

## Pore water pressure in slopes composed of multi-layer geological structure

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Increasing in pore water pressure in the slopes during heavy rainfall events is considered as an important factor inducing landslides. Sliding surface of many of these landslides locates on the boundary between different rock/soil strata. We need to know spatial distribution of the pore water pressure in slopes composed of multi-layer geological structure in order to explain occurrence mechanism of these landslides. Many of prior studies generally analyzed slope stability under condition that the pore water pressure is same as the hydrostatic pressure. These studies ignored influence of depth profile of hydraulic parameters on magnitude of the pore water pressure. We, therefore, tried to understand spatial distribution of the pore water pressure on the basis of the continuity equation and equation of motion for seepage flow in two-dimensional slopes with multi-layer soil structure. Our study clarified that the water velocity as well as the depth profile of the pore water pressure are affected by depth profile of the hydraulic conductivity in the saturated zone. Pore water pressure agrees with hydrostatic pressure in case that the saturated zone develops on the impermeable soil layer. Meanwhile, pore water pressure is smaller than hydrostatic pressure in case that bottom of the saturated zone contacts with unsaturated zone. In this case, magnitude of the pore water pressure depends on the difference in the hydraulic conductivity between upper and lower layers. In addition, pore water pressure is highest at a layer boundary. Our analysis results agree with the general landslide characteristic that the sliding surface locates on a layer boundary.

Keywords: landslide, pore water pressure, multi-layer soil structure, seepage flow

## Landsliding phenomenon under abnormal weather conditions: a case study

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To examine the initiation and movement mechanisms of landslides occurring during abnormal weather conditions, we have been monitoring a landslide on Nisenotani area in Miyazaki Prefecture, Japan. The monitoring items include the weather conditions (rainfall and air pressure), moisture content of surficial soil layers, groundwater table, and displacements (by means of borehole wire extensometer, surficial extensometer, and total station). Cracks appeared on the slope after a heavy rainfall and borehole investigation revealed that this landslide is a large compound one, consisted of several sub-blocks. Our dense monitoring is performed on a small block of the toe part, and our results showed that: (1) landsliding was initiated by a heavy rainfall, but was not less affected by small rainfall; (2) landsliding varies with air-tide; (3) lower part of the sliding sub-block had been continuously compressed; (4) the sliding surface and the compressed soil layer had been effectively identified by means of a surface-wave technique.

Keywords: Abnormal weather, air pressure, Rainfall, landsliding, groundwater table

## Extreme Rainfall Effect on Slope Hazards along Mountain Roadway

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Due to the global climate changes, the scale and frequency of natural disasters are more difficult to predict and measure. Extreme rainfall often brings astonishing amount of water and causes very serious damage in the mountain areas. And for different environment conditions, the slope hazards induced by rainfall would be different like geology, topography or location. Therefore in this research, the authors considered the elevations, slope aspect, slope gradient and geology to compare and analysis the rainfall effect on slope hazards by using the historic landslides records. And the major method of rainfall analysis is the snake line model that is using dual-indexes of rainfall- short term rainfall intensities and accumulated rainfall data. Short term rainfall intensities mean hourly rainfall, 3 hourly rolling rainfall, 6 hourly rainfall and so on. The most important of these rainfall analyses are trying to find some regulars in occurrence of slope hazards. Furthermore, the authors also collected different hazard types in order to try to get the rainfall characteristics of different disasters. In this research, the authors used the Da-Jia River upstream region (Taiwan) as the case study. In this region, over than half area the slope gradient is larger than 55%. Through the results of the analyses, the authors get some important conclusions. Firstly, in the environment conditions, the effects of slope gradient, elevation, and geology are obvious. Secondly, the effect of slope aspect is according to the rainfall events. Finally, in extreme rainfall events, the trend of occurrence time in different hazards can be observed. According to the above conclusions, it can be effective to make decisions to prevent disasters and reduce lost.

