

## Analysis of landslide monitoring using an e-GPS system and multi-antenna GPS technology Analysis of landslide monitoring using an e-GPS system and multi-antenna GPS technology

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Based on GPS technology, this study monitored the movement of the landslide that impacted Taiwan's Formosa Freeway. Two monitoring systems and two data-processing software programs were employed. Auxiliary data were obtained from the GPS, raingauges, inclinometers, and water table meters for landslide analysis. The goal of multi-sensor monitoring was to construct an automatic early warning system for driver safety. Analytical results indicate that the landslide moved on average 1 cm/month in the southeast direction; that is, it moved slowly toward the Formosa Freeway, thereby posing a potential safety hazard for drivers. The positioning precision of the multi-antenna GPS (0.18, 0.25, and 0.57 cm in the north, east and vertical directions, respectively) was better than that of static relative positioning (0.29, 0.44 and 1.01 cm) and that of e-GPS technology (1.69, 1.35 and 2.45 cm).

キーワード: e-GPS, multi-antenna GPS, landslide, Taiwan  
Keywords: e-GPS, multi-antenna GPS, landslide, Taiwan

## 沖縄島南部玉城におけるGPS測距による地這りの可能性

## A Possible Slope Failure monitored by GPS Ranging in Tamagusuku Village, Southern Region of Okinawa Island

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沖縄県南部、玉城（たまぐすく）での国土地理院によるGPS観測点の変動状況より、この地点が緩やかな地這りを起こしている可能性、また、このことが降水量に連動した可能性について、最新の記録をもとに考察を行う。

## 伏野地すべり地における地震時の間隙水圧変動

## Fluctuations in pore-water pressures triggered by earthquakes at the Busuno landslide

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### 1. 背景

近年、わが国において地すべり災害を引き起こした地震として、新潟県中越地震（2004年, M6.8）や新潟県中越沖地震（2007年, M6.8）岩手・宮城内陸地震（2008年, M7.2）などがある。地震によって難透水性の地すべり地の地盤がせん断・圧縮応力を繰り返し受けると、過剰間隙水圧と想定される水圧変動が観測されることがあり、これによる斜面の不安定化が指摘されている。

岡本ら（2006）は地すべり地の現地観測により、地震時に間隙水圧がスパイク状に変化することを示した。しかし、例えばどのような揺れに対して間隙水圧が鋭く反応するのかといった、地震動と間隙水圧変動の定量的な関係については言及していない。そこで、本研究では地すべり地における地震動の振動特性と間隙水圧変動の関係について、現地観測データをもとに解析をおこなった。

### 2. 観測・解析方法

筆者らは第三紀層の再活動型地すべり地である新潟県上越市伏野峠地区地すべり（以下、伏野地すべり地）にて観測をおこなっている。

#### ・地震

本研究では2004年新潟県中越地震（EQ1）およびその最大余震（EQ1'）、2007年新潟県中越沖地震（EQ2）、2011年長野県北部地震（EQ3）およびその最大余震（EQ3'）、以上の5つの地震動について解析をおこなった。伏野地すべり地では2010年から地震観測を開始したためEQ3およびEQ3'は実測できたが、それ以前の地震データ（EQ1、EQ1'、EQ2）は実測値が無い。そこでそれらは、伏野地すべり地から約10km離れた防災科学技術研究所 K-net 安塚 (NIG 024) の観測値に司・翠川 (1999) による断層最短距離の距離減衰式を適用して伏野地すべり地での最大加速度・最大速度を推定した。また、観測した地震波の応答をみるため、応答スペクトルを求めた。

#### ・間隙水圧

伏野地すべり地は移動の様式から上部・中部・下部ブロックに分けられ、このうち中部ブロックに間隙水圧計を埋設し、10分間隔の観測をおこなった。EQ1,1'、2の観測時は5基の間隙水圧計をすべり面近傍に設置したが、その後、全ての計器が積雪荷重により圧壊したため下部ブロックに新たに2基を埋設し、EQ3,3'時はこの2基を用いて観測した。また、間隙水圧計の観測が10分間隔となっているため、地震発生時から記録時まで時間差が生じ、観測値のまま使うことにより過剰間隙水圧値を過小に見積もることが予想された。この点を改善するため、地震後の消散過程より減衰曲線を作成し、ピーク時の間隙水圧を推定した。ただし、この減衰曲線の適用範囲は上昇した間隙水圧にのみ適用した。

### 3. 結果と考察

a>地震時の間隙水圧変動から、地震を契機に間隙水圧がスパイク状に変動（過剰間隙水圧）していることがわかった。そして、その変動方向は上昇箇所と下降箇所に分かれた。間隙水圧の減衰曲線より推定した間隙水圧変動値は、EQ3時に最大14.2 kPa、最低3.3 kPaとなった。

b>地すべり地にて地震と間隙水圧が同時に観測されたのはEQ3,3'時のため、特にEQ3,3'に注目する。EQ3の最大加速度は南北成分・東西成分に比べて上下成分が低いことが特徴的であり、EQ3'時も同様に上下成分のみ低い傾向であった。フーリエ解析の結果から、南北・東西成分は周期分布がよく似ており、卓越周期は0.3秒付近にどちらも分布していることがわかった。上下方向は0.05-1秒の間の広い周期帯で優勢であり、卓越周期は2.8秒であった。

c>EQ3以外の地震動による間隙水圧変動は大きくて3kPa以下であることから、EQ3時の水圧変動が極端に大きいことがわかる。その要因としてEQ3,3'発生時には地すべり土塊上に3mの積雪があり、積雪層の長期載荷によるすべり層の圧密という要因が重なり大きな水圧変動を起こした可能性が推察される。

d>5つの地震時における間隙水圧変動と地震波各成分の関係を解析したところ、地震前後の間隙水圧変動と相関関係にあるのは上下方向の最大加速度・最大速度・卓越周期と高い相関を示した。

以上の結果から、最大加速度以外にも最大速度や卓越周期、また地震動の卓越方向が間隙水圧変動に影響を及ぼす可能性があることがわかった。

# Japan Geoscience Union Meeting 2013

(May 19-24 2013 at Makuhari, Chiba, Japan)

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HDS06-P03

会場:コンベンションホール

時間:5月23日 18:15-19:30

## 引用文献

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キーワード: 地震動, 過剰間隙水圧, 最大加速度

Keywords: seismic motions, excess pore water pressure, peak ground acceleration

## 2012年7月極端降雨による阿蘇山カルデラでの高速地すべり - 土石流 Extremely rapid debris slide - debris flows induced by extreme rainfall on Aso volcano caldera slope in July 2012

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An extreme rainfall affected Kyushu Island of western Japan in July and induced hundreds of fluidized landslides claiming tens of casualties. Especially on the Aso volcano caldera cliff, a number of extremely rapid debris slide ? debris flows were induced and affected the downslope communities. Measured trigger precipitation was recorded by the nearby ground-based station of the AMeDAS network (Automated Meteorological Data Acquisition System) as about 80 mm/h for consecutive 4 hours. Analysis of Radar Rain-gauge Analyzed Precipitation operated by the Japan Meteorological Agency showed landslide affected area almost coincided with the ones of heavier precipitation. Most of the landslides were initiated on the boundary of strongly weathered soils, which used to be new volcanic accretion materials. Outstanding features of these landslides are: (1) This area had been affected by similar heavy rainfall decades ago, however, again a number of landslides took place in the nearby past scars; (2) Many of the soil slide bodies are shallow less than 5 meters deep and possibly immediately transformed into debris flows or mud flows and traveled long distance to reach the downslope communities; (3) Visual observation of the sources showed the high possibility that some of the slides were apparently induced by liquefaction. Similar cases were reported of past 2 landslide disasters in Japan. This strongly suggests that excessive rainfall can trigger numerous mud flows of unexpected reach. We conducted close field study at a typical soil slide - mud flow site. It originally initiated as debris or soil slide on a thin steep bedding plane of about 34 degrees consisting of coarser accretion materials. Needle penetration test showed comparatively weaker strength in the layer. It is underlain by a layer of finer materials. Such a higher permeability contrast could contribute to higher susceptibility of excess pore pressure generation. We took soil samples from the vicinity of sliding surface and conducted pore-pressure-controlled ring shear test. We increased pore pressure at constant rate

until failure after applying normal/shear stresses of certain ratio representing the steepness of the sliding surface for the normally consolidated (of 100 kPa) specimen prepared by disturbed samples. Immediately after failure took place, we observed quick and large drop of shear resistance in a few seconds. Although the applied normal stress of this test is larger than the actual one, this implied strongly the occurrence of the sliding surface liquefaction. The resultant shear resistance was so small and it can explain the mechanism of those long run-out and low apparent friction angle of those landslides.

キーワード: 極端降雨, 地すべり, 土石流, 過剰間隙水圧, カルデラ壁

Keywords: extreme rainfall, landslide, debris flow, excess pore pressure, caldera cliff

## Investigation of landslides on inner slope of Mt.Aso caldera triggered by heavy rainfall in Northern Kyushu in July 2012

## Investigation of landslides on inner slope of Mt.Aso caldera triggered by heavy rainfall in Northern Kyushu in July 2012

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Mt. Aso caldera is one of the largest calderas in the world. It is also known for typhoons and heavy rainfall during the rainy season. These relatively annual events have triggered shallow landslides and debris flows, which have caused severe casualties, destroyed properties and displaced local city dwellers. From July 11 to 14, 2012, an intensive rain fell on the Northern Kyushu during rainy season. a value higher than the highest local precipitation recorded in the last decade. This high precipitation triggered shallow landslides, especially around the rim of the caldera, which affected many villages and local settlers. Detailed field investigation was conducted to study the motion mechanism of shallow slope failures triggered by the heavy rainfall. A representative site, which is located in Ichinomiya, Aso-gun, Kumamoto Prefecture was selected for this study. Several field geotechnical tests were carried out in the landslide site. Portable cone penetration tests were conducted to evaluate the nature and degree of consolidation of the sediments which are mainly composed of tephra and pyroclastics; in-situ permeability tests were conducted with variations in depth of hand-drilled bore holes so as to measure rainfall infiltration rate. Representative soil samples were collected from different layers of the main scarp for particle size distribution analysis, shear strength tests, and other laboratory soil strength analyses. Results obtained from detailed field and laboratory investigations carried out in the area show that the main factors contributing to the occurrence of shallow landslides and debris flows are incessant rainfall, surficial drainage and runoffs, topography, geologic and soil strength properties. These factors are enhanced by the interplay between the steep wall of the caldera (over 30 degrees) and high precipitation coupled with high number of irregular cracks that acts as conduits for easy infiltration to subsurface drainage system. Another process that could have affected the slope stability could be from steady undercutting of the slope toe by strong surface floods, which overtime reduces the shear strength of the material leading to shallow sliding failure.

キーワード: Landslide, Rainfall, Mt.Aso caldera, Northern Kyushu

Keywords: Landslide, Rainfall, Mt.Aso caldera, Northern Kyushu

## 山地河川における洪水時の地盤振動特性に関する一考察 Study on characteristics of ground vibration during times of flooding in mountainous rivers

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深層崩壊等大規模な土砂移動現象は発生時に地盤振動を生じることが知られており、高感度な地震計ネットワークを活用して発生時刻や発生箇所、および規模の推定が試みられている。一方、例えば豪雨・洪水時には地震計の計測データにホワイトノイズが増幅することが確認されている。ホワイトノイズの増幅はSN比の低下に直結することから、前述のような振動波形の利活用において支障をきたすことが考えられる。しかし、この現象が何に起因して生じるのかは明らかにされていない。

本研究では、山地河川で観測された流量データと振動データを用いて、豪雨時に生じるホワイトノイズの増幅の分析および振動イベントに対する比較を行った。また、洪水時に観測された土砂移動現象の振動について分析を行った。その結果、ピーク流量を観測する前の流量と振動に相関があることを明らかにした。また、検討事例では土砂移動現象と洪水を分離することが可能であった。

キーワード: 振動センサー, 洪水, 流量, 速度振幅, 土砂移動現象

Keywords: Vibration sensor, Flood, Discharge, Amplitude of velocity, sediment movement phenomenon

## Simulations of seismic signals induced by landslides by numerical coupling of PFC and FLAC

### Simulations of seismic signals induced by landslides by numerical coupling of PFC and FLAC

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We developed a two-dimensional numerical coupling approach using the Particle Flow Code (PFC) and Fast Lagrangian Analysis of Continua (FLAC) code to simulate the flow process of landslides and rock avalanches. We used the Xiaolin rock avalanche as a case study. The sliding of the rock fragments was simulated by PFC. When the rock fragments impact on the top boundary of FLAC, forces and displacements of the boundary grids will be transmitted between the two codes. We assigned monitoring locations in the coupled numerical model to record the seismic signals induced by the simulated rock avalanche. The time-frequency spectrograms of the seismic signals were analyzed using Hilbert-Huang transform (HHT) for examining the seismic characteristics. The simulated results were compared with the seismic signals recorded during the landslide from a broadband seismic station, SGSB, which is 11.4 km away from the Xiaolin landslide site.

