post failure movement. For example, the Hanokidaira landslide triggered by the 2011 Tohoku earthquake had replaced the debris of about 100, 000 m^3 and killed 13 people. The 1949 the Imaichi earthquake with a magnitude of 6.4 had also triggered more than 80 landslides (Morimoto, 1951), resulting great damages to local properties and lives. However, the initiation and movement mechanism of such kind of catastrophic landslides had not been fully understood. In this study, we surveyed some typical landslides triggered by the 1949 Imaichi earthquake, and examined the geological features of these landslides. We also took samples from the field and kept them in natural moisture state by putting them in plastic bags. We sheared them in both natural moisture state and fully saturated state under undrained or natural drained condition. We did not dry the sample in all the tests to avoid the possible change in clay mineral (halloysite). Our test results showed that all these samples had their residual shear resistance lowering to a very small value with progress of shearing after failure, indicating that the landslide occurring on this kind of pyroclastic fall deposits can suffer from rapid movement. The lower permeability of the sample retarded the dissipation of high excess pore-water pressure generated with the shear zone and then would enable the long runout of the displaced materials. The initiation process of the samples also indicated that strong ground motion during the earthquake would be the prerequisite and the strong ground motion might have resulted from the nonlinear site response features of unsaturated soil layers.

Keywords: earthquake, fluidized landslide, tephra, pumice

Revisit the classical Newmark displacement method for earthquake-induced wedge slide

*CheMing Yang[1], HuiYun Cheng[1], WenJie Wu[1], ChangHsuan Hsu[1], JiaJyun Dong[1], ChyiTyi Lee[1]

1.Graduate Institute of Applied Geology, National Central University, Taiwan

Newmark displacement method has been widely used to study the earthquake-induced landslides and adopted to explore the initiation and kinematics of catastrophic planar failure in recent years. However, surprisingly few researchers utilize the Newmark displacement method to study the earthquake-induced wedge slide. The classical Newmark displacement method for earthquake-induced wedge sliding assumed the wedge is rigid and the vertical acceleration, as well as the horizontal acceleration perpendicular to the sliding direction, is neglected. Moreover, the friction coefficients on the weak planes are assumed as unchanged during sliding. The purpose of this study is to test the reasonableness of the aforementioned assumptions. We design the geometry of the wedge and input the synthetic seismicity to trigger the wedge slide. This study uses Newmark displacement method to evaluate the influence for neglecting the vertical acceleration of ground motion firstly. This study uses Newmark displacement method incorporating the rigid wedge method (RWM) and maximum shear stress method (MSSM) to evaluate the influence of wedge deformation. The influences for neglecting the horizontal (perpendicular to the sliding direction) acceleration that incorporating RWM and MSSM are both assessed. In addition, the effects of asymmetric wedges incorporating RWM are also evaluated for neglecting the horizontal (perpendicular to the sliding direction) acceleration. Besides, this research incorporates the velocity-displacement dependent friction law in the analysis to evaluate the influence of constant friction coefficient assumption. Results of this study illustrated that the aforementioned assumptions have significant effects on the calculated permanent displacement, moving speed, and failure initiation. To conclude, this study provides new insights on the initiation and kinematics of an earthquake induced wedge slide.

Keywords: earthquake-induced landslide, wedge slide, Newmark displacement method, rigid wedge method and maximum shear stress method, velocity-displacement dependent friction law

Temporal changes in debris flow characteristics and topography in a debris-flow initiation zone in Ohya landslide, Japan

*Fumitoshi Imaizumi[1], Yuichi S. Hayakawa[2], Norifumi Hotta[3], Haruka Tsunetaka[4], Satoshi Tsuchiya[1], Okihiro Ohsaka[1]

1.Faculty of Agriculture, Shizuoka University, 2.Center for Spatial Information Science, The University of Tokyo, 3.Faculty of Life and Environmental Sciences, University of Tsukuba, 4.Graduate School of Life and Environmental Sciences, University of Tsukuba