Keywords: Landslides, Rainfall

## Shallow Landslide Susceptibility Mapping for Selected Areas in the Philippines Severely Affected by Super Typhoon Haiyan

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Super Typhoon Haiyan, considered as one of the most powerful storms recorded in 2013, devastated the central Philippines region on 8 November 2013. In its wake, Haiyan left 6,190 fatalities, 28,626 injured and 1,785 missing, as well as damage amounting to more than USD 823 million. To mitigate damage from similar events in the future, it is imperative to characterize hazards associated with tropical cyclones such as those brought by Haiyan, with detailed studies of storm surges, landslides and floods. Although strong winds and powerful storm surges up 15-17 feet were the primary causes of damage, landslides studies are also vital in the rehabilitation of typhoon damaged areas. Cities and municipalities of Leyte (7,246.7 sq. km) and Samar (13,121 sq. km) provinces, the heaviest cities area during the onslaught of Haiyan, require detailed and up-to-date hazard maps for their rebuilding and disaster mitigation programs. In order to delineate areas susceptible to rainfall-induced shallow landslides and generate a worst-case scenario hazard map of the two provinces, Stability INDEX MAPPING (SINMAP) software was used over a 5-meter-resolution Interferometric Synthetic Aperture Radar (IFSAR)-derived digital elevation model (DEM) grid. SINMAP has as its theoretical basis in the infinite plane slope stability model. Topographic, soil-strength and hydrologic parameters (cohesion, angle of friction, bulk density and hydraulic conductivity) were used for each pixel of a given DEM grid to compute for the corresponding factor of safety. The landslide maps generated using SINMAP are found to be highly consistent with the landslide inventory derived from high-resolution satellite imagery dated 2003 to 2013. The landslide susceptibility classification found in the landslide hazard maps are useful to identify no-build, areas that can be built upon but with slope intervention and monitoring as well as places that are safe from shallow landslides. These maps complement the debris flow and structurally-controlled landslide hazard maps that are also being prepared for rebuilding Haiyan's devastated areas.

Keywords: Natural Hazards, Landslide, Hazard Mapping

## Calculation of Shallow-Landslide Rainfall Threshold for Libon, Albay, Philippines Using TRIGRS

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In a rainfall event caused by a cold front and a low pressure area during the 14th until the 21st of February 2008, the Albay province experienced several landslides with \$4.6 million in damages to infrastructure alone. Aside from delineating areas that are highly susceptible to landslide, it is important to determine shallow-rainfall threshold aid in the development of an early warning system. The study area was carried out on an area in Libon town in Albay with approximately 1000 residents living near the high hazard area. Using TRIGRS software (Transient Rainfall Infiltration and Grid-based Regional Slope-stability analysis), 6 different sustained rainfall intensities with the duration of 24 hours were simulated to a 5-meter resolution IFSAR (Interferometric Synthetic Aperture Radar)-derived DEM (Digital Elevation Model). Topographic, soil strength, and hydrologic parameters were assigned to each pixel of the given DEM grid to compute for the factor of safety using the theory on Infinite Plane Slope Stability to produce a shallow-landslide susceptibility map. The values of the different rainfall intensities were selected to represent different rainfall events equal (1.26mm/hr), less than (.5 and 1mm/hr) and greater than (1.5, 2.73, 7.5 mm/hr) the infiltration rate of the soil. After comparison, there were no observed differences in the hourly variation of the Factor of Safety Maps for 1.26 mm/hr and greater intensities. The rainfall threshold determined to be 4.5 to 5mm of effective accumulated rainfall on which the pixels that failed ( $FS < 1$ ) matched the landslide inventory from 2003-2014 and the shallow-landslide hazard map. This study shows that in determining rainfall thresholds for shallow landslides the effective infiltration rate and hydraulic diffusivity of the soil serves as factors on how fast the slope reaches instability during a rainfall event. The results of this study may be treated as the worst case possible due to the sustained intensities and may be further improved through simulations using data of actual rainfall events, considering varying rainfall intensities and durations.

Keywords: Landslide, Shallow, Rainfall, GIS, Albay, Philippines

## Sensitivity of the initiation of debris flow to initial soil moisture

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The initiation of debris flows is commonly attributed either to fluidization as a result of rainfall induced landslides or to gully erosion induced by concentrated run-offs. A series of flume tests have been performed to show how the initial soil moisture influences the initiation of debris flows. At the start of each experiment, surface run-off was generated over loose granular deposits, triggering debris flows. These experimental debris flows enacted different scenarios according to the small variations among the initial soil moistures. In the loose granular deposits with initial soil moistures ranging from 1% to 5%, most run off water could infiltrate and trigger a landslide, which accelerated within one second to speed over 1 ms<sup>-1</sup> and then transformed into a debris flow. In the same soil deposits with initial moistures >5% or <1%, the debris flow was initiated by slow gully erosion with episodic events of damming and breaching due to small-scale landslides occurring on the side-slopes of the erosion valley. The slope failures were not triggered by positive pore pressure but by a decrease in suction due to the wetting of the soil. This suction decrease in initially unsaturated slopes explains why the transformation of these slope failures into debris flows are due not only to an increase of pore pressure leading to soil liquefaction, which is one of the expected triggering mechanisms, but also to a loss of the cohesive strength of the soil.