キーワード: PFC, FLAC, HHT, Xiaolin, landslide  
Keywords: PFC, FLAC, HHT, Xiaolin, landslide



## Variations of topographic feature of a Major Typhoon Variations of topographic feature of a Major Typhoon

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In August 2009, in Taiwan, Typhoon Morakot with a maximum rainfall of over 2,900 mm, induced over 23,000 landslides in mountainous area throughout southern Taiwan. One large scale deep-seated landslide, the Hsiaolin landslide, with an area of about 250 ha, buried the entire village causing 397 casualties, the disappearance of 53 people, and the destruction of over 100 houses (Lin et al., 2011; Tsou et al., 2011). The LiDAR-derived 2m resolution DEMs before and after Typhoon Morakot was utilized in this study to perform the relation between slope and contributing area. Montgomery and Foufoula-Georgiou (1993) suggested a partitioning of the landscape into drainage and slope regimes that include hillslopes (Region A), unchanneled valleys (Region B), debris flow-dominated channels (Region C), and alluvial channels (Region D). The comparison of slope-area relationship of Hsiaolin village before and after Typhoon Morakot indicates, no matter pre or post typhoon, the slope-area figure shows four regions with different scaling responses. However, there are remarkable for the significantly variation of scaling pattern in slope-area diagram after the deep-seated landslide. Sediment mass produced by deep-seated landslide with approximately  $2.7 \times 10^7$  m<sup>3</sup> (Wu et al., 2011) depleted from hillslope, nearly 90m deepest failure depth resulted in outward extend of upstream catchment boundary. Huge amount of sediment mass was transported downward also formed significant deposition in debris flow channel and alluvial channel, respectively. These phenomenon also reflects in slope-area graph, contributing area at parting between Region I and Region II migrate from 20 m<sup>2</sup> to 50 m<sup>2</sup>, that means hillslope length become longer due to outward development of upstream catchment boundary. The local slope in debris flow channel (Region C) and alluvial channel (Region D) both become gentler after this catastrophic landslide. The analysis only after an intense event, really represent a strategic tool for a directly quantification of the processes that affected and significantly changed the earth surface.

キーワード: DTM, High resolution topography, LiDAR, Slope?area relation

Keywords: DTM, High resolution topography, LiDAR, Slope?area relation

## ALOS パンシャープン立体視画像による山体重力変形の微地形判読 - 2009年台風モラコットによる台湾小林村の深層崩壊 Visualization of precursory features of Typhoon-induced Shiaolin landslide by ALOS pan-sharpened stereoscopic imagery

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Precursory topographic features of gravitational slope deformation may provide a clue in predicting potential sites of catastrophic landslides. Visual photo-interpretation of high-resolution images such as optical satellite imagery and aerial photographs together with field survey remains the most used method to recognize the precursory topographic features and locate gravitational slope deformation. Here, we utilized ALOS pan-sharpened stereoscopic imagery of anaglyph to recognize the precursory topographic features before Typhoon Morakot-induced catastrophic Shiaolin landslide in southern Taiwan on 9 August 2009. Developed by the coauthors, Ryuzo Yokoyama and Michio Sirasawa, the ALOS pan-sharpened stereoscopic imagery is generated from the data of PRISM (a panchromatic stereo mapping sensor of 2.5 m resolution) and AVNIR-2 (a visible and near infrared sensor of 10 m resolution). We compared it with underlying geological structure that was exposed by the catastrophic landslide and was investigated after the event. The results indicate that the source area had the precursory topographic features: irregularly shaped bulges and depressions in many locations, suggesting the slope had been gravitational deformed beforehand. At least four of the locations were confirmed that the precursory topographic features were related to gravitationally deformed beds of alternating beds of sandstone and shale on a dip slope. The deformed beds were buckled and result in undulating beds or asymmetrical folds near the exposed ground surface. Consequently, the precursory topographic features might reflect the internal geological structures of the deformed slope. Besides, several slopes near the Shiaolin landslide site also appear as gravitational deformed slopes and can be characterized as potential sites of large and catastrophic landslides.