Understanding of the debris flow behavior in the initiation zone is essential for the development of mitigative measures, such as warning systems and structures. Volume and surface topography of sediment storage in the initiation zones change with time affected by the sediment supply from hillslopes as well as the evacuation of sediment by occurrence of debris flows. However, influences of such changes on characteristics of the debris flow are not well understood because of a lack of field data. To clarify interactions between accumulation conditions of sediment storage and debris flow characteristics in the initiation zone, we conducted field observations in the Ohya landslide, central Japan, using video cameras and water pressure sensors. We also analyzed DEMs obtained by TLS (Territorial Laser Scanning, 12 periods) and airborne LiDAR (Light Detection and Ranging). Comparison of slope gradient maps calculated from DEMs with different resolutions (from 0.1 to 10 m) showed that 5 m is the best grid size to extract typical geomorphic units, such as rock slopes, talus slopes, and channels. Areas of talus slopes and channels were larger and gradient of channel was steeper when total volume of storage was higher. Flows that monitored by our video-camera system could be classified as either flows comprising mainly muddy water, or flows comprising mainly cobbles and boulders. Flows comprising mainly muddy water are turbulent and are characterized by black surfaces due to high concentrations of silty shale, whereas muddy water is almost absent at the surface of flows comprising mainly cobbles and boulders. The former flow is considered as fully saturated debris flow which can travel on gentler channels, while the latter flow is considered as partly saturated debris flow which is typical on steep channels. The former flow was predominant phase of the debris flow when only small volume of storage existed in the initiation zone, while the latter flow was predominant phase when volume of storage was large. Thus type of flow is likely affected by volume of channel deposits.

Keywords: debris flow, TLS, airborne LiDAR

Past and modern landslides controlled by lithology and geologic structures of accretionary complexes in eastern Kii Peninsula, central Japan

*Satoru Kojima[1], Hidehisa Nagata[2]

1.Department of Civil Engineering, Gifu University, 2.Fusuido, Ltd.

The relationship between large landslides and geologic characters of accretionary complexes were examined in the Chichibu belt on the eastern part of the Kii Peninsula, central Japan. The rocks in this area consist of Jurassic accretionary complexes composed of basalt, limestone, chert, Permian–Triassic boundary siliceous shale (PTBS), mudstone, sandstone, and mélanges with sheared shale matrices. We examined prehistoric landslides (the Karako, Sono, Kasagi, and Aso landslides), and the modern Kasugadani landslide that was triggered by the Typhoon Meari on 29–30 September 2004. Although the age of the Sono landslide was estimated at 20,440 ±70 BP and 20,820 ±70 BP based on AMS-^{14}C ages of wood fragments embedded in the dammed lake sediments, the ages of other prehistoric slides are unknown. All of the landslides occurred on dip slopes. The bedding, foliation, and fault planes of the rocks in the area generally trend E–W and dip to the north, although those in the Kasugadani area dip to the south as a result of local folding. The landslides selectively slid along the planes of 1) PTBS horizons that were less strong than those of underlying chert, 2) lithologic boundaries with physical contrasts, or 3) boundary faults between mélange units. These geologic structures, including the north-dipping bedding/cleavage/fault planes, were formed during Jurassic subduction–accretion and later uplift processes. The movement directions estimated for the 269 landslides and unstable slopes in this region are also N–NNE, and their slip planes are subparallel to the general bedding/cleavage planes in this area. Thus, future slides are also likely to occur on north-facing slopes.

Keywords: landslide, geologic structure, accretionary complex

River incision, climate change, and bedrock landslides in a high-relief mountainous landscape in Japanese Alps

*Yuki Matsushi[1]

1.Disaster Prevention Research Institute, Kyoto University

The present study attempts to reveal role of long-term river incision and climate change in triggering deep-seated bedrock landslides and thus shaping high-relief mountainous landscapes in a tectonically active region. We curried out GIS(Geographic Information Systems)-based analysis of a 10 m mesh DEM (Digital Elevation Model) and dating of paleo bedrock landslides using TCN (Terrestrial Cosmogenic Nuclide) in Japanese Alps. The topographic analysis revealed long-sectional shape of hillslopes, which is statistically steeper at lowest parts reflecting active undercutting by river incision. The spatial distribution of hillslope angles accords with the output of a simple stability model for bedrock landsliding with a set of parameters of weak rock-mass shear strength. This results imply that river incision and bedrock landslides maintain a quasi-dynamic-equilibrium state of topography with accompanying slope break on hillslopes. Samples for exposure dating were collected from top of boulders on landslide deposits or bare rock slip surfaces. Effect of snow shielding on nuclide production were corrected, and calibrated by radiocarbon dating for some deposits yielded by the identical landslide event. The ages of landslide deposits concentrated in Holocene especially at just after the transition from the last glacial to present interglacial era, and also recent period during the last 3 kyr. These results imply that climate change has potentially instigated the occurrence of bedrock landslides and thus contributed to form and maintain bedrock dominated topography in high-relief mountainous ranges with steep hillslopes adjacent to incised valleys.

