Dating a past landslide event found on tephra-mantled slope of Takanoobane lava dome, Aso volcano, Japan

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On 16 April 2016, strong earthquakes (Mw7.0 main shock and subsequent aftershocks; hereafter the 2016 Kumamoto earthquake) struck Kumamoto prefecture and triggered numerous landslides on hillslopes of Aso volcano, southwestern Japan. Landslide on tephra-mantled slope of Takanoobane lava dome (hereafter the Takanodai landslide) caused the most serious damage due to its long runout. To assess future risks for landslides on tephra-mantled slopes, it is important to clarify landslide history of the lava dome. We found a 100-m-wide hollow adjacent to the Takanodai landslide. This report shows the results of tephrostratigraphic observation at the hollow and radiocarbon dating for buried paleosols that indicate the occurrence of a landslide event about 7,200-7,000 years ago.
Takanoobane lava dome, a hummock formed by lava-flow eruption about 51,000 years ago (51ka), has very gentle slope of (5-15 degree). The slope is mantled by unconsolidated tephra layers (mainly consist of silty ash and soil) accumulated after the lava dome formation. The tephra layers include three key layer: Kusasenrigahama pumice (Kpfa; 30ka), pyroclastic fall deposits produced by the largest eruption after the Aso caldera formation (90ka~), and two widespread tephras, Aira-Tanzawa tephra (AT; 29ka) and Kikai-Akahoya tephra (K-Ah; 7.3ka). Accumulated thickness of the layers is about 13 m at the most. The Takanodai landslide formed slip surface in Kpfa or buried paleosol beneath Kpfa, and consequently eroded tephra layers accumulated during the last 30,000 years.
By using detailed topographic map developed based on LiDAR observation in January 2013, we found many hollows which could be formed by erosion of tephra layers on the slope of the lava dome. The Takanodai landslide occurred on southwest-facing slope, where no hollows were found before the 2016 Kumamoto earthquake. On south-facing slope adjacent to the landslide, a 100-m-wide hollow bordered by a horseshoe-shaped knick line were observed. Cross sections of the knick line had unclear, rounded shape with 3-6 m drop, suggesting that head scarp of past landslide(s) was buried under tephra layers produced after the landslide event.
In profile of boring core at the center of the hollow (BV28-1), tephra layers above the Takanoobane lava was only 4.80 m thick, and lacked three key layers (i.e., Kpfa, AT and K-Ah). The uppermost layer of BV28-1 was 2.30-m-thick kuroboku-loam alternations. Apparently disturbed soil layer, which included carbonaceous materials and fine particles of orange pumice (Kpfa?), was found between 2.30 and 3.15 m depth. Meanwhile, yellowish sandy ash-fall layer between 3.15 and 3.30 m depth appeared undisturbed due to its clear boundaries at the both sides. Buried paleosol just below the ash-fall layer was gradually changed dark-brownish silty soil to brownish volcanic ash soil at around 3.60 m depth, directly overlying the Takanoobane lava (4.80 m depth~).
Comparing these stratigraphic features to profiles observed in boring core at the top of the lava dome (BV28-2) and outcrops at the head scarp of the Takanodai landslide, unconformity of BV28-1 became clear. We considered that an erosional surface was located within the disturbed layer between 2.30 and 3.15 m depth, and the kuroboku-loam alternations above the layer developed after erosional event. In addition, the yellowish sandy ash-fall below the erosional surface could be correlated to either basal fall unit of Kpfa or Mizunomoto pumice 1 (MzP1; 31ka), based on its facies and mineral assemblage.
As results of radiocarbon dating (AMS method) for two paleosols sampled from BV28-1, we obtained conventional ^{14}C ages: 6,170±30 yrBP from kuroboku of 2.20 m depth, and 27,410±110 yrBP from

dark-brownish paleosol of 3.35 m depth. Calibrated results (2 σ) of these ages were 7,164-6,976 calBP and 31,445-31,064 calBP, respectively. The ages were match with our hypothetical process (i.e., timing and extent of past erosional events) which formed the present topographic and stratigraphic features on the slope of the lava dome.

The above results explain that tephra layers accumulated during the past 23,000 years (from the 30ka Kpfa eruption to the 7.3ka K-Ah eruption) has been eroded at the hollow observed in this study, while the erosional surface was buried under soil layer (kuroboku-loam alternations) developed during the last 7,000 years. This finding indicates the possibility that strong earthquake(s) struck Aso volcano regions just after the K-Ah eruption (about 7,200-7,000 years ago), and triggered mass movements on the slope of Takanoobane lava dome as same manner as the Takanodai landslide of the 2016 Kumamoto earthquake.