Keywords: debris flow, soil moisture, initiation

## Gully development on flows and deep-seated slides in the Mangaoporo catchment, North Island, New Zealand

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Mass movements and gully erosion are widespread phenomena in many steep, erosion prone catchments. Understanding gully erosion on unstable slopes is important for the management of slopes as well as for management of river systems, as large quantities of sediment are supplied by gully erosion directly into river systems causing off-site damage.

The development of gullies on unstable slopes is not well understood. In this study gully development on slopes affected by mass movements was analysed in 14 headwater catchments of the Mangaoporo catchment, North Island, New Zealand. Bedrock consists of Cretaceous-aged, highly crushed and sheared mudstones and sandstones. Deforestation by European settlers at the beginning of the 20th century for pastoral farming was followed by reforestation for wood production from the 1980s. Sequential aerial photographs from 1939 to 2005 were interpreted to map mass movements and the development of gullies. Digital elevation models were extracted from aerial photography using ERDAS to assess the applicability of the commonly applied topographic threshold approach for gully incision.

Flows of varying depth occurred in all catchments underlain by mudstone, while the catchment consisting of alternations of mudstone and sandstone were affected by deep seated sliding and secondary shallow sliding. Deep (few meters to 15m) gullies were located at the toe of mass movement bodies. Such gullies developed oversteepened sidewalls, which in turn initiate extensive mass movements at the gully walls. Shallow (about 1 -2m deep), hundreds meter long gully arms extended upslope. Topographical changes by active flows and slides caused stream capture or gully destruction. Cracks and scraps functioned as incision pathways.

The topographic threshold approach is not appropriate for unstable slopes, as the mass movement topography exhibits irregular drainage pattern and gully incision depends on the morphology of mass movements. New approaches need to be developed for gully incision on unstable slopes to understand the spatial and temporal variability of incision dynamics on unstable slopes.

Keywords: gully erosion, flow, slide, New Zealand

## Quantifying the seismic response of slopes: observed and modelled amplification from the Port Hills of Christchurch

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**ABSTRACT:** Before the Christchurch 2010/11 earthquake sequence the influence of site effects on landslide triggering during earthquakes was reported in many studies, but evaluating these effects has been difficult through lack of high-resolution data, especially the lack of local ground motion instrumental observations. As a result of the Christchurch 2010/11 earthquake sequence we now have high temporal and spatial resolution data, including subsurface geotechnical and geophysical information that allows quantification of the amplification relationships between the near surface geology, topography and seismic inputs.

This paper presents preliminary results on site effects in the Port Hills of Christchurch caused by near surface material impedance contrasts and slope morphology. Results from small scale temporary arrays installed on several of the large rock slopes that failed repeatedly during the earthquakes suggest amplification factors of up to 300% of peak ground acceleration when compared to free field rock outcrop peak ground accelerations. These are corroborated not only by two dimensional seismic site response analyses using synthetic earthquake motions as inputs to the models but also by comparing recorded ground motions from borehole and surface seismometers.

Based on these findings it is apparent that particular slope shapes and material contrasts can significantly amplify peak ground accelerations during earthquakes. At present in New Zealand such amplification effects are not routinely taken into account when designing earthworks or structures on slopes or in landslide risk assessments.