Keywords: deep-seated bedrock landslide, slope break, terrestrial cosmogenic nuclide, glacial-interglacial cycles, quasi-dynamic-equilibrium

An investigation on self-potential variation and seismic signals caused by sliding of laboratory scale model slopes

*Zheng-yi Feng[1], Shang-Hao Lin[1], Hsueh-Pin Tan[1], Han-yi Huang[1], Yu-Fang Chiu[1]

1.Department of Soil and Water Conservation, National Chung Hsing University, Taichung, Taiwan

This study monitored the self-potential variation and seismic signals during sliding experiments for laboratory scale model slopes when the slopes subject to rainfall and groundwater level increasing. The sensors installed including non-polarized electrodes, accelerometers, pore water pressure gauges, and water content gauges for data collection. The results show that the self-potential variation can be used qualitatively to indicate groundwater condition and movement of the sliding body of the model slopes. The seismic signals caused by the three types of sliding processes of the model slopes, including single sliding, multiple sliding and successive sliding, can be easily identified. In addition, the frequency content and time-frequency spectra of the three sliding processes were calculated and compared. We also found that the amplitude and high frequency portion of the seismic signals were attenuated for the case of a model dip slope with a weak clay layer.

Keywords: landslide, slope, seismic signal, self-potential, model test

Detecting and measuring catastrophic landslides using seismology

*Colin Peter Stark[1], Göran Ekström[1], Clément Hibert[2,1]

1.Lamont-Doherty Earth Observatory, Columbia University, 2.Institut de Physique du Globe de Strasbourg

Massive, rapidly accelerating landslides generate surface waves detectable on seismometers many 100s of kilometers distant. Time-series single-force inversion of the long-period phases allows approximate reconstruction of the progressive unloading and reloading of the solid earth below the sliding mass. We thus obtain the dynamics of bulk landslide motion and its location. The bulk 3d momentum vector approximates the mass-scaled evolving velocity; by assuming constant mass for the main phase of acceleration and deceleration we can infer a mass-scaled runout trajectory; calibration against satellite imaging of mass-center displacement leads to an estimate of landslide mass. We have developed and applied this methodology to the global detection of >10Mt landslides on a near-real-time basis for several years, and the inventory of such events leads us to make several important conclusions: (1) several such massive landslides go unreported each year; (2) the majority of unreported events take place in SE Alaska and the Himalayas-Karakoram; (3) only supraglacial landslides exhibit long-runout; (4) supraglacial landsliding is a significant and underestimated player in the erosion of glaciated landscapes; (5) on rare occasions, a teleseismically detectable landslide triggers a tsunami, and the precise timing, location and dynamics gleaned from single-force inversion provides an exciting new constraint on tsunami physics.

Keywords: landslide, seismology, tsunami

Stick-slip Motion Preceding a Landslide

*Masumi Yamada[1], James Mori[1], Yuki Matsushi[1]

1.Disaster Prevention Research Institute, Kyoto University

The characteristics of seismic signals generated by the mass movement are considered to reflect the property of the sliding surface, and the use of seismic data for landslide study attracts more attention recently. In the meantime, scientists seek for precursory signals before the large failure of landslides in the seismic data. Here we analyzed the seismic data associated with 2015 Rausu landslide, and found intermittent tremors before the substantial mass movement.
The Rausu landslide started moving before 6:30 on April 24 based on the eyewitnesses, and the large deformation occurred between 11:30 and 16:30 on the day (see the Figure). The size of the landslide is about 380 times 260 m, and the sliding distance is 10-20 m with the rotation of 8 degrees clockwise. The coastal seafloor uplifted and emerged above the level of high-tide due to the buckling of the layers at the toe of the landslide.
A seismogram near the Rausu landslide recorded curious intermittent tremors one day before the substantial mass movement. Each tremor has almost identical waveforms, and the amplitude increases linearly as a function of time. The tremors continued about 20 hours, and on the next day, a large deformation was observed.
This tremor sequence is an evidence of the stick-slip movement of the landslide before the large failure occurs. The identical waveforms suggest that the source location and mechanism are very similar in the sequence, which indicates the tremors are generated at a particular small area. The amplitude and interval of the tremors may reflect the physical properties of the slip surface. The constant interval of the tremor occurrence suggests that the shear stress accumulation was very stable at the precursory creeping stage. This is the first observation suggesting that the heterogeneous structure such as asperities on the slip surface play an important role to control the movement of landslide, and adding a new aspect on the conventional understanding of the mechanism to control the mass movement.