Keywords: Aso volcano, Takanoobane lava dome, Tephrostratigraphy, Kusasenrigahama pumice, paleosol, 14C age

Landslides on the tephra slope with the sliding surface formed in pumice and volcanic soil beds triggered by the 2016 Kumamoto Earthquake, western part of Aso caldera, Kyushu, southern Japan

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The Kumamoto earthquake occurred on 16th April 2016 with a moment magnitude of 7.0 and induced many landslides in the western part of the Aso caldera. One of the most devastating landslides induced by this earthquake occurred on tephra slopes, because they occurred on rather gentle slopes and ran out long distances. We investigated the topography and geological features of these landslides and analyzed mineralogy and physical properties of each tephra layer. Their sliding surfaces were accommodated in characteristic beds: The most dominant beds were pumice beds, next were volcanic soil layers, and the much less numbers were scoria layers and volcanic ashes.
The basement of the survey area consists of lava flows and pyroclastic rocks with a wide range of chemistry from basalt to rhyolite (Ono and Watanabe, 1985). They are thickly covered by tephras, of which volcanic soil can be classified from color tone (Watanabe and Takada, 1990); we classified the volcanic soil into brown volcanic soil (Br), black volcanic soil (Bl), and blackish brown volcanic soil (BlBr). The pumice beds distributed to the most in the surveyed area is Kpfa of about 30 ka in age (Miyabuchi et al., 2003).
All of the pumice beds and Vs layers that accommodated sliding surfaces, had a clay mineral, halloysite. The most common pumice beds with sliding surfaces was Kpfa, and other pumice beds accommodating sliding surfaces were very few. The weathering extent of Kpfa varied from rather fresh one to intense one and the pumice clasts of Kpfa with sliding surfaces were intensely weathered to become clayey materials. Vs layers accommodating sliding surfaces were mostly BlBr layers, in which desiccation cracks were made when dried, suggesting that their high water contents just after the landslide. All of the investigated landslides with sliding surfaces in BlBr layers had no pumice layers with them, and landslides involving BlBr and Kpfa layers had sliding surfaces in Kpfa layer. This fact may suggest that that Kpfa could be the most preferable layer for a sliding surface to be made in. Landslides with sliding surfaces in BlBr layers probably occurred on slopes that lacked Kpfa layers because of original non deposition or subsequent removal by landslides. Landslides with sliding surfaces in pumice layers were mainly distributed on gentle slopes at the foot of the Aso central cones, while the landslides with sliding surfaces in BlBr layers were distributed on relatively steeper slopes. Original non deposition may be attributable to so steep slopes for their deposition or their small supply from the eruption sources.

Keywords: Kusasenrigahama pumice (Kpfa), Volcanic soil, Halloysite

Evaluation of slope stability for the earthquake-induced sediment due to intense rainfall

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On April 16, 2016, the Kumamoto earthquake, the second of the two significant earthquakes has occurred in Japan, and associated aftershocks, appears to have triggered numerous landslides. Though the position of Kumamoto earthquake-induced landslides are published as point data by Geospatial Information Authority of Japan (GSI), in general, it is a big problem to extract the distribution of landslides in a wide area. In addition, high-intensity rainfall caused many shallow landslides, leading to significant damage, and it is possible that the instable sediment which is triggered by earthquake is going to collapse in the future. In a previous study of GIS-based 3D slope stability analysis[1)], it requires not only the geological parameters but also distribution of the collapse sediment.
Therefore, the purpose of this study is to monitor landslides activities for emergency disaster control, and evaluate slope stability of earthquake-induced sediment in a high intense rainfall condition to minimize damage of landslides in the future. The study involves three part: extracting earthquake-induced landslides information, simulating sediment which was triggered by intense rainfall to get soil parameter, and evaluation of slope stability of Kumamoto earthquake-induced sediment.

As a result, SAR is able to provide landslides interpretation using color composition in Aso-Kumamoto and as a real-time system it is a very good way to minimize earthquake damage. It is clear that non-compacted sediment type has the best result as Kuroboku soil. There is high possibility that collapse type is similar with non-compacted sediment collapse if the soil structure of landslides is Kuroboku soil.

