On the fluidized landsliding phenomena on gentle slopes triggered by the 2016 Kumamoto Earthquake

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During the 2016 Kumamoto earthquake, numerous landslides had been triggered in Minamiaso Village. Most of the landslides originated on steep slopes, whereas some of them occurring on gentle slopes were fluidized and the displaced debris travelled long travel distance, resulting in causalities and severe damage to many houses on the downslope. In this study, we examined the geological features of these fluidized landslides occurring on gentle slopes, and performed both in-situ direct shear tests and dynamic ring shear tests on the soils taken from the sliding surface. During the tests, the samples were prepared at different initial water contents, and dynamic tests were performed by applying cyclic loadings with regular frequency and amplitude of shear stress, and also by coseismic loading referred from seismic motion recorded in a seismic station nearby. Based on these results, we finally analyzed the possible initiation and movement mechanisms of these fluidized landslides.

Keywords: fluidized landslide, earthquake, tephra

LANDSLIDES CAUSED BY THE 14 NOVEMBER 2016 KAIKOURA EARTHQUAKE, SOUTH ISLAND, NEW ZEALAND.

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At 12.03 am local time on 14th November 2016 (UTC: 11.03 am 13th November 2016) a shallow magnitude 7.8 earthquake, with an epicentre located near Waiau in North Canterbury, struck the North Canterbury and Marlborough regions of NZ. The strong ground shaking caused widespread damage to buildings and infrastructure across the sparsely populated areas of the northeast of the South Island. The most visible consequence of the strong ground shaking was widespread landslides. Given the sparsely populated area affected by landslides, only a few homes were impacted and there were no recorded deaths due to landslides.

Tens of thousands of landslides were generated over 10,000 km^2 of North Canterbury and Marlborough, with the most intense landslide damage concentrated in 3500 km^2 around the areas of fault rupture. Landslides caused major disruption with all road and rail links with Kaikoura being severed. The landslides affecting State Highway 1 (the main road link in the South Island of New Zealand) and the South Island main trunk railway extended from Ward in Marlborough all the way to the south of Oaro in North Canterbury.

A feature of this earthquake is the large number (more than 200) of valley blocking landslides it generated. This was partly due to the steep and confined slopes in the area and the widely distributed strong ground shaking. The largest landslide dam has an approximate volume of 12(±2) M m^3 and the debris from this travelled about 2.7 km down slope where it formed a dam blocking the Hapuku River. The long-term stability of cracked slopes and landslide dams from future strong earthquakes and large rainstorms are an ongoing concern to central and local government agencies responsible for rebuilding homes and infrastructure. A particular concern is the potential for debris floods to affect downstream assets and infrastructure should some of the landslide dams breach catastrophically.

The majority of landslides occurred in two geological and geotechnically distinct materials: Neogene sedimentary rocks (sandstones, limestones and siltstones) where first-time and reactivated rock-slides were the dominant landslide type, and; Torlesse “basement” rocks (greywacke sandstones and argillite) where first-time rock and debris avalanches dominated.

At least thirteen faults ruptured to the ground surface or sea floor, with these surface ruptures extending the Emu Plain in North Canterbury to offshore of Cape Campbell in Marlborough. The mapped landslide distribution reflects the complexity of the earthquake ruptures. The landslides are distributed across an elongated area consistent with the elongated area affected by fault ruptures and intense ground shaking. The landslides are not clustered around the earthquake epicentre. Initial results from our landslide investigations suggest: predictive models relying only on ground-shaking estimates may underestimate the number and size of the larger landslides that occurred. The largest landslides triggered by the earthquake are located either on or adjacent to faults that ruptured to the ground surface. Surface faults

may provide a plane of weakness or hydrological discontinuity and adversely oriented surface faults may be indicative of the location of future large landslides.