キーワード: ALOS パンシャープン立体視画像, 山体重力変形, 大規模地すべり, 微地形

Keywords: ALOS pan-sharpened stereoscopic imagery, gravitational slope deformation, catastrophic landslide, precursory topographic feature

## Experimental examinations of the soil-water characteristics of a loess soil, China Experimental examinations of the soil-water characteristics of a loess soil, China

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In Northwest of China, many loess landslides have occurred without obvious triggering factors (i.e., rainfall, earthquake, etc). These landslides have loess that is desiccated from the ground surface to a considerable depth, and pore-water pressure at shallow depths is generally negative with respect to atmospheric pressure. To understand and analyze the pore-water pressure distribution of these slopes and then provide evidence for their stability analysis subjected to matric suction, it is essential to study soil-water characteristics. Furthermore, the soil-water characteristic curve (SWCC), representing the relationship between volumetric water content and matric suction, has been developed to interpret and predict the mechanical behaviors of unsaturated slopes. In this study, A set of experimental trials were carried out to examine the influences of initial dry density, moulding water content and particle size fraction upon the soil-water characteristics of loess soil in Northwestern China. The experimental results were obtained by using a conventional volumetric pressure-plate extractor. The results indicated that volumetric water content had a monotone-decreasing nonlinear relationship with matric suction for all loess specimens. However, the dry density had considerable influence on soil-water characteristics. When the dry density increases, the air-entry value increases and rate of desorption decreases. Moreover, by comparing the soil-water characteristics of the specimens that have the same dry density but were compacted at different initial water contents, it was found that the initial moulding water content could affect soil structure (aggregation) significantly. Higher initial water content specimens had a higher air-entry value and a lower rate of desorption. The specimens with different particle size fractions appeared to exhibit distinct soil-water characteristics. A coarse-grained specimen had a lower air-entry value and higher rate of desorption compared with a fine-grained specimen.

キーワード: loess landslide, soil-water characteristic, dry density, water content, particle size fraction

Keywords: loess landslide, soil-water characteristic, dry density, water content, particle size fraction

インドネシア アンボン島ワイエラ川で発生した天然ダム (速報)  
PROMPT REPORT OF NATURAL DAM FORMED IN THE WAY ELA RIVER, AM-  
BON, INDONESIA

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On July 13, 2012, a huge natural dam was formed by the large scale landslide in the Way Ela River, Ambon, Maluku, Indonesia. Its height is about 150 meter. It still remains and its water level keeps high. In the downstream of the natural dam, there is a village with populations of 5,000, which is exposed to the catastrophe in case of the collapse of the natural dam. In order to prevent the damage from collapse of natural dam, Indonesian government has been promoting the countermeasures such as constructing a spillway, and establishing the early warning system. We have investigated the site of the Way Ela River three times and collected information about the natural dam. Here, we promptly report the interim results about the natural dam based on the information obtained so far.

Keywords: natural dam, Indonesia, landslide

湿潤亜熱帯気候下のバッドランドにおける泥岩の急速風化・侵食のメカニズム: 台湾南西部鮮新 更新統泥岩地域の例  
Rapid weathering and erosion mechanisms of mudstone in a badland under the humid, subtropical climate: A case study in a

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台湾南西部には、乾季と雨季の明瞭な亜熱帯季節風気候の下で、鮮新 更新統泥岩地域に鋭利な尾根とガリに特徴づけられる無植生のバッドランドが形成されている。この泥岩は、自然含水状態で一軸圧縮強度がおよそ5~10 MPaと硬質であるが、急速に侵食され、バッドランドを形成するとともに種々の環境問題を引き起こしている。筆者らは、現地観測及び採取試料の分析によって、この泥岩の急速な風化・侵食メカニズムを明らかにすることを試みた。バッドランドの斜面に設置した侵食ピンから、侵食速度は平均で年間9 cm y<sup>-1</sup>に及び、北アメリカ西部、イタリア南部、スペイン南東部等の半乾燥 乾燥地域のバッドランドに比べ極めて速いことが判明した。また、斜面表層部の水分と塩分濃度の1年半にわたる観測と、雨季(7月)と乾季(4月)の斜面から採取されたボーリングコア試料の物理的性質の分析から、乾季と雨季の繰り返しの伴う風化侵食過程について検討した。乾季には、斜面表層約20 cm以浅は乾燥し含水率を減じると同時に、強度を増した。そして、乾季の稀な降水の浸透と乾燥により湿潤と乾燥が繰り返され、表層部での蒸発強度の増加に伴い乾季の間に表層へ塩分が集積した。乾季の終わりから雨季の始めには、表層約10 cm以浅は含水率が高く、間隙水の塩分濃度も高くなり、その後の連続的降雨で塩分濃度が徐々に希釈されるとともに膨潤し、低いかさ密度、高い間隙比となった。この低いかさ密度と高い間隙比は、泥岩内部の水の化学的浸透作用によって引き起こされたと解釈された。その結果、この表層部は著しく強度を低下させ、侵食された。雨季の後期には深さ15 cm以深の岩石はほぼ飽和したが、侵食が発生した後、乾季に入ると斜面表面は再び乾燥し、上述の現象が繰り返された。