Keywords: Kumamoto earthquake, landslide, slope stability

Study on landslide-susceptible slopes by heavy rain in the Aso Caldera, Southwest Japan

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The Aso Caldera located in Kyushu, Southwest Japan has been affected by concentrated occurrences of surfacial landslides in the tephra layers in the recent decade. This study aims to propose the detection of slopes with landside susceptibility by heavy rain based on interpretation of LiDAR-based high-resolution topographical maps. Remnants of past landslides are widely distributed on the tephra-covered slopes. Analysis on the locations of recent landslide occurrence indicates that surrounding slopes of remnants of surficial landslides and steep valley side slopes are prone to landslides by heavy rain. Inside of past landslide slopes partially covererd with collapsed materials also may become susceptible after time of tephra deposition.

Keywords: landslide, tephra , Aso Mountains

Deep-seated catastrophic landslides induced by large earthquakes along the Nankai and Sagami troughs

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We examined 32 landslides induced by large earthqukes along the Nankai and Sagami troughs and we made field investigations for 11 landslides and found their geological causes. They were induced by the 684 Hakuho, 1707 Hoei, 1854 Ansei Tokai, 1854 Ansei Nankai, or 1923 Kanto earthquake. One of the most outstanding landslide types was of pyroclastic fall deposits induced by the 1923 Kanto earthquake: those landslides occurred rather gentle slopes and had high mobility. We confirmed 3 landslides (Shinseiko, Nebukawa, and Nebukawa station) of this type and probably other 7 landslides could be of this type. One landlside horizon accommodating a sliding surface was the Tokyo Pumice about 65 ka, which covers wide area in Kanagawa and Tokyo area, suggesting future potential landslides. We have recognized many older landslides of this type on LiDAR images.
Another type of landslides was toppling failure of slate, Neogene sedimentary rocks, and Mesozoic accretionary complexes. We confirmed 6 such landslides of this type (Kanagi, Oya, Shirotoriyama, Shichimenzan, Ikeyama, and Nakagochi). Ikeyama landslide may be a complex of toppling and sliding. Oya and Shirotoriyama landslides made landslide dams, which breached later and severe damage downstream. Kanagi and Ikeyama landslides could have occurred in combination with large earthquakes and following rainstorms.
Another typical example of earthquake-induced landslides was buckling failure of stratified rocks: alternating beds of sandstone and mudstone and mixed rocks at Ishigami and conglomerate at Shimobe. Buckling type landslide was found only two locations, but it has been induced by many other earthquakes. Shimobe landslide probably made a landslide dam because the deposits have a mound on the opposite side.
There occurred many rain-induced landslides in the outer belt of southwest Japan, and we have found many of them can be attributable to thrust faults with large brittle crushed zones, which may be a different setting from those of earthquake-induced landslides.

Keywords: Landslide, Nankai Trough earthquakes, Prediction of potential sites

Distribution of highly saline groundwater in the areas with many landslides in the southern Niigata Prefecture

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Numerous numbers of landslides have occurred in the areas of Neogene sedimentary rocks in the southern Niigata Prefecture. They have been called Tertiary type landslides and their occurrence has been attributed to the weakness of those rocks, but recent studies have found highly saline groundwaters beneath some landslides and suggested those groundwaters may be related to landslide activity (Watanabe et al., 2009). However, distribution of highly saline groundwater in wide areas is not known and the actual relationship between highly saline groundwater and landslides has not been validated. We have conducted geological surveys and the CSAMT geophysical exploration in and around the Nagakurayama anticline, where many landslides and gravitational slope deformations are recognized.
The Nagakurayama anticline consists of Neogene massive tuff, mudstone, and alternation of tuff and mudstone beds, which are folded with an axis of NNE-SSW and plunging to the north and the south. The hinge line is along a ridge. There are many landslide units on both wings of the anticline, and there are linear depressions along the ridge. Other anticlines and synclines are aligned subparallel to the Nagakurayama anticline in the Higasi-kubiki hills, Niigata (Takeuchi and Kato, 1994).
Our CSAMT survey showed that the surveyed area is widely underlain by zones of low resistivities (<10 Ω m) generally deeper than about 100 m and that much higher resistivity areas are present shallower than the level. High resistivity zones extend much deeper just beneath the linear depression. Comparing with the results with geological cross sections, higher resistivity zones may correspond to tuff and the linear depression. The interstitial water of mudstone may be highly saline water in the depth and might be replaced by fresh water at shallower zones. The replacement could deteriorate rocks and likely be the basic causes of landslide occurrence.

Keywords: Deep-seated groundwater, Resistivity, Landslides

Development history of ridge-top depressions east of Kamikochi, central Japan: Correlation between Nagakabe Ridge and Tokugo Pass

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The ridges between Mt. Chogatake and Tokugo Pass in the Japanese Northern Alps, about 2,500 m above sea level (asl), have round-top and steep-slopes. Deep-seated gravitational slope deformations with topographic features such as multiple ridges and ridge-top depressions are well-developed on the NE-SW trending ridges, because the basement rocks in this area are Jurassic accretionary complexes with bedding planes generally striking NE-SW. The sediments accumulated in the ridge-top depressions were cored by using hand-auger boring system at the 2,000 m (asl) point on the Nagakabe Ridge (Point A) and at the 2,150 m (asl) point to the NE of Tokugo Pass (Point B), and the lithology of the sediments were described and the refractive index of volcanic glasses in very-fine sand fractions were measured. The sediments at Point A are mostly composed of silty to sandy mud, although those at Point B are volcani-clastics. Two cores drilled at Point A have peaks of volcanic glass contents of the K-Ah tephra (7,300 cal BP) at 67 and 90 cm depth, respectively, while the core at Point B includes K-Ah glass at all depths. The sediments at Point B are probably originated by the volcanic activities of Mt. Yakedake, which is located about 9.5 km WSW from Point B, about 2,000-5,000 years ago on the basis of their sizes and compositions. The sediment accumulation rates are calculated ca. 0.1 mm/y for the points A, and faster than 0.26 mm/y at Point B. The difference is also related to the distance and direction from Mt. Yakedake of these points.

Keywords: deep-seated gravitational slope deformation, double ridge, landslide

Early Holocene large landslide in the Goansawa River Basin on the southern slope of Mount Amari in Yamanashi Prefecture, central Japan

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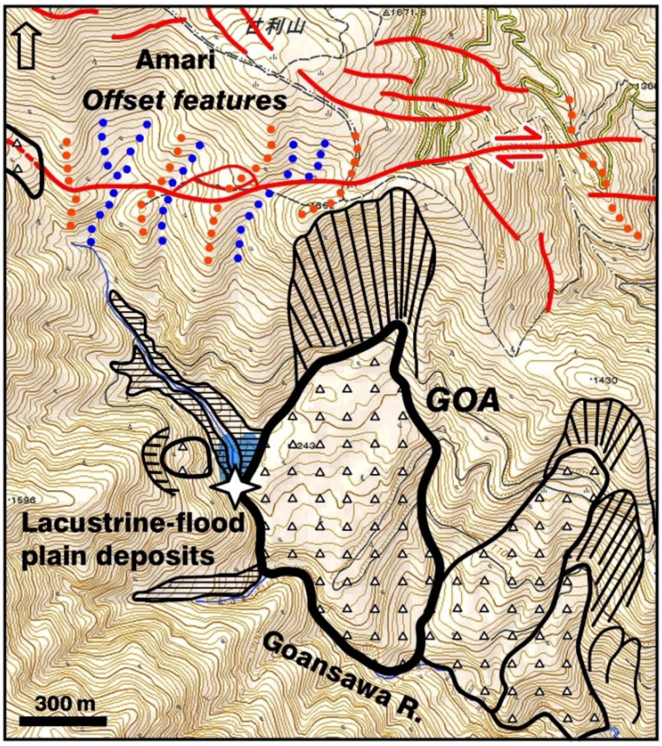
This presentation describes the features of a large-scale landslide as well as a synchronous dammed-lake and a flood plain occurred in the early Holocene from Quaternary geological and geomorphological perspectives. This landslide, called Goan-sawa landslide (GOA), has a set of distinct head scarp and landslide body on the southern face of Mount Amari (1740 m ASL) in the Koma Mountains. The estimated volume of landslide body is over V=1.2×10^7 m^3. Thick lacustrine and flood plain deposits formed by damming of the landslide body provide chronological constraints of GOA. Radiocarbon ages of fossil wood fragments and a very thin tephra bed of the Kikai-Akahoya (7300 cal BP) in the lacustrine and flood plain deposits demonstrate that the initial activity of GOA and formation of the dammed-lake took place during 8000-7700 cal BP. A dammed-lake persisted for 3000 yr until ca. 5000 cal BP. A possible trigger of the initial movement of GOA is a paleoearthquake derived from nearby or remote active faults including active plate margins such like Suruga and Nankai Troughs. In particular, the southern behavioral segment of the Itoigawa Shizuoka Tectonic Line Active Fault Zones situated 5 km east of GOA is a strong candidate that was displaced around 8400-7200 cal BP. Furthermore, this presentation provides a conspicuous lineament with systematic dextral offsets of minor ridges and channels on the southern face of Mount Amari, just behind the main head scarp of GOA. This extensive surface feature would reflect large-scale deep-seated gravitational slope deformation of Mount Amari and may relate to the activities of GOA. An attached figure is a geomorphological map of GOA and its adjacent slopes. A star indicates the outcrop locality of dammed-lake and flood plain deposits.