Keywords: Kaikoura, earthquake, landslides, dams, New Zealand, faults

Finite element simulation for seismic ground response in mountainous areas at the time of 2015 Nepal Gorkha Earthquake

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In this study, the 3D dynamic elasto-plastic finite element method is used to simulate the overall distributions of earthquake-induced slope failures in the targeted area in intermountain regions in Nepal, which can be regarded as a pilot case survey for future detailed investigations. The analytical method adopted in here is almost the same as the previous relevant studies by the authors (e.g., Wakai et al. (2015)). The area is located near the Dhunche Town along the Trishuli River, in the transition zones between the higher and lesser Himalayas.
In the analysis, nonlinear material properties of the ground as well as 3D topography, geological conditions and input motion are taken into account appropriately. Those factors strongly influences the dynamic amplification effects relevant to slope failures. The numerical results obtained from this analysis include the distributions of the maximum horizontal acceleration response and residual displacement at the ground surface, and the maximum shear stress mobilized in the surficial layers. After the comparisons of the results between the calculated one and observed facts in local areas, it can be concluded that the proposed numerical method has a sufficient ability to predict the phenomena and can be possibly utilized for predicting overall dis-tribution of earthquake-induced landslide which would be helpful for developing landslide susceptibility maps in mountainous areas in Nepal.

Keywords: earthquake, Nepal, finite element method

Silent Landslide -Waveform Records from a Seismometer Settled on a Moving Landslide Block-

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We recorded seismic waveforms during landslides using a seismometer settled on a moving landslide block with the thickness about 5 m. The landslide started to move at eleven O’ clock on Jun. 17, 2016, continuing to move for next 20 hours, together with the seismometer. We examined the seismograms and running spectrums, and resultantly, only ten events with short durations were found during sliding. We also calculted the background amplitude levels in the several frequency bands. They marked higher values, compared with those in sunny days. However, such high amplitudes were experienced several times in the cases of past heavy rains and storms. Therefore, these high background amplitude levels derived from ambient noises due to rain, winds, and oceanic waves. We could conclude that the landslide generated very small seismic energies, at least below the ambient noise level.

Application of the high-resolution APHRODITE precipitation product to rainfall-triggered fatal landslide occurrence in Nepal

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Rainfall triggers landslides worldwide, and understanding the relationship between local precipitation and slope failure is important in mitigating against disaster. The southern slopes of the Himalayas experience tremendous numbers of fatal landslides due to steep mountain slopes and heavy precipitation in summer monsoon season.
This study uses the fatal landslides database over Nepal assembled using systematic metadata online search tools identifying the location of a landslide between 2004 and 2015. A daily rain-gauge based grid precipitation (APHRODITE, 0.05 degree) data is used for the same period. We concentrate on the summer monsoon season (June-September), and rainfall-driven landslides with fatalities. Two clear west-east oriented rain-bands are observed from the west to the east of Nepal. These heavy precipitation zones correspond to the mountain slopes of Great Himalaya (north band) and Mahabharat (south band). Many fatal landslides occur along the north band, but that is few along the south band. The most number of fatal slides occurred in July, but the largest number of fatalities occurred in August. As a result, in some areas the probability of landslide occurrence increased as the amount of daily precipitation increased.
We classified pentad precipitation pattern over Nepal and found a linkage between weak monsoon indices and heavy precipitation in the central and the western part of Nepal. Especially, in July, when global monsoon signal is strong, moisture converges in India and Nepal has less precipitation. On the contrary, when the monsoon trough is weak, moisture tends to converge in Nepal. Namely, the Indian-monsoon break phase causes heavy precipitation in either western and the central Nepal. The areas 1) Farwest Hill, 2) Mid-west Hill, 3) West Hill and 4) Central Hill have strong negative correlation between monsoon index and local precipitation, where percentage of fatal landslide occurrence is very high. Landslide risks exceeds 50% if they have more than 100 mm rainfall in two days in those areas.

Keywords: Himalayas, precipitation, APHRODITE

A flume test for seepage and overtopping failures of model landslide dams

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A flume test was performed for seepage and overtopping failures of model landslide dams. We used non-polarized electrodes and accelerometers to monitor the self-potential variation and seismic signals during the failure processes. For the seepage failure tests, we found that self-potential variation corresponds well during the head ward progressive erosion failure of the model dam. In addition, repeating sliding of the model dam was observed and can be proved by the recurrent seismic signals. For the overtopping failure tests, the self-potential dropped sharply when the electrodes were exposed outside a model dam, which can be applied to indicating the eroded positions of a model dam.