Analysis of seismic waves excited by landslides - a case for Izu-Oshima Island on Oct. 16, 2013 –

*Issei Doi[1], Toshitaka Kamai[1], Gonghui Wang[1], Yuichi Morita[2]

1.Disaster Prevention Research Institute, Kyoto University, 2.Earthquake Research Institute, University of Tokyo

Records of ground motions due to landslides had been observed frequently thanks to the enhancement of the recent seismic network (e. g. Yamada et al., 2012; Ogiso and Yomogida, 2015). These records may enble us to estimate locations and timing of landslides which are especially important to understand the mechanism of landslides in association with geology, hydrological environment and precipitation distribution.

On Oct. 16, 2013, large-scale landslides took place due to extreme rainfall in Izu-Oshima Island in Japan. Accompanied with the Izu-oshima landslide disasters, seismic waveform records which recorded landslide signals were obtained at more than ten stations operated by Oshima Volcano Observatory of ERI, U. Tokyo. Using these waveform records, this study shows the effectiveness and limits to estimate the spatio-temporal distribution of the shallow landslides.

We detected at least 95 landslide events in the seismograms. Particle motions obtained with narrow (2-3 Hz) bandpass-filtered seismic waveforms showed that the Rayleigh waves were dominant at a certain time window. Therefore, assuming the observed waves as surface waves, the movement of the source regions was estimated using spectral amplitude ratios among stations. It was found that the source regions were determined with a small error radius at the earlier stage of one event, though the source regions at the latter stage were limited only in the slope-strike direction. This fact was considered to be due to the spreading of the regions where seismic energies were radiated.

The locations in the slope-strike direction for the detected landslide events were firstly situated mainly in the northern regions of the failure region at 2:00, then moved to the south with increasing frequency around 3:00-4:00, and then terminated past 5:00. The first large-amplitude event occurred only after one event, which suggested that large-scale failures suddenly might have occurred without small failures.

Geological map (Kawanabe, 1998) shows that the orthopyroxene-augite basalt scoria and spatter involved in the eruption in the 14th century cover the top side of the northern failure slope, within which the slip surface was observed (Terajima et al., 2014). On the other hand, the southern failure slope is also covered by basalt scoria but scoria involved in 14th century eruption did not reach there. Therefore, we suggested that one reason for the occurrence time difference in landslide events in the northern and southern slopes was geology difference.

Acknowledgments: We used the meteorological data recorded by JMA.

Experimental investigation on the frictional behavior of granular materials: Implications for better understanding landslide mobility

*Yao Jiang[1], Gonghui Wang[2], Toshitaka Kamai[2]

1.Graduate School of Science, Kyoto University, 2.Disaster Prevention Research Institute, Kyoto University

The frictional properties of granular materials provide fundamental insights into geophysical processes such as landsliding and earthquake faulting. Some previous experimental studies have shown that the mineralogy of constituent materials plays a first-order control on the transitions of mechanical behaviors, including sliding stability or instability. Moreover, other laboratory investigations have demonstrated the importance of shear rate as a primary control on the strength properties, leading to rate-strengthening or rate-weakening. Despite these efforts, however, neither the knowledge of general relationships among mechanical conditions, material properties and frictional behavior nor the underlying processes are well understood. Here we report on a suite of ring-shear experiments designed to investigate the influence of grain interfaces on the granular frictional behavior over a wide range of shear rates. Samples, consisting of granular halite and mixtures of granular halite and silica sand, were sheared at room temperature and constant normal stress of 400 kPa, and we varied the proportions of halite by weight. The same loading procedures were adopted during each experiment, and the acoustic emissions (AEs) were monitored with a sampling rate of 1.0 MHz. We found that: (1) the pure halite sample shows stick-slip instability, but the pure silica sand sample exhibits stable-sliding; (2) inclusion a low concentration of halite is strongly to modify the frictional behavior and specifically to reduce its ability to sustain stable-sliding for silica sand sample; (3) the stress drop and recurrence time of instability events increase with increasing halite contents, but the occurrence of plastic deformation increases the recurrence time. Ultimately, we discussed the related energy dissipation process considering the released acoustic energy to evaluate the landslide mobility.

Keywords: frictional behavior, acoustic emission, shear rate, landslide mobility, halite