キーワード: バッドランド, 泥岩, 風化, 侵食, スレーキング

Keywords: Badlands, Mudstone, Weathering, Erosion, Slaking

## 海底地すべりのケーブルへの衝撃力および運動機構についての模型実験 Model test of the submarine landslide impact forces acting on cables and the motion mechanism

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Communication cables, which cross the oceans between continents all over the world, are sometimes damaged due to the occurrence and motion of submarine landslides, causing interruption of data transmission, and even of international communications. When cable failure occurs, the economic loss is vast for cable restoration coupled with temporary or permanent breach in information transmission. Submarine landslides are usually triggered by many factors which include rapid sedimentation, retrogressive failure, earthquake and tectonic activity, gas hydrate dissociation and wave loading. These activities cause severe damage to transocean fibre optic cables. Direct observation of this phenomenon is still not enough because these events occur deep beneath the sea surface, and direct observation of submarine landslide would be extremely expensive and difficult because of its unpredictability. Many features of submarine landslides and the damage they cause to communication cables are unclear. The aim of this study is to use experimental approach to analyze and understand the motion mechanism of submarine landslides and its effect on communication cables. Our interest in submarine landslides lies in disaster mitigation of communication cables. An experimental apparatus to study submarine landslides was developed for this purpose. The apparatus consists of a wheel-shaped hollow disc of height 1.8m, an axle shaft at the center and a trough with a width of 0.4m at the inner circumference. Submarine landslides is simulated by using silica sand-water mixture in the lower part of the trough as the wheel rotates in a anticlockwise direction on the axle shaft with silica sand-water mixture in the same direction of motion, all controlled by a speedometer. Using this apparatus, with silica sand no.7-and no.8-water mixtures for these experiments, normal stress, shear stress, pore water pressure on the bottom of the apparatus and impact force on a communication cable model were measured using high definition transducers, sensors and data loggers. Experiments were carried out considering four factors: (1) the effect of motion velocity of submarine landslides; (2) the effect of submarine landslide volume; (3) Material composition of submarine landslides; and (4) the effect of different cable diameters. From data obtained from series of experiments, the friction angle of submarine landslides and impact force on a communication cable was obtained. In addition, small plastic balls which have specific gravity similar to silica sands were used as tracers to observe the characteristic bulk movement of soil masses during the experiments; results obtained were compared with the friction angle and impact force on a cable. Result obtained from the experiments show that four critical values of velocities and five stages of soil mass flow evolution conditions exist in these experiments. Impact force on the communication cable model is high for submarine landslides with low motion velocity, but decreases until the velocity gets to a critical value where liquefaction occurs, and subsequently increases in a linear fashion with velocity. On the other hand, friction coefficient is positively correlated with velocity of soil mass, but shows different tendency before and after the critical value of velocity. Also, large diameter cables are subjected to high impact forces. When the diameter of the cable is increased by 10%, the impact force also increases by 50%. The experiment with setting height of 20mm showed the high impact force. Conversely, experiments with higher setting height (40mm and 80mm) showed low impact force. This may be due to the influence of different relative densities of submarine landslide sediments. Although it is difficult to simulate the flow conditions which occur in deep water, we hope the test results provide some hints for communication cable design and cable positioning in the ocean.

キーワード: 海底地すべり, 運動機構, 海底ケーブル, 内部摩擦角

Keywords: submarine landslide, motion mechanism, submarine cable, internal friction angle