Keywords: Earthquake induced landslides, topographic amplification, earthquake hazards

## Distribution loess landslides triggered by the 1920 Haiyuan earthquake and their formation mechanisms

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The 1920 Haiyuan Earthquake ( $M=8.5$ ) is one of the strongest earthquakes in Chinese modern history, and directly resulted in more than 200,000 people dead. The Earthquake induced a large number of landslides. Among them, we investigated 544 landslides in the meizoseismal area, and found that the distributions of the landslides are mainly concentrated in the southeastern part of the seismogenic fault, but the relationship with the NW-trending seismogenic fault is not noticeable. Further investigation indicated that such distribution is mainly controlled by two types of factors. One is the nearly SN-trending secondary faults concealed under the loess cover. The other one is the thickness of the loess. The landslide is more intensive in those areas with thicker loess and the density of the landslides decreases with the decreasing in the loess thickness, while landslides occurring in the bedrocks are very rare.

Investigation shows that the sliding surface of a large number of loess landslides is extremely gentle with the apparent friction angle ranging between 8 -11 degrees. Liquefaction phenomenon was found on a large number of areas in loess tableland along both sides of the river in the meizoseismal area. This is likely one main reason for the occurrence of landslides with very gentle sliding surface angle. Laboratory testing of undisturbed loess of these regions indicated that the sand content ranges from 3% to 15%, silt content is about 65% - 85%, clay content between 10% - 20%, and thus this kind of soil belongs to silt. But the sand content showed uneven distribution and high sand content occurred in local area. Dynamic triaxial tests showed the saturated loess could suffer from liquefaction failure.

However, there existed a large number of low angle slip surface, large runout and high mobility loess landslides in the slope zone with low underground water level. Loess is characterized by large pores with high compressibility and low strength. Scanning electron microscopy revealed that cement of loess particles were dispersed particulate, distributed discontinuously attached to the particle surface or accumulated at the point of the contact in the skeleton, the adhesive strength is very low. The earthquake occurred in December of that year's winter. Due to very low water content of loess, relatively dry shallow loess easily shattered and collapsed under strong shaking of extreme earthquake. Therefore this caused occurrence of the high-speed and long runout landslide.

Finally, we conclude that because of the special geological characteristics of loess, there are more than two types of landslide mechanism: one is the liquefaction occurring on the loess layer affected by the groundwater level; the other one is the collapse of loess structure under strong earthquake.

## Geomorphological and Geological Features of The Collapsing Landslides Induced by The 2009 Padang Earthquake.

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The Mw7.6 Padang earthquake in 2009 attacked the northwest of Sumatra, Indonesia, and triggered many landslides, which killed at least 130 people at one village. We made satellite image interpretations, field investigations, and laboratory tests to identify the geomorphological and geological features of these landslides. As a result, we found that the number of landslides was 159, materials that slid were pumice fall deposits, and their sliding surface was made within the base of the pumice layer where pumice grains were mixed with underlying lahar and heavily weathered. These landslides had the following characteristics: 1) they occurred in the areas with pumice beds with >3 m thickness, which was controlled by the distance from their source; 2) the pumice fall deposits had a slope-parallel layering, which had been cut at the foots of slopes; and 3) the mixed layer at the base of the pumice beds was heavily weathered to be clayey materials with abundant halloysite.

We made an isopach map of the pumice fall deposits, which is so-called Qhpt and believed to be from Maninjau Caldera. The isopach contours, however, showed that Qhpt is from Tandikat Volcano, and that landslides occurred in clusters in the areas with pumice beds thicker than 3.5 m.

Qhpt beds had slope-parallel bedding, but they were undercut by subsequent river incision. Interpretations of stereoscopic satellite images and field surveys showed that there are four terraces along the Magung River, and Qhpt covers widely distributed higher terraces (Lh) of lahar younger than 80 ka and middle terraces (Lm) but are cut by lower terraces (L11 and L12) as well as small nearby tributary gullies. This undercutting likely reduced the support of Qhpt beds from downslope.

The mixed layers, in which sliding surfaces were formed, were heavily weathered and very weak; weaker than the main Qhpt above and the lahar below. XRD analyses showed that pumice grains of the main part of Qhpt scarcely had halloysite but pumice grains and weathered lahar in the mixed layers were rich in halloysite. The formation of halloysite could be attributed to the interaction between the materials of the mixed layers and the water coming through Qhpt beds; water, which gets Si and other chemical components from the volcanic glass of pumice, may become stagnant in the mixed layers because they are much less permeable than the Qhpt beds above. This would be a preferable condition of halloysite formation.