Keywords: landslide dam, seepage, overtopping, dam breach, flume test

Morphological changes of a gully complex forming on landslide deposits and implications for erosion variability

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Gully complexes are landforms which are initiated by incision of water erosion (gully erosion) and further enlarge by mass movements due to oversteeping gully walls. These rapidly erosion landforms can reach the ridge top and comprise their entire catchment. Gully complexes cause on-site damage such as loss of fertile land and destruction of infrastructure. Off-site damage includes river aggradation and negative effects on aquatic habitats, as large quantities of sediment are supplied from slopes to rivers.
The transition from gullies to gully complexes has been described in many publications. Here the focus is on the erosion variability of a large gully complex eroding into landslide deposits. Morphological changes are assessed on decadal scale during the past 60 years to understand erosion varability in a gully complex.
The gully complex is 1.6km long and has a catchment area of 1.2km^2. The complex is located in the Waipau catchment on the North Island, New Zealand. The study area consists of variably indurated, sheared and crushed mudstone and thin sandstone of Late Cretaceous age. Most of the study area is used for pastoral farming.
Aerial photography taken in 04.1957, 09.1971, 06.1988, 05.2005, and 01.2012 was interpreted to map active and inactive landslides, gullies, and the gully complex itself. Differential digital elevation models were calculated using ERDAS IMAGINE Photogrammetry to estimate topographic changes.
Mapping results for the earlier decades indicate that inactive deep seated landslides cover the western section of the catchment right up to the gully channel. On the steeper eastern slopes small-scale gully erosion and falls occured. Next to an increase of the gully complex over all time slices, a prominent 210m long and 355m wide active slump was evident on the 1988 imagery, which buried the channel of the gully complex by 3-8m. The new gully channel developed 31-45m east of the original channel by undercutting the gully flank. This indicates that the development of gully complexes on unstable slopes are not uni-directional, as landslides deposits are reworked by slumping followed by excavation by water incision. Incision into highly erosion-susceptible materials such as deposits of inactive landslides might be continued until sediment storage is depleted.
These finding might help to develop approaches on gully complex development on erodable landslide deposits, which include the spatial and temporal variability of incision and infill as well as high sediment export rates to appropriately and effectively manage such erosion prone environments.

Keywords: gully complex, landslide deposit, New Zealand

Dating rock failure by speleothem and cave use of Japanese monkeys: a case study of Saru-ana Cave in the karst region along Kurobe Gorge in eastern Toyama Prefecture of central Japan

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Saru-ana Cave, a main cave system in the karst region, approximately 120 m and 40 m in plan length and relative height respectively, consists of combined galleries of horizontal passages and vertical shaft. It opens onto the south-facing steep cliff, which has probably originated as rupture surface of an ancient rock failure. In this study, we have investigated the cave and its surrounding landform comprehensively, and conclude that ancient rock failures occurred at least twice during the last 14,500 years, and opened the entrance of the cave intermittently.

The karst region for research is heavily snowy area where snowfall cover ranges in depth from 2 to 3 meters in winter. The Japanese monkeys (*Macaca fuscata*) of this area use Saru-ana Cave for protecting themselves against severe winter coldness during the mid-snow season. Five ^{14}C ages measured from skeletal remains of Japanese monkeys recovered from the cave inside are 500-2,740 cal BP, suggesting that the cave entrance has been opened to the cliff surface since 2,800 cal BP.

Speleothems, which are secondary deposits in caves, form generally under the cave environment: completely dark space with nearly 100 % moisture. Around the entrance of Saru-ana Cave, there are abundant speleothems, which cover the ceiling and walls, and they had already been dried to stop growing due to aridification, sunlight from the entrance and active air circulation between inside and outside of the cave. The existences of speleothems around the entrance suggest that the area around the present cave entrance was primarily enclosed by the limestone mass, hence speleothems could grow under the cave environment.

A specimen of a stalactite collected around the entrance consists of the two layers: the inner typical stalactite has concentric, transparent layers, and the outer tufa-like layer is similar in porous and white-colored to tufa deposits, which usually precipitates outside the cave. 14,400 BP of ^{230}Th age were measured from outermost surfaces of the stalactite layer and 9,500 BP from outermost surfaces of the tufa-like layer, respectively. In general the growth cessation of speleothems is caused by decreasing or suspension of supersaturated H_2O-CO_2-$CaCO_3$ solutions supply through the fissures of the limestone bedrock or aridification within the cave due to active air circulation. The presence of tufa-like layer suggests that the environment around the present entrance during the 14,400-9,500 BP period was not suitable for speleothems to glow. The ancient rock failure about 14,400 years ago removed the surficial rock masses of steep slope to let the enclosed cave passage to be opened physically to the outside. ^{230}Th age for the outermost tufa-like layer indicates that more ancient rock failure probably occurred after about 9,500 years ago and activated the air circulation between the inside and outside of the cave.

Here we formulate the rock failure-induced cave-opening hypothesis based on ^{230}Th ages for a stalactite, ^{14}C ages of the skeletal remains of Japanese monkeys and behavior as cave use by Japanese monkeys, to be more precise, at least two ancient rock failures occurred about 14,400 years ago and during 9,500-2800 years ago. For dating the slope movements within the karst region, various pieces of information obtained from caves; e.g. speleothems, behavior as cave use by some kinds of mammals, and others, may be useful tools.

Keywords: rock failure, stalactite, cave, cave use, Japanese monkey, speleothem

Rock avalanches controlled by a thrust fault and river incision in an accretionary complex of the Shimanto Belt

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The purpose of this study was to clarify the geological and geomorphological background of rain-induced rock avalanche occurred in the Shimanto accretionary complex. We performed the detailed geological survey for the area of 5.4 km^2 in the middle of the Kii Mountains in Japan. In this area, the two large rock avalanches (Akatani and Akatani-east, both have the volume over 10^6 m^3) induced by the heavy rain of Typhoon Talas in 2011. Using the 1 m DEMs made before and after the landslides, we performed the detailed geological survey and geomorphological analysis of deep-seated gravitational slope deformation. We investigated the distribution of the thrust faults with the incohesive brittle facture zone in the mountain slopes and the inner structures of these thrusts. And, we performed the mineralogical analysis, permeability test and direct shear test to know the material features of the gouge. Around the Akatani landslide we investigated the faults distribution in the slope by boring data.
As a result, we found out that the two large rock avalanches have the main sliding surfaces corresponding to the same thrust (we named the Kawarabi thrust) with the clayey brittle fracture zone with the maximum width of 6 m. Two landslides slid under the condition of wedge failure consisting of the Kawarabi thrust and some high-angle faults. It is estimated that the gravitational deformations started at the timing when the depth of the Kawarabi thrust under the slope toe reached the threshold value. The Kawarabi thrust has the clayey crushed materials to the surrounding rock mass, and form the discontinuity of ground water, and prevent the ground water flows, and builds up the pore water pressure in the heavy rain.

Keywords: rock avalanche, thrust, river incision, accretionary complex, gravitational slope deformation, rain

A flexural toppling failure in the northern Central Range, Taiwan

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On December 19, 2016, a rockfall occurred on the right bank of the Baishi Valley at the downslope of the Taigang village, in Taiwan. The rockfall continued lasting more than two weeks, opened a number of new tension cracks in the head area and the rock masses did not travel far, but formed a steep cone at the foot of the slope. However, no trigger for the collapse is evident. Geologic and geomorphic investigations indicate the rockfall occurred in a old landslide scar within a gravitational deformed slope at its lower part. The strata is mostly composed of argillite and alternating beds of sandstone and mudstone at the foot of the slope. The argillite strata has well developed slaty cleavage, which strikes NE–SW and generally dips at 80˚ along the riverbed to the north of this slope, but was observed to have flexurally toppled downslope in the landslide scar and in the deformed slope. In addition, the alternating beds are also bent downslope. Toppled beds had open fractures, which had been created during toppling deformation, and had also resulted in small scarplets of about 1 m high beyond the landslide crown. Moreover, morphological phenomena on the upper slope such as a ridge-top depression and a juxtaposing convex slope indicate that the slope deformation have already taken place long before and this deformation provides a basic cause for the occurrence of rockfall event.

Keywords: flexural toppling, rockfall, gravitational slope deformation, Taiwan