Keywords: Deep-seated gravitational slope deformation, Kikai-Akahoya tephra, Itoigawa-Shizuoka Tectonic Line Active Fault Zone, 14C ages, Quaternary geology and geomorphology



Amari
Offset features
GOA
Lacustrine-flood
plain deposits
Goansawa R.
300 m

A slope failure at Shiretoko-Rausu, Hokkaido, in August 2016

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Many typhoons came near Hokkaido in August 2016. These gave damages in Eastern Hokkaido. The precipitation reached 554mm between 9days, 15th to 23rd August, at Shiretoko-Rausu, Eastern Hokkaido, where annual precipitation is ca.1600mm. The largest slope failure at the time occurred at Kaigan-cho, in Rausu, at 4 pm on 24th, 29 hours after the rain stopped. The failure occurred repeatedly between about 30 minutes from the gentle piedmont on a terrace. The source of this slope failures is 60m length, 40m width and 8-10m depth. The amount of collapsed sediment was estimated to be 19,000m3. The collapsed debris is high liquidity, and reached the coast more than 100m away (equivalent friction coefficient: H/L=0.3).
The primary source of the collapse consists of poor sorted sediments, silt with angular, on alternation of gravel and mud with low permeability. This is periglacial sediment, which is common slope deposit in Hokkaido, northernmost Japan. This sediment holds much water after heavy rain as a result of loose and high permeability. A vertical hole, 3m in diameter, appeared in the deposits. Groundwater streams concentrate on the base of the sediment. Because piping holes were eroded by the streams, the vertical hole was formed by the collapse of one of the piping holes.
Andesite is distributed behind the collapsing slope deposits, and the andesite is lower permeability than the slope deposits. This causes that the groundwater level of the andesite rises appeared to be delayed. It is likely that the slope failure occurred with a delay due to the supply of the groundwater from the andesite behind. Because the front of the slope sediment has disappeared by the slope failure, groundwater flowed and formed piping falls due to water level difference.

Keywords: slope deposits, periglacial deposits, piping hole, groundwater level, slope failure, heavy rain

The disaster prevention system by open source hardwere and the acceleration sensor

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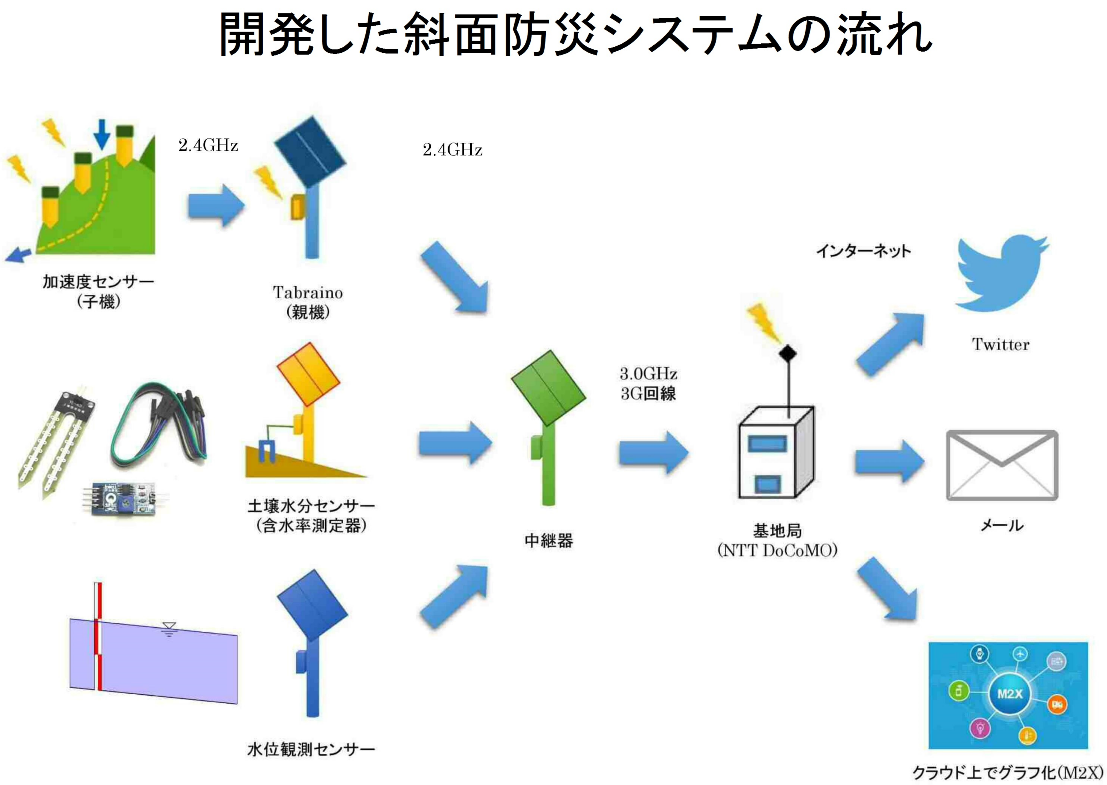
Japan, in August 2014 received a large-scale landslides caused by torrential rain in Hiroshima City. This disaster is repeatedly generated every year, the number tends to increase. As a factor, there is such as thing, humid climate and steep terrain that the Japanese archipelago of the ground is made of igneous rock. In addition, it is expected the occurrence of such disasters in the future by guerrilla heavy rain and earthquakes. So, we went the terrain and ground survey of the places at which occurrence of landslides from the history of past disasters is expected. Also we developed an inexpensive slope disaster prevention system using the acceleration sensor. This system will reduce the damage of the landslide disaster.
In this paper, it was the subject of investigating the Isehara, Kanagawa Prefecture Oyama. Describes the development of disaster prevention system by the survey results, the ground survey methods and acceleration sensor that was made in that location

Keywords: landslide, Sediment disaster, acceleration sensor, open source hardwere, disaster prevention system



Application of analysis method using S-DEM data for landslide measurement

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1. Introduction
In recent years, disasters associated with abnormal weather such as “guerrilla rainstorms” have occurred. In particular, in Japan there is an increasing risk of occurrence of various slope failures such as slope collapses of shallow depth and debris slides, but it is difficult to predict the occurrence of slope failures and take preventive measures because it is difficult to capture phenomena that are prognostic of slope failure. Observation methods for wide-area slopes using ground-installed equipment such as extensometers have not been in widespread use because of the cost and labor involved. Therefore, the development of a new slope monitoring approach is needed. In this paper, we propose a measurement and analysis method for computing the movement of slopes, using point cloud data, with a high degree of accuracy. We discuss the results of an experiment in an actual slide debris field and report the applicability of our proposed method.

2. Method for analysis of slope displacement
In general ,a ground data filtered from original data of LiDAR survey system becomes relatively monotonous Digital Elevation Model(DEM) which removes the influence of vegetation (Mukouyama ,2011). We developed a method that can extract the minute topography from the original laser data by using only the laser data from below a certain height from the ground surface. The result from the method developed here has a resolution of 10 cm. This analysis were used "MIERRE" that was developed Nakanihon Air Services. Its experimental trials were performed to verify the applicability of our proposed method, and the results show that more than approximately 0.4 m changes in the displacement of the slope could be detected in the area where a debris slide occurred (Kikuchi et al,2017).

3. Application of our method
The Location is located two area of slope displacement on reservoir of dam. We measured the minute displacement of landslides between the first and second surveys. The laser point clouds data density of the laser scanner on the airplane in the specification was in the range of 100 to 120 m2, and 5 to 10% of them reached the ground surface. The amount of displacement at the measurement point in Non-moved block indicates the accuracy of our measurement technique.

3.1 Test field A
Test field A is a debris slide site facing the reservoir. From the results of minute topography and field work, it was presumed to be a slope on which surface collapse will proceed. In the case of the measurement of the two times LiDAR-data, the maximum displacement amount of 4.6 m was confirmed within the range of the altitude difference from the reservoir altitude to the upper end of the surface collapse of about 100 m (show in the left-hand fig.2). This result estimates processing of debris slide on the surface layer confirmed in the field work. In addition, since 0.3-1 meter deformation in the reservoir direction is recognized in the upper rock block of the surface collapse.

3.2 Test field B

Test field B is a landslide due to heavy rain of typhoon 12 which occurred in September 2012. The landslide is not observed on the landslide map by the National Research Institute for Earth Science and Disaster Resilience. It is presumed a Primary landslide. As a result, the fluctuation vector quantity is a detection quantity of about ±0.3 m which is a range of almost error inside and outside the landslide block (show in the right-hand fig.2), and there is no tendency for the direction of the vector to be collected, so that a significant fluctuation exceeding the error. It is judged that it will not be accepted, and we will continue to measure regularly in the future.

4. Conclusions
In this study, we developed a technique for measuring slope displacements using three dimensional laser point group data, or LiDAR data. In this technique, we used only the laser data that is reflected from objects at heights of 2–5 m from the ground surface. Moreover, we developed a matching method for images created from the limited laser point group data in order to compute displacements using time series laser data. Experimental trials were performed to verify the applicability of our proposed method, and the results show that more than approximately 0.3 m changes in the displacement of the slope could be detected in the area where a debris slide occurred as shown in Fig. 2. We have demonstrated that it is possible to expand the applicability of airborne laser surveying to monitor slope failure by using the method proposed here.

Keywords: Landslide, Digital Elevation Model, Point cloud data, Monitoring of slope movement

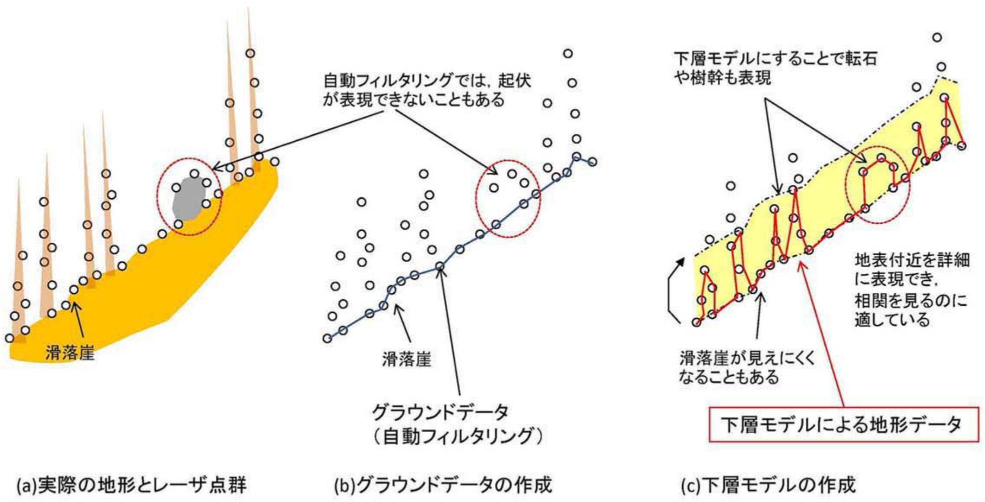

図-1 グランドデータと下層モデルを使用することによる得られる点群の違い

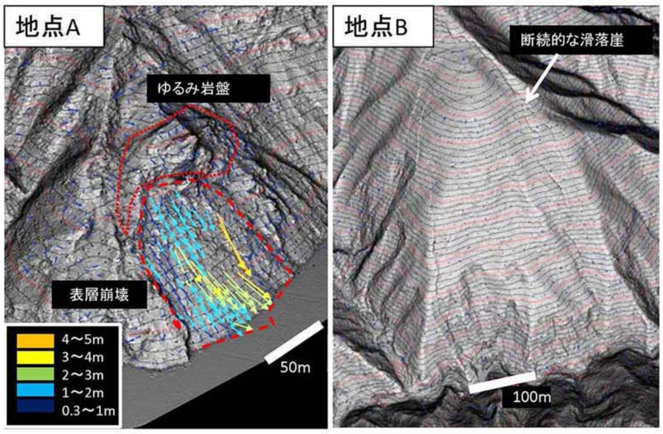

図-2 各地点の変動ベクトル解析結果