Infinite slope stability analysis using geotechnical parameters, pumice bed thickness, and slope angles, which we obtained, suggested that landslides with sliding surfaces within the mixed layers could be triggered by the shaking of the 2009 Padang earthquake. The natural water contents of the materials of the mixed layers exceeded their liquid limits, which suggests that they would behave like a liquid after remodeling.

The geological history, which is volcanic eruption, weathering, and undercutting by river incision as stated above, is typical in tropical volcanic areas. That means we can make a hazard map of such a catastrophic landslide induced by earthquakes on the basis of geological development.

Keywords: 2009 Padang earthquake, Halloysite, Collapsing landslide, pumice fall deposits, weathering

## The seismic signals from the model slope failure and erosion tests

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High intensity rainfalls in mountainous areas often induce floods. The floods could erode riverbank slopes and cause them to landslide. This study selected Landao Creek of Huisun Experimental Forest (Nantou, Taiwan) as the in-situ test site for the model slope failure and erosion tests. We built a large size model soil slope and an artificial landslide dam in Landao Creek for the tests. The Nengau agricultural channel at the upstream of Landao Creek was setup to control the inflow to Landao Creek. Therefore, the artificial landslide dam were overtopped when the retention space were full by the inflow water. Consequently, the dam breached and caused the model soil slope to be eroded by the flooding water. The model soil slope failed partially due to the erosion and generated seismic signals during the slope materials sliding down. We installed of several accelerometers sensor on the model soil slope to collect seismic signals generated. We present two test results in this study. The seismic signals were analyzed using the Hilbert-Huang Transform for time-frequency spectrograms. We explored the characteristics of seismic signals due to the model soil slope sliding and the flooding. In addition, we can use the time-frequency spectrograms to identify the timings when the model slope slid repeatedly.

Keywords: Landslide, slope, erosion, seismic signal, flood, dam

## Characteristics of the slope failures in Izu-Oshima Island on Oct. 16, 2013, inferred from seismic waveform records

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On Oct. 16, 2013, large-scale slope failure took place due to extreme rainfall in Izu-Oshima Island in Japan. The precipitation reached over 90 mm per hour from 1:00 to 5:00 before and during the period when the failures took place. Through geological surveys by us and Natural Disaster Research Council, piping holes were observed on the collapsed slopes, which suggested that the ground water spouted due to high water pressure. It is important to grasp the detailed behaviors of water and sediment movement in order to reduce the slope disaster in the volcanic regions.

Signals of failures and their related sediment movements were recorded many times by several seismometers installed around by Oshima Volcano Observatory of ERI, Univ. of Tokyo. The seismic signals were observed almost at the same time at several stations. Four major signals were detected from 2:00-3:00, while at least a few tens were observed from 3:00-5:00. These signals had unclear initial phases and long (several minutes) durations. The amplitudes increased almost at the same time at the beginning among the stations, while the times when they attained the maximum values were earlier at the stations located in the upper side of the slope. These facts indicate that the vibrations were firstly generated in the upper side of the slope, then moving toward the downside.

Acknowledgments: We used meteorological data recorded by JMA.

Keywords: slope failure, seismic waveform, sediment movement

## Friction law of gouges from monotonic and cyclic shear tests - implications for rockslide triggered by earthquakes

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The differences of soil strength under static and dynamic loading have been well recognized. This study utilized rotary shear apparatus to elucidate the friction coefficient of gouge materials under monotonic and cyclic shearing conditions. A rigid block model incorporating the velocity/displacement dependent friction law from monotonic tests was adopted to simulate the dynamic shearing behavior. Basically, the friction coefficient under maximum shearing velocity was well depicted. However, the friction coefficient under zero velocity for dynamic shearing tests was overestimated. A frequency factor, which taking the healing effect into account, was successfully incorporated into the friction law to simulate the variation of the friction coefficient under dynamic loading condition. The modify friction law with consideration of the cyclic shearing frequency was used to evaluate the triggering of a dip slope rockslide during earthquake. It is illustrated that the cyclic shear induced from the earthquake is critical for the initiation of large scale rockslide. The influence of seismic loading on earthquake-triggered rockslide can thus be evaluated quantitatively.

Keywords: monotonic and cyclic shear, velocity and displacement dependent, friction coefficient, rotary shear test, gouge, earthquake triggered rockslide

## Fast Shear Behaviour of Granular Material and Rapid Landsliding Phenomena

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Many rapid landsliding events are normally catastrophic in which granular masses flow with extremely low friction. In order to prevent and mitigate the disaster, it is essential to better understand their mechanisms of initiation, motion and deposition. Although a great deal of research and attention has been focused on the unusual physical features for rapid landsliding events, the dependence of frictional properties on particle characteristics and test conditions has not yet been clearly understood. In the present research, we performed a set of experimental studies to examine the grain-scale frictional properties. We used two kinds of glass beads to examine how particle size affected the strength and stability of granular materials by employing a large ring-shear, and sheared the samples by changing the shear rate from 0.1 to 100 mm/s under different normal stresses (50, 100, 200, 400 kPa). It was found that the influence of shear rate on the residual shear strength for glass beads was negligible, while the stress fluctuation was observed for different particle sizes. Three distinct spectral peaks were identified in the frequency spectra for the two glass beads by utilizing Discrete Fourier Transform (DFT) method. According to the frequency spectra, we found that the stress fluctuation of glass beads was closely related to the particle size. Then we analyzed the role of particle size in the fast shear behaviour of granular materials and their relationship to the rapid landsliding behavior of rock avalanche.

Keywords: fast shear behavior, rapid landsliding, glass beads, particle size, shear rate, stress fluctuation

## Changes in particle size distribution of clayey material at a catastrophic landslide base

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In August 2009, a catastrophic rockslide avalanche was initiated by a cumulative rainfall of 1676.5 mm by Typhoon Morakot in the southern mountainous region of Taiwan. The landslide occurred on slopes extending from head scarp to the opposite riverside with a fall height of 830 m and generated the runout distance of 3.2 km long. The mobility of the landslide was high, indicating by its low apparent friction angle of 14 degrees and velocity of 70 to 120 km hr<sup>-1</sup> in 95 s. The landslide claimed more than 400 people dead and missing when the village of Shiaolin was destroyed directly in the path of the landslide. We found clayey material in many locations at the base of the landslide deposits. Two samples S1 and S2 and one sample D1 of clayey material were respectively collected from the base of the remaining debris in the lower part of source area and the base of the deposits in the depositional area. Their mineralogy and particle size distribution were analyzed using an X-ray diffractometer (Rigaku Gaigerflex RAD IIB) and a laser diffraction particle size analyzer (Shimadzu, SALD-3100), respectively. The X-ray analysis indicates that the samples are the same material, in terms of texture and mineralogy, consisting of illite, chlorite, quartz, feldspar, and calcite. Besides, particle size analysis shows that samples S1 and S2 of the source area had two particle size modes at 15  $\mu\text{m}$  and 50 – 100  $\mu\text{m}$ , and sample D1 of the depositional area had one mode at 15  $\mu\text{m}$ . This difference between the samples may reflect pulverization during movement of the material from the source area to the depositional area. The overall particle size distribution is narrower in sample D1, and the mean grain size ( $D_{50}$ ) decreased from 11.03  $\mu\text{m}$  in sample S2 to around 8.96  $\mu\text{m}$  in sample D1. Sample S1 has larger amounts of finer fractions than do samples S2 and D1, and its distribution curve has a flattened top in comparison with the other two samples, which could be attributed to intense shearing between bedrock and debris. The results suggest that the clayey material at the landslide base and the increasing fine-grained content of the clayey material during shearing are assumed to have a significant impact on its long, rapid movement.

Keywords: rockslide avalanche, high mobility, clayey material, particle size distribution

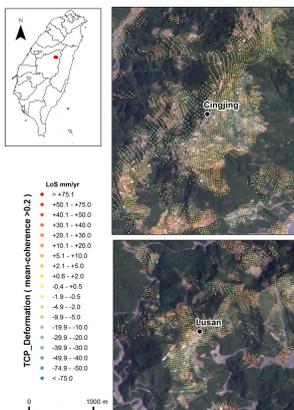
## Application of TCP-InSAR technique for the Deep-Seated landslides detection and monitoring at Cingjing village, Taiwan

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Taiwan located at an active mountain belt and subtropical climate environment, severe gigantic landslide that have caused considerable damages commonly occurred in mountainous areas. After the 2009 Hsiaolin landslide that caused 450 casualties, how to identify potential sites of Deep-Seated landslides, evaluate their activity and susceptibility become an important issue. In the past few years, our research team has processed many slope failures that have caused considerable damages by using airborne LiDAR Digital Elevation Model (DEM), and implemented related analyses for the goal of deep-seated landslide. Cingjing village located at Centre Taiwan is well known as one of the three high altitude agriculture area in mountainous regions. In this study, we using TCP-InSAR interferometry from ALOS/PALSAR images to detect and monitoring the landslide activity and its susceptibility of deep-seated deformation over a large area. The method obtains more ground deformation information than other InSAR approaches, providing more comprehensive analytical results for the slope related hazard studies. Our TCP-InSAR result shows a significant subsidence pattern around the Cingjing area. Comparing the surface deformation data and the field investigation records, several imperceptible deep-seated landslide locations are found and the boundaries can be identified as well as the spatial distribution of instability to them. The deposition pattern also implies different landslide development types on the slopes. This case study shows the great potential of TCP-InSAR evaluating the slope activities and deformation in the vegetated mountain area. Combined with topography signatures from high resolution digital elevation model data, it will be an effective way to determine the stability of slopes and potential hazard locations over a large area.

Keywords: Deep-Seated landslides, TCP-InSAR technique, Airborne LiDAR, Cingjing village



## Preceding topographic features of catastrophic landslides in an accretion complex in the Kii Mountains

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Slope movements is one of the major processes of denudation as well as erosion and transportation by rivers or glaciers, and many slope movements themselves are induced by river or glacier erosion. We investigated the linkage of river erosion, deep-seated gravitational slope deformation, and catastrophic landslides in the Kii Mountains Japan, where occurred tens of catastrophic large landslides during 1889 Totsukawa typhoon and 2011 typhoon Talas. The consequent fatalities were 168 and 56, respectively. The Kii Mountains is underlain by the Cretaceous to Neogene Shimanto accretional complex in large areas and has paleosurface remnants in higher elevations. The paleosurfaces have been newly incised by rivers, of which the Kumano River catchment occupies the central part of the Kii Mountains. The new incision of the Kumano River proceeded with the upstream propagation of knickpoints, which developed well-defined convex slope breaks on interfluvial slopes. High-resolution DEMs clearly delineated deep-seated gravitational slope deformations, which are characterized by scarps, linear depressions, and bulges, aligned along the convex slope breaks, suggesting that they were induced by gravitational instability induced by the erosion undercutting. The catastrophic landslides during the 1889 Totsukawa typhoon and 2011 typhoon Talas occurred had been preceded by deep-seated gravitational slope deformation on newly incised inner valley slopes. Most of the landslides had sliding surfaces along undulating minor faults, probably thrusts, which might have made rock bridges when shearing along preferably oriented parts of the faults occurred. Catastrophic slope failure may occur when those rock bridges are finally fractured.

Keywords: gravitational slope deformation, landslide, accretion complex

## Recognition of large scaled deep-seated landslides using high resolution topography and case studies in Taiwan

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High resolution topography and topographic characteristics of large scale deep-seated landslides (landslide area >10 ha) are used to interpret large scale deep-seated landslides in an area of 4980.8 km<sup>2</sup> and a total number of 1607 potential large scale deep-seated landslides are recognized. The results show that main distribution of potential large scale deep-seated landslides in Kao-Ping River watershed is near structural lineaments and both sides of the river.

Two cases discussed in the study are on the right bank of Baolai River in Baolai, Kaohsiung City and on the left bank of Luliao River in Yanping Township, Taitung County. Typhoon Trami (08/20~08/22), Typhoon Kong-Rey (08/27~08/29) and Typhoon Usagi (09/19~09/22) are main typhoon events of 2013.

Potential landslide area, average slope angle and main lithology of case I is 96.6 ha, 31.1° and argillite. GPS data show a maximum horizontal displacement of 27.6 cm to southwest and a maximum subsidence of 20.5 cm after Typhoon Trami and Typhoon Kong-Rey. Surface extensometer data show the extension amount of 8 cm and 5 cm after three typhoon events. Potential landslide area, average slope angle and main lithology of case II is 6.4 ha, 32.5° and slate. A landslide with an area of 2 ha happened in the range of case II after Typhoon Usagi. These two cases indicate that rainfall and riverbank erosion are important factors on triggering large scale landslides.

Keywords: deep-seated landslides, GPS