Abstract Volume of
The Fifth World Landslide Forum

02 – 06 November 2021

Kyoto International Conference Center, Kyoto, Japan

Organized by

The International Consortium on Landslides (ICL), Global Promotion Committee of International Programme on Landslides (IPL-GPC), Kyoto University (KU), Japan Landslide Society (JLS), Japanese Geotechnical Society (JGS), Japan Society for Natural Disaster Science (JSNDS), and Japan Association for Slope Disaster Management (JASDiM)

Picture on the cover page
Landslides in Hiroshima, Japan after the heavy rainfall in July 2018
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On the Prediction of Landslides and Their Consequences

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The general assumptions and the most popular methods used to assess landslide hazard and for risk evaluation have not changed significantly in recent decades. Some of these assumptions have conceptual weakness, and the methods have revealed limitations. In this work, I deal with populations of landslides i.e. numerous landslides caused in an area by a single trigger (e.g. a rainstorm, an earthquake, a rapid snowmelt event), or by multiple events in a short or long period. Following an introduction on what we need to predict to assess landslide hazard and risk, I introduce the strategies and the main methods currently used to detect and map landslides, to predict populations of landslides in space and time, and to anticipate the numerosity and size characteristics of the expected landslides. For landslide detection and mapping, I consider traditional methods based on the visual interpretation of aerial photographs, and modern approaches that exploit the visual, semi-automatic or automatic analysis of remotely sensed images. For landslide spatial prediction, I discuss the results of a global review of statistical, classification-based methods for landslide susceptibility assessment. For the temporal prediction, leveraging on a global analysis of geographical landslide forecasting and early warning systems, I discuss short term forecast capabilities and their limitations. Next, I discuss long term landslide projections considering the impact of climate variations on landslide projections. For landslide numerosity and size characteristics, I discuss existing statistics of landslide area and volume obtained from large populations of event-triggered landslides. This is followed by an analysis of the landslide consequences, with emphasis on a spatial-temporal model of societal landslide risk in Italy. I end offering recommendations on what I think we should do to make significant progress in our collective ability to predict the hazard posed by populations of landslides, and to mitigate their risk.

Keywords: Prediction, Maps, Susceptibility, Hazard, Model, Consequences, Risk

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Design Recommendations for Single and Dual Debris Flow Barriers with and Without Basal Clearance

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Debris flows pose threats to sustainable development in many countries worldwide, including China, Japan, Switzerland and USA. To mitigate these flows, rigid and flexible barriers are commonly installed along the predicted flow paths. To arrest large volumes of debris flow, several barriers may be installed in series to create a cascading effect to progressively decelerate and retain the debris. Barriers may even be designed with a basal clearance to allow small discharges to pass underneath the barrier to reduce the peak impact force. Despite the importance of barriers as life-saving assets, their design remains essentially empirical because of the highly heterogeneous and scale-dependent nature of debris flow. These features of debris flow have hindered an understanding of their fundamental impact mechanisms, thereby hampering the development of scientific design guidelines to enable robust and cost-effective barriers. This forum paper presents a collection of physical experiments modelling the impact mechanisms of the two extreme cases of water and dry granular flows, and two-phase debris flows against single and dual rigid barriers, and a single flexible barrier. Furthermore, the effects of a basal clearance on the impact dynamics of dry granular flow against a single rigid barrier are examined. Experiments were conducted at two different scales, including 5 m-long and 28 m-long flumes. Based on the observed impact mechanisms and measured data, a newly developed analytical framework for designing multiple rigid barriers was evaluated. Recommendations and procedures are provided for the design of single and multiple rigid barriers with and without a basal clearance.

Keywords: Debris flow, Impact, Rigid barrier, Flexible barrier, Multiple barriers, Physical modeling, Basal clearance

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The Rockfall Failure Hazard Assessment: Summary and New Advances

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The estimation of rockfall hazards is usually based only on hazards related to rockfall propagation. The rockfall failure hazard is not currently well defined, and only a few studies have truly addressed this topic. The basics of slope stability assessment are reviewed. Here, we propose a summary of the standard methods used to assess susceptibility to rock mass failure, mainly based on techniques from the mining industry or tunneling. Most of them are qualitative. Many susceptibility scales have been described. Due to computer power and the high-resolution topography in real 3D, topography analysis and standard kinematic tests have been adapted and improved to obtain rockfall susceptibility. Hazard assessments based on the power law are one of the best and only ways to obtain a real assessment of rockfall hazard failure; however, they present some drawbacks that must be solved. The most promising avenues of research for rockfall failure hazards are linked to rock mass strength degradation, which is currently observed using high-resolution 3D monitoring of cyclic deformations with hysteresis. These are the resulting movements caused by groundwater circulations, thermal cycles, earthquakes, rainfall, etc. In conclusion, the rockfall hazard will be improved by better understanding these processes in addition to the chemical weathering effect.

Keywords: Rockfall, Failure, Hazard, Degrading factor, Susceptibility

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Progress and Lessons Learned from Responses to Landslide Disasters

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Landslides have the incredible power to transform landscapes and also, tragically, to cause disastrous societal impacts. Whereas the mechanics and effects of many landslide disasters have been analyzed in detail, the means by which landslide experts respond to these events has garnered much less attention. Herein, we evaluate nine landslide response case histories conducted by the U.S. Geological Survey over the past two decades and summarize the event history, the response conducted, and the lessons learned from each event. We group the responses into three categories—providing event context from past events, addressing ongoing hazards, and acquiring data for the future—and present the nine case studies accordingly. We also summarize the progress in landslide response that has been made over the past two decades, including insights and advancements on the preparation for such events, the use of new technologies, and the importance of clear communication between all parties during disasters. We believe that exchanging and sharing experiences such as these will promote more clear and successful approaches for responses to landslide disasters in the future.

Keywords: Landslide, Disaster, Response, Catastrophic

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Behind-the-Scenes in Mitigation of Landslides and Other Geohazards in Low Income Countries—in Memory of Hiroshi Fukuoka

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Landslide science and geohazard mitigation in low income countries requires strong planning, but mainly a fundamental day by day management of what is behind-the-scenes. This is relevant since unexpected problems can appear anytime, and in the interim, most of the mitigation measures require a strong interconnection with local communities. This is a problem since it requires flexibility and capacity of adaptation to unpredictable matters. On the other hand, it is a great opportunity since it shifts our way of working from the traditional approach we study in University, to something that is more social, historical and anthropologically oriented. In this view, to work in low income countries does not require solving only the problem, but also helps the local community to understand how to do it. This means transferring scientific knowledge into the investigation phase (IP), as well as deeply collaborating in the mitigation phase (MP). More specifically, recovering and empowering local knowledge very often based on coherence between environment/heritage conservation, local materials, local climate, recovering and empowering traditional restoration techniques based on long term experience, as well as adapting to local socio-economy. Only with this approach is it possible to work in many countries of the world, they may be poor in science, but very rich in history and dignity. That's why humbleness and competence should guide any interventions. This article is dedicated to Hiroshi Fukuoka. He had clear concepts in mind in relation to this topic. Fukuoka operated to not only to make his high level of knowledge available, but he also offered cooperation and friendship, joining deep knowledge with immense social acceptance of his studies.

Keywords: Landslide, Geohazards, Mitigation, Behind-the-scenes, Low income countries

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Recent Advances in the Methods of Slope Stability and Deformation Analyses

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Landslides are among one of the most devastating natural disasters affecting millions of people, causing tens of thousands of deaths and resulting in millions to billions of dollars of damage annually. Examination of historical data suggests an increase in the number of slope failures along with an increase in the two major triggers—an increase in the number of significant earthquakes and wetter than average annual precipitations. These trends highlight the continued need to improve landslide science and understanding. This paper presents a summary of the recent advances in knowledge pertinent to the methods of slope stability and deformation analyses starting with the state of practice as detailed by Prof. J. Michael Duncan in 1996. Specifically, the paper focuses on the improvements to the computational and graphical capabilities with the widespread use and availabilities of computers, the ability to perform macro level stability analysis for regions, the advent of probabilistic slope stability analyses, developments in slope stability analyses of unsaturated slopes, and new methods to perform deformation analyses. Several case studies highlighting these advances are also included.

Keywords: Slope stability, Macro level stability analyses, Probabilistic slope stability, Unsaturated slopes Deformation analyses, Back-analyses

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Theme 1 Sendai Landslide Partnerships and Kyoto Landslide Commitment

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Kyoto 2020 Commitment for Global Promotion of Understanding and Reducing Landslide Disaster Risk

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The Sendai Landslide Partnerships 2015–2025 was proposed and adopted as a voluntary commitment to the Sendai Framework for Disaster Risk Reduction. The Partnerships was signed by 22 global stakeholders committing to contribute to landslide disaster risk reduction. Under the Partnerships, ICL published a full color open access book "ISDR-ICL Sendai Partnerships 2015– 2025" as Vol. 1 of Advancing Culture of Living with Landslides and two volumes of ISDR-ICL Interactive Landslide Teaching Tools. The Partnerships is effective for the promotion of landslide disaster risk reduction. However, it will be phased out by 2025. Landslide disaster risk reduction will remain a key necessity and become even more important after 2025 due to climate change and urban development. ICL and the partners of the Sendai Landslide Partnerships wish to develop this initiative further to 2025, 2030 and even beyond. Therefore, the Kyoto 2020 Commitment for Global Promotion of Understanding and Reducing Landslide Disaster Risk (KLC2020) was developed. Partners of KLC2020 are called upon to attend the meeting of the joint signatories and the declaration of the launching of KLC 2020 in November 2020.

Keywords: Sendai landslide partnerships, Sendai framework for disaster risk reduction, Sustainable development goals, Paris climate agreement, Interactive teaching tools

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International Consortium on Landslides (ICL): Proposing and Host Organization of SLP2015-2025 and KLC2020

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The International Consortium on Landslides (ICL) was founded at the UNESCO-Kyoto University joint Symposium in January 2002. The ICL also decided to create the International Programme on Landslide (IPL) and a new international journal Landslides in the foundation meeting in 2002. The ICL was registered as a legal body under Japanese law in 2002 as a non-profit scientific organization. The ICL proposed the 2006 Tokyo Action Plan and exchanged a MoU to each of seven global stakeholders (ICL Supporting Organizations, ISO). Together with ISO, the ICL founded the triennial World Landslide Forum (WLF) in 2008, and in 2015 proposed the Sendai Landslide Partnerships 2015–2025. Based on partnerships, ICL and ISO are organizing the Fifth World Landslide Forum (WLF5) and will launch the Kyoto 2020 Commitment for Global Promotion of Understanding and Reducing Landslide Disaster Risk (KLC2020) on 5 November 2020.

Keywords: Sendai landslide partnerships (SLP), Kyoto landslide commitment (KLC), International programme on landsides (IPL)

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The ICL Journal Landslides—16 Years of Capacity Development for Landslide Risk Reduction

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Capacity building and capacity development for landslide risk reduction is an important pillar of the International Consortium on Landslides, Kyoto, Japan. This non-governmental organization with close to 100 full members, associates and supporters was established in 2001, and among many activities in this first two decades we may raise the latest overreaching one, namely the Sendai Partnerships 2015–2025 as the free commitment to Sendai Framework on Disaster Risk Reduction 2015– 2030. The Kyoto Commitment 2020 to be discussed and accepted at 5th World Landslide Forum in Kyoto in November 2020, again stresses the importance for the ICL to raise awareness and enhance preparedness for landslide disasters as the ICL efforts for capacity building and capacity development in this field. The ICL stimulates landslide research that has to support capacity building for landslide risk reduction. Springer Nature publishes the journal Landslides: Journal of the International Consortium on Landslides since 2004. Being examined in the past by different authors from bibliometric and editorial point of view, this review paper focuses on the journal's 16 years of achievements (2004– 2019). In these 16 years, 1313 papers were published on 16,286 pages, written by 5534 authors and with more than 1.1 million downloads and nearly 25,000 citations as in early 2020. The bibliometric analysis of Landslides and its comparison with a few selected similar journals of high reputation, among them Engineering Geology and Bulletin of Engineering Geology and the Environment, confirmed high rankings of Landslides in the research categories of geological & geotechnical engineering and engineering geology. Strong and weak points are discussed from the bibliometric point of view, stressing the need for higher internationality of co-authorship of published articles in order to be true international journal. Continuous publishing and the move to a monthly journal in 2018 has further increase journal's h-index and

cited half-life of citations, but further editorial efforts should be directed to attract excellent review papers and focused technical notes to increase cites per paper and the number of Highly Cited papers. Until 2020, Landslides is the foremost journal in the field of landslide disaster risk reduction, and the top young international journal in the fields of geotechnical engineering and engineering geology.

Keywords: Capacity development, Citation analysis, Education, International collaboration, Journal metrics, Scientometric analysis

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UNITWIN-UNESCO/KU/ICL Landslide, Earthquake and Water-related Disaster Risk Management for Society and the Environment Cooperation Programme

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UNITWIN is the abbreviation for the university twinning and networking scheme. This UNESCO programme was established in 1992. During ICL foundation meeting in January 2002, participants from UNESCO advised to link the planned International Programme on Landslides (IPL) to one of UNESCO Programme for the promotion and the authorization. Then, ICL applied for UNITWIN programme to UNESCO soon after the foundation of ICL in 2002. UNITWIN-UNESCO/KU/ICL Landslides Mitigation for Society and the Environment Cooperation Programme was established in 2003 at Kyoto University, Kyoto, Japan. In 2010, the UNITWIN-UNESCO/KU/ICL Cooperation Programme was extended to "Landslide and Water-Related Disaster Risk Management" to deal with rainfall-induced landslides on slopes, as well as flood, sediment and debris flows in river systems. In 2019 the UNITWIN-UNESCO/KU/ICL UNITWIN Cooperation Programme was further extended to Landslide, Earthquake and Water-related Disaster Risk Management for Society and the Environment Cooperation Programme. This paper describes its progress and the activities of capacity development including the list of students and post-doctoral researchers within this programme.

Keywords: UNESCO, UNITWIN, International Programme on Landsides (IPL), International Consortium on Landslides (ICL), Kyoto University

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International Programme on Landslides (IPL): A Programme of the ICL for Landslide Disaster Risk Reduction

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A new international scientific programme on Landslides was a major agenda in the foundation meeting of the International Consortium on Landslides in January 2002. The foundation of the International Programme on Landslides (IPL) was agreed at the first meeting of the Board of Representatives of the ICL at UNESCO in November 2002. This initial stage of IPL had coordinating projects proposed by the ICL and member projects proposed by each ICL member. The first IPL project was publication of International Journal of Landslides. The current second stage of IPL was defined by the 2006 Tokyo Action Programme on Landslides as an international programme managed by the IPL Global Promotion Committee consisting of ICL and ICL supporting organizations. The second stage of IPL includes IPL Projects conducted by ICL member organizations, the triannual World Landslide Forums and the World Centres of Excellence on Landslide Risk Reduction (WCoE). This paper describes those activities and presents the list of WCoE since 2008 and the list of IPL projects both in the initial stage of IPL projects (2002–2008) an in the second stage of IPL projects (2008–present).

Keywords: Sendai landslide partnerships 2015–2025 (SLP), Kyoto landslide commitment 2020 (KLC), International programme on landslides (IPL), IPL projects, World center of excellence (WCoE)

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Central Asia—Rockslides' and Rock Avalanches' Treasury and Workbook

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More than 1000 large-scale rockslides, rock avalanches and DSGSDs exceeding ca. 1 million cubic meters in volume have been identified in the Central Asia region embracing the Pamir, Tien Shan, and Dzungaria mountain systems that belong to six states—Afghanistan, China, Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan. Most of the catastrophic slope failures are prehistoric and quantitative parameters (area of the deposits, total area affected, volume, runout, height drop, etc.) of about 60% of them have been measured. Arid climate and lack of forestation provide preservation of landforms created by such slope failures of various types and good expressiveness of outcrops eroded in the landslide deposits. The case studies from this region are very didactic and the Kokomeren River basin in Central Tien Shan was selected for a 2 weeks long field training course—the Kokomeren Summer School on Rockslides and Related Phenomena that has been running annually since 2006.

Keywords: Central Asia, Rockslide, Rock avalanche, Field training, Pamir, Tien Shan, Dzungaria

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Results of Recent Monitoring Activities on Landslide Umka, Belgrade, Serbia—IPL181

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Results of recent monitoring activities conducted from 2014 to 2019 are presented in the paper as a part of IPL 181 Project progress report. Recent monitoring activities are concentrated on several landslide monitoring techniques— automated GNSS monitoring system measurements, geodetic benchmark survey monitoring, UAV imaging, processing and analysis, and PSInSAR data processing and analysis. Results of all monitoring activities were analysed and used for cross-correlation and for verification of monitoring results obtained from different techniques. Displacement rates from GNSS measurements indicate that object point UmkaGNSS2 has moved 0.30 m towards the North and 0.50 m towards the West, while the vertical displacement was approximately −0.15 m for the 2014–2018 time span. Similar range of GNSS displacement rates were found in previously published results from monitoring activities realized from 2010–2014. PSInSAR data analysis also showed good correlation between nearest PS points and GNSS point for the same period of monitoring. Results from UAV and geodetic benchmarks survey showed very good correlation in displacement vectors' direction. According to the analyzed data it could be concluded that all monitoring results are in compliance with previous research results and confirm that the Umka is slow to very slow moving landslide with cyclic acceleration and deceleration phases.

Keywords: Landslide, Monitoring, GNSS, Geodetic survey benchmarks, UAV images, PSInSAR

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Landslides in Weathered Flysch: From Activation to Deposition (WCoE 2017–2020)

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The Faculty of Civil and Geodetic Engineering of the University of Ljubljana (UL FGG), Slovenia, Europe, was voted in 2017 at the 4th World Landslide Forum in Ljubljana, Slovenia to be one of the 20 new World Centres of Excellence (WCoE) in Landslide Disaster Reduction for the period 2017–2020. This successful nomination followed the periods 2008–2011, 2011–2014, and 2014–2017 in which UL FGG successfully fulfilled the role as one of the WCoEs. We can divide the activities of the WCoE at UL FGG into international and national research activities. The international ones consisted of the ICL related activities, the international cooperation, the European research activities, and the bilateral cooperation. The national ones consisted of the national projects and the national research program "Water Science and Technology, and Geotechnics". In the paper, the before mentioned activities of the WCoE at UL FGG are elaborated into more detail, with a short list of top publications to show the dissemination and capacity building efforts.

Keywords: Capacity building, Debris flows, Flysch, Laboratory experiments, Landslides, Slovenia, WCoE

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Report of the Croatian WCoE 2017–2020: From Landslide Mapping to Risk Assessment

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In this paper scientific activities of the Croatian Landslide Group (CLG), World Centre of Excellence on Landslide Risk Reduction (WCoE) of the International Consortium on Landslides (ICL) for the period 2017 2020, are shortly described. The results of scientific research are presented through the fields of landslide science related to landslide identification and mapping as well as landslide hazard and risk assessment. It is concluded that the resulting landslide inventory maps in detailed scale as well as landslide susceptibility and risk maps in large and small scale, provide necessary information for landslide risk management in Croatia at local and national level. Besides application of scientific results in Croatia, the general objectives of the ICL WCoE are reached by contributing to landslide risk reduction.

Keywords: Landslide maps, Landslide inventory, Susceptibility assessment, Risk assessment, Dinarides, Pannonian basin

The abstract is from the book "K. Sassa et al. (eds.), Understanding and Reducing Landslide Disaster Risk, Volume 1 Sendai Landslide Partnerships and Kyoto Landslide Commitment, pp 241-250"

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Advanced Technologies for Landslides (WCoE 2017–2020)

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The UNESCO Chair on Prevention and Sustainable Management of Geo-Hydrological Hazards, Department of earth Sciences, University of Florence has been a member of the International Consortium on Landslides (ICL) since 2002 and was designated as one of World Centres of Excellence (WCoE) for Landslide Risk Reduction four times for 2008–2011, 2011–2014, 2014–2017 and 2017–2020 with a project entitled "Advanced technologies for Landslides". In this paper we describe the activities carried out by the UNESCO Chair as a member of ICL and as WCoE and its contribution to the risk reduction policies promoted by the 2020 Kyoto Commitment.

Keywords: Italy, Landslides, Monitoring, Remote sensing, Risk reduction, Kyoto commitment

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Complex Geomorphological and Engineering Geological Research of Landslides with Adverse Societal Impacts

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The Czech World Centre of Excellence (WCoE) on Landslide Risk Reduction 2017–2020 entitled as "Complex geomorphological and engineering geological research of landslides combined with assessment of adverse societal impacts" included research, education and awareness of landslide risks. Originally, the only participants were Charles University and the Czech Academy of Sciences; however, in the last two years we were joined by another two Czech institutions (Brown Coal Research Institute and Czech Geological Survey), strengthening possible impact of the work performed within the scope of the International Consortium on Landslides. In terms of landslide research, we focused on various topics, i.e. national landslide susceptibility zonation, paleogeomorphological landslide research, rainfall triggering mechanism, a database of giant landslides, landslide dam analysis, glacial lake outburst floods, merging satellite-based landslide inventory data with on-site geomorphological investigations, and landslide susceptibility modelling. We performed our activities both at home and abroad. During the period starting from 2017, we performed various activities aimed at increasing the awareness of the general public as well as experts involved in landslide risk reduction. Student graduation works was performed in the framework of the WCoE at all levels (Bachelor's, Master's and Doctoral). In addition, we contributed to the overall ICL/IPL activities by performing editorial work, reviews and evaluations for the journal Landslides, book publications and IPL projects, as well as the WCoE.

Keywords: Landslide risk reduction, World centre of excellence, Capacity building, Community participation

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Report of the IPL-219, IPL-220 and Croatian WCoE 2017–2020: From Landslide Investigation to Landslide Prediction and Stabilization

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In this paper we described a part of scientific activities of the Croatian Landslide Group (CLG), World Centre of Excellence (WCoE) on Landslide Risk Reduction of the International Consortium on Landslide (ICL) for the period 2017–2020 including activities of IPL Projects IPL-2019 Rockfall Hazard Identification and Rockfall Protection in The Coastal Zone of Croatia and IPL-220 Kostanjek Landslide Monitoring Project (Zagreb, Croatia). The results of these scientific activities are presented through the fields of landslide science: landslide investigation and testing, landslide monitoring, landslide modelling and landslide stabilization and remedial measures. The manuscript presents the major results achieved in previously listed fields in the frame of Croatian Landslide Group WCoE activities and two IPL Projects

Keywords: Landslide investigation, Laboratory testing, Monitoring, Landslide modelling, Landslide stabilization

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Ichi-Nichi-mae (The Day before the Disaster) Project for Landslide Awareness and Risk Communication

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Raising public awareness against disasters is one of the main pillars of disaster reduction policy in Japan. Numerous educational materials have been developed to raise public awareness on disasters. However, it has been often the case that these materials are not seriously accepted by adults and have not led to preventive action. To address this issue, a new program; 'Ichi-Nichi-Mae (the Day before the Disaster) Project' for Disaster Awareness was initiated by the author in the Cabinet Office of Japan in 2005. This program interviews people who have been seriously affected by a major disaster, by posing the question 'What would you do if you were back the day before the disaster?' and edits the most impressive personal stories which give clues for future preventive action. The interviews cover a wide variety of adults who experienced disasters, from housewives to small business owners, large enterprise employees and public servants who worked on site to cope with a disaster. Wide varieties of disasters are covered. These episodes are compiled and have been used for disaster awareness seminars and have proven to be effective, since the real episodes experienced by individuals are true to life and in many cases bear sincere lessons learnt, generates empathy, and make participants feel that it may happen to them. To date, more than 800 episodes are stored in the Cabinet Office Disaster Management Website. http://www.bousai.go.jp/kyoiku/keigen/ichinitimae/index.html
12 episodes of landslides, 3 induced by earthquake, 9 induced by heavy rainfall, are available on this website. In Japan, after a landslide with casualties, scientific investigation is done to identify the causes and mechanism, however eyewitness evidence was not systematically collected. These episodes told by survivors of landslides bear live lessons for reducing human losses by landslides. Some episodes indicate, how the survivors sensed the initial signs of landslides. Others indicate, how the survivors escaped by prior recognition of safe routes.

Keywords: Public awareness, Personal experience, Storytelling, Psychology, Reduction of human loss
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Landslides in Greece and related legislation: difficulties and potential improvements

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Landslides in Greece is the second in impact on socioeconomic cost geohazard after earthquakes. According to HSGME records for a three-year period (2015-2017), the total number of damaging landslides were more than 319, while for the same period, 9 fatal landslides caused 5 deaths and 7 injuries.

Legislation related to the mitigation of impacts due to geohazards (among them of landslides) on large engineering works such as highways, dams and buildings of high importance (hospitals, schools) is of great quality and follow the European standards. It is worth mentioning that aforementioned legislation started to be improved exponentially after 1995, when a major landslide (Malakasa) occurred in a close distance to Athens, the capital of Greece, that destroyed completely a section of the main railway of the country, as well as a part of the major highway, causing great transportation problems.

Moreover, there is national legislation that introduces geohazard assessment into urban planning; “Geological housing suitability studies” were first introduced in 1998 and have been amended in 2007. The scope of aforementioned studies, is to assess geo-problems in relation to built environment and the definition of areas that need conservation and protection such as geological resources or facilities linked with high geo-environmental risks. The studies result in (1) zonation of urban areas with respect to their suitability for housing, (2) description of the required conditions or the necessary measures, for soil improvement or other required protective measures (engineering works, special type of foundation, permission for construction of certain types of buildings) in order to achieve safety in regions that are been characterised as suitable under certain conditions, (3) if needed, description of additional investigations, (4) vulnerability of infrastructures and large engineering works – relevant mitigation measures.

Finally, a national system exists for the financial compensation of people suffered from landslides but procedures are very slow and problematic. There is a need for further development of appropriate legislation for Urban management, for rural road network as well as of the compensation system.

Keywords: legislation, landslides, urban planning, large engineering works

The abstract is from the One-Page Abstract of The Fifth World Landslide Forum, pp 3

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Emerging Issues and Innovative Strategies for Landslides Risk Management

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Landslides have adversely affected development and demography of the hilly terrain due to sudden and widespread disasters, particularly in developing countries like India, Nepal and Pakistan. These landslides are often triggered due to rainfall, river erosion, seismic and artificial vibrations, drainage changes, deforestation, mining, unscientific and unplanned development or construction activities. It involves several different types of issues that emerge as a challenge in the process of landslides risk reduction and enhancement of resilience. Such emerging issues include sustainable development and climate change adaptation besides the impacts on local population, economy, environment, infrastructure and resources. The casualties in terms of loss of human lives and the cost of recovery from the landslide disasters could not be contained or controlled well despite all endeavours to reduce the incidences and impacts of landslides through implementation of various structural and non-structural measures. Hence, it has been felt that innovative strategies for landslide risk management are the dire need of the present time and the same has been worked out through a national level task force by the National Disaster Management Authority in India. The formulation of national and local strategies for disaster risk reduction and resilience has also been emphasized under 5th target in the Sendai Framework for Disaster Risk Reduction. The strategies focus on landslides database, inventory, mapping, monitoring, prevention, mitigation, preparedness, early warning, alert and communication as well as efficient response, recovery and redevelopment. It also highlights the need for training and capacity enhancement on landslides risk management using state of art technology along with traditional, locally time tested indigenous techniques for slope stabilization. It also focuses on networking, linkage and coordination amongst different stakeholders. The paper will present the national strategy for landslide management in India.

Keywords: Landslides, Strategies, Issues, Management, Innovation

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The root causes of landslide vulnerability in Bangladesh

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Communities living in the Chittagong Hill Districts (CHD) of Bangladesh recurrently observe landslide disasters during the monsoon season (June–September). CHD is primarily dominated by three distinct groups of hill communities, namely, urbanized hill (Bengali), indigenous tribal, and stateless Rohingya refugees. Landslide vulnerability amongst them is complex and varies between physical, social, economic, environmental, institutional, and cultural dimensions. This study aims to understand the driving forces of landslide disasters in the region by emphasizing human factors. Data from the three contrasting communities were collected through participatory workshops, in-depth interviews, and fieldwork observation. The participants were local people and landslide experts who were purposefully selected from five case study communities in the CHD. They ranked different socio-economic problems, identified causes of landslides, and proposed landslide mitigation action plans. Results suggest that the urbanized Bengali and Rohingya refugee communities are highly vulnerable to landslides. The urbanized hill communities largely deal with poverty, social injustice, lack of planning regulations, and illegal hill cutting issues, whereas the Rohingya refugees' predominant constraints are linked to the ongoing genocide and state-sponsored violence in Myanmar hindering their sustainable repatriation, and their protracted living conditions in Bangladesh. The indigenous tribal communities are comparatively resilient to landslides due to their unique history, traditional knowledge, cultural heritage, and lifestyle. Landslides in the CHD should be characterized as socio-natural hazards since the components of landslide disasters are profoundly intertwined with the culture–conflict–corruption nexus.

Keywords: Landslides; Culture; Rohingya; Indigenous people; Conflict

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Hydrated halloysite: the pesky stuff responsible for a cascade of landslides triggered by the 2018 Iburi earthquake, Japan

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Coseismic landslides generated by strong earthquakes can substantially increase the devastation imposed on society and humanity, especially when such seismic events occur in unconsolidated pyroclastic fall deposits that are prone to destabilization. The catastrophic 2018 Hokkaido Eastern Iburi Earthquake triggered thousands of shallow liquefied landslides in pyroclastic fall deposits, 1 day after the passage of Typhoon Jebi. The landslides were highly mobile and had long runouts. We here report novel findings pertaining to distinctive properties of the widely distributed, weathered Plinian Ta-d tephra deposit from Tarumae volcano, and their impact on the spatial clustering of the Iburi landslides. Distribution of the landslides is positively correlated with the dispersal of Ta-d. Liquefaction occurred in the weathered Ta-d pumice, despite the absence of unconfined groundwater. The Ta-d pumice also has lower soil strength than other local pumice units. The volumetric soil moisture content of weathered Ta-d pumice is very high (>90%) and exceeds other soil layers, regardless of precipitation variation. The presence of hydrated halloysite was confirmed by X-ray diffraction. The halloysite enhances the shaking-triggered liquefaction, because it maintains weathered Ta-d pumice in a highly saturated and exceedingly loose state, even in the absence of unconfined groundwater. This is inconsistent with the traditional concept of liquefaction that generally occurs in sandy soils below the groundwater level.

Keywords: Iburi earthquake-triggered landslides, Liquefaction, Ta-d pumice, Hydrated halloysite

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Impact of multi-hazard interaction on risk assessment

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Multi-hazard process chains are complex event involving multiple hazardous processes. Common examples are co-seismic landslides and simultaneous triggering of flash floods and landslides due to extreme precipitation. Due to the complexity, and lack of reliable modelling methods, relatively little is understood about the impact of multi-hazard interactions on risk assessment. We present an integrated multi-hazard analysis of impact from tropial cyclones on Dominica. Through general extreme value analysis, design storms with return periods between 1 and 100 years were produced. Using the LISEM model, hydrology, flash floods, slope stability, slope failure and landslide/debris flow runout were simulated for each potential event. The model was calibrated with high accuracy on the impacts of the 2017 Hurricane Maria. The results provide counter-intuitive insights into how multi-hazard interactions influence events. In a significant number of cases, increased trigger intensity does not equate to increased impact, or surface hazard intensity. For tropical cyclones in particular, insurance rules or policy-related documents can be based on the return period of the triggering event (e.g. hurricane peak wind velocity). Secondly, many types of interactions shaped the dynamics of the simulated events, as well as the impact from real events on Dominica. Dilution of mass movements increases runout, and additional drag leads to a very strong increase in deposition near urbanized areas. Investigation of physical processes in such situations should strongly consider the relevance of these interactions. Finally, the simulation ensemble highlights the spread in model outcomes due to intrinsic uncertainties. While these are significant due to complexity of the model, they are insignificant compared to the errors made in traditional approaches where hazards are considered in isolation. While this is partly due to the high intensity of the triggering events on Dominica, it provides evidence that the recent developments in integrated multi-hazard models have reached a discussion phase of applicability.

Keywords: Landslides, debris flows, flooding, multi-hazard

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Numerical Simulation for Tsunami Generation Due to a Landslide

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Tsunamis generated by falling rigid bodies, or a falling fluid, have been numerically simulated using the MPS model, in the vertical two dimensions. The tsunami height, immediately after the large circles enter the water, does not depend much on the offshore still water depth, while the tsunami-height reduction is suppressed, when the offshore still water depth is shallower. Conversely, the tsunami height, immediately after the small circles enter the water, increases as the offshore still water depth is shallower. Both the tsunami height, immediately after the falling bodies enter the water, and the reduction rate of tsunami height, are larger for the large circles than for the small circles. Furthermore, in the cases where the falling bodies include both the large and small circles, the reduction rate of the water level near the wave source is larger, when the large circles are also stacked on the offshore side at the initial condition. The tsunami height of the first wave, immediately after the rigid masses enter the water, is almost the same regardless of the rigid-mass shape. The tsunami height of the second wave is larger than that of the first wave in the cases of the right-angled isosceles triangles and the right triangles. The reduction rate of tsunami height for the rigid masses is larger than that for the circles. When the falling body is any of the three rigid masses, a tsunami component traveling toward the shore and running up the slope is confirmed. When the slope is milder underwater, the tsunami height due to the falling fluid is larger than that for the uniform-slope case.

Keywords: Tsunami, Landslide, Rigid body, MPS method

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Dealing with Mass Flow-Induced Tsunamis at Stromboli Volcano: Monitoring Strategies Through Multi-Platform Remote Sensing

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Volcano landslides or explosions-induced mass flows constitute an important trigger of tsunamis. Even if landslide-induced tsunamis can produce more local impacts comparable earthquake-induced tsunamis, large volume failure of volcanic edifice may cause tsunamis with widespread effects. Considering this, successful strategies for volcano slope instability detection must involve the integration of different methodologies for mapping, monitoring, and automated approaches for early warning, integrating field-based studies, geomorphological mapping, remote sensing data, geophysical and geochemical investigations, and/or numerical modelling. In this contribution, the applications of different remote sensing techniques products for the identification, mapping, and forecasting mass movements in the island of Stromboli are presented. The integration of space-borne and ground-based Synthetic Aperture Radar displacement data with the analysis of (topographic- and SAR amplitude images based) change detection allowed the identification the evolution of the slope instability phenomena and the geomorphological processes affecting the Stromboli unstable slopes. Ground based SAR devices are the key-instruments for the operational approach to mitigating landslide risks, being used to monitor the slope instability and to detect the inflation/deflation of the crater area. It is crucial to emphasize the importance of smart integration of space borne-derived hazard information with permanent-sited, operational monitoring by GBIn- SAR devices to detect areas impacted by mass wasting and volcanic activity.

Keywords: Volcano slope instability, Landslide-induced tsunami, InSAR, GBInSAR, Topographic change detection, SAR amplitude, Stromboli

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Tsunami Disaster caused by the 1923 Great Kanto Earthquake and the Importance of Submarine Landslides

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The present study reverified the tsunamis caused by the 1923 Great Kanto earthquake using a high‐resolution seafloor topography. The tsunami heights calculated by a fault model agreed with the observed tsunami heights at certain areas inside Tokyo Bay and the southern part of the Boso Peninsula, however, are found to have a large discrepancy with the observed tsunami heights particularly in coastal areas of Sagami Bay and the eastern part of the Izu Peninsula despite the improvement of the calculation accuracy over previous studies. We confirmed that the bathymetric changes which were observed before and after the 1923 Great Kanto Earthquake corresponded to the submarine valleys of Sagami Bay, based on the analysis and comparison with the current submarine topographic data. The results of the analysis of the bathymetric changes and associated seafloor ground dynamics of Sagami bay and Tokyo bay mouth demonstrate that submarine sediments were deposited at the foot of submarine scarps, and significantly outflowed on gentle slopes. The mechanism of the 1923 Great Kanto earthquake tsunami event is therefore considered to be closely linked to the earthquake induced submarine landslides. Tsunami simulations and their verifications considering the seafloor ground dynamics and submarine landslides revealed in this study are described as a subject of future study.

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Post-event Field Surveys of the 2018 Tsunamis in Palu Bay and Sunda Strait

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Two tsunamis that occurred at the end of 2018 in Indonesia provide important data and lessons in tsunami disaster mitigation. The first incident was the Palu/Sulawesi tsunami that occurred on September 28, 2018 while the second was the Sunda Strait tsunami that occurred on December 22, 2018. Both the tsunamis were generated by landslides, in which case Palu's landslide was triggered by the Mw 7.5 earthquake and in the case of the Sunda Strait by marine volcanic activity. A team which has members from Indonesia and Taiwan conducted two field surveys to measure the run-up height and inundation distance as well as the level of damage in the disaster area. The survey results have been published, but considering that there were several other teams that conducted surveys and also publications for the events in Palu and the Sunda Strait, it is deemed necessary to compile data from each survey team. This abstract informs the compilation of run-up and inundation data on the Palu and Sunda Strait tsunamis. In addition, our team also has a large number of photos and videos that have not been analyzed yet. Therefore, we also provide analysis in the form of a description of the damage to buildings that are very close to the shoreline by comparing the photos and videos with images from Google Street View and Google Earth. From them, it is recommended to stakeholders, especially in Indonesia, to enforce regulations regarding buildings in coastal areas and coastlines in order to reduce casualties when a tsunami occurs. In addition, a very large number of semi-permanent buildings around the coastline needs serious attention and strict regulation to achieve better spatial planning because these buildings are very weak and prone to tsunamis.

Keywords: tsunami, field survey, run-up, inundation, landslide, damage, mitigation, semi-permanent buildings

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Three-dimensional Simulation on the Rockslide and Mudslide Generated Tsunamis

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This study incorporates the Bingham and bi-viscosity rheology model with the Navier–Stokes solver to simulate the tsunamis excited by slump-type landslides. The change between un-yield and yield phases of the slump material is controlled by the yield stress and yield strain rate in Bingham and bi-viscosity models, respectively. The volume-of-fluid method is used to track the interfaces between three materials: air, water, and soil. The model is validated by the laboratory data of the benchmark landslide tsunami problem and the survey data of the failure of the gypsum tailings dam in East Texas in 1966. A series of rheological properties analyses is performed to identify the parameter sensitivity to the tsunami generation. The results show that the yield stress plays a more important role than the yield viscosity in terms of the slump kinematics and tsunami generation. Moreover, the scale effect is investigated under the criterion of Froude number similarity and Bingham number similarity. With the same Froude number and Bingham number, the result from the laboratory scale can be applied to the field scale. If the slump material collected in the field is used in the laboratory experiments, only the result of the maximum wave height can be used, and significant errors in slump shape and moving velocities are expected.

Keywords: landslide tsunamis; slumps tsunami; Bingham model; bi-viscosity model; tailings dam; mudslide; Navier–Stokes; scale effect; Bingham number; Froude number

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Submarine landslide study in a drum centrifuge

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Submarine gravity flow of seafloor soil deposit is an increasingly important subject for research in relation to the stability of the offshore wind power facility and foundations of offshore structures as well as its devastating consequence on tsunami generation. The behaviour of gravity flow is mainly governed by the gravity acting on the sediment. Usual flume tests under 1g condition cannot reproduce in-situ gravity flows due to a much smaller mass of the sediment than a proto-type one. The centrifuge model testing technique is a realistic means of reproducing a submarine gravity flow.

I present the application of a drum type centrifuge model testing apparatus to the study of subaqueous gravity flow. In the drum-centrifuge, the water channel rotates with a steady high angular velocity so that the centrifugal acceleration Ng could act on the channel. Under a given centrifugal acceleration, a scaled model can be used to generate the stress conditions equivalent to the prototype scale. Furthermore, the drum-type centrifuge does not have side walls of the channel, which is a problem in a beam-type centrifuge model, so that long-distance flows could be observed.

The subaqueous gravity current of dense slurry composed mainly of clay and silt, observed in the centrifuge experiments, will be presented. A range of centrifuge experiments with varying water contents of the slurry was performed under a centrifugal acceleration of 50 gravities. The critical water content at which the type of gravitational flow transits from a mass movement to a gravity current was found. Furthermore, liquefaction or fluidization induced-gravity flow composed of sand and silt will also be presented. Here, dissipation of excess pore pressures is important for a distance of gravity flow.

Keywords: centrifuge modelling, gravity flow, slurry, liquefaction, fluidization

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Sendai voluntary commitments: landslide stakeholders and the all-of-society approach enhanced by UNDRR

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The resilience of communities and nations is a necessary condition for sustainable development. Building resilience, however, is not always a straightforward process and requires joint efforts, an all-of-society approach. Thus, the commitment, goodwill, knowledge, experience, and resources of all stakeholders contributing to disaster risk reduction (DRR) are crucial. In UNDRR's Sendai Framework Voluntary Commitments online platform, the work of all stakeholders can be showcased and tracked. Using novel data from this platform, this article presents descriptive information about the types of commitments made by stakeholders working on landslides. Results suggest that landslide is the third most covered hazard. Commitments working on this hazard have a more balanced distribution of global, regional, and local actions as compared with the whole sample. Also, landslide commitments tend to display higher levels of collaboration (as measured by the number of organizations involved) and longer duration (a commitment will last 7.6 years on average). Common issues being addressed include capacity development, risk management, and community-based DRR. When looking at specific regions and countries, there are opportunities for increased partnerships and effectiveness in topics such as knowledge sharing and technology solutions. The systemic nature of risks is increasingly apparent, and this article may stimulate further studies analyzing complexity and the joint action of all stakeholders committed to accelerate the implementation of the Sendai Framework.

Keywords: Stakeholders, Landslide, All-of society, Commitments

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Contribution of the collaborative effort of the Czech WCoE to landslide risk reduction at the Machupicchu, Peru

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The paper presents the long-term collaboration of the Czech research group organized under the World Centre of Excellence with Peruvian experts from the National Archaeological Park of Machupicchu (Parque Arqueológico Nacional de Machupicchu). The collaboration monitored potentially dangerous slope movements at the archaeological site. This was achieved with the installation of an environmentally friendly network of dilatometric instruments, taking into consideration the strict requirements for site protection and the provision of long-term, reliable results. The 17-year-long monitoring (not continuous) identified no major hazard to the archaeological site which used to support decision of site managers to limit the entrance of tourists to the Intiwatana hill since 2019. Historical photographs of Czech travellers (from 1949, 1950, 1954, and 1961) were shared with Peruvian experts, who compared them with the oldest photos from the explorer Hiram Bingham and the most recent situation. The photographs were used to document the historical development of selected structures inside Machupicchu as well as landslide occurrences on the surrounding slopes. We think this is a good example of a successful collaboration in the adoption of a robust and reliable monitoring approach into the regular practices of the site mangers.

Keywords: Landslides, Risk reduction, Master plans, Movement monitoring, Machupicchu, Photo monitoring, Peru

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Landslides at UNESCO-Designated Sites

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UNESCO-designated sites (World Heritage sites, Biosphere Reserves and UNESCO Global Geoparks) promote sustainable development, and focus on the protection of natural and cultural heritage or the conservation and sustainable use of biodiversity and geological resources. More than 2000 UNESCO-designated sites may be partly or entirely exposed to various natural hazards, including landslides, with potential impacts on the communities living in or near the sites, and on their livelihoods. Because of their high cultural and symbolic value, the impact of the loss or damage of a UNESCO-designated site can resonate across the world. In the domain of landslides risk reduction, UNESCO cooperates with International Consortium on Landslides to evaluate landslide risks and regional at local levels and promote good practices in landslide risk management.

Keywords: UNESCO designated sites, Landslides, Global exposure assessment, Natural heritage, Cultural heritage

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Traditional Knowledge and Local Expertise in Landslide Risk Mitigation of World Heritages Sites

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Landslide mitigation in UNESCO and other heritage sites requires an approach that safeguards the site. This approach is put in place in order to avoid any modifications of the original status in terms of authenticity and integrity. To do so, any mitigation project has to provide effective solutions—very often innovative—to be combined with original architecture and environment. The harmonisation of advanced solutions with historical heritage then requires a mitigation project (sometimes pioneering), with a design that minimises the impact of new intervention. This possibly will aid in recovering traditional materials and/or solutions or the re-use of original construction techniques. In low income Countries, the usage of original construction techniques ensures maintenance by local workers, hence enhancing sustainability. The present research investigates 10 UNESCO and other heritage sites affected by landslides, in an attempt to understand whether traditional techniques and local expertise may play a role in mitigating the expected damage and, at the same time, maintaining the original authenticity and integrity of the site. The investigation demonstrates that the mitigation of landslide risk through traditional techniques can help in the preservation of the integrity and authenticity of the heritage site, enhancing local job opportunities and ensuring long term maintenance. A similar result can also be achieved when making recourse to modern low impact measures (e.g. Nature-Based Solutions). Evidently, it is not always possible to apply the cumulative body of knowledge, know-how, practices and representations maintained and developed by peoples with extended histories, to all typologies of mass movements. The best focus is found in the application to shallow landslide phenomena, with limited involved volumes.

Keywords: UNESCO world heritage site, Landslide, Mitigation, Traditional knowledge, Local expertise

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Integrating Kinematic Analysis and Infrared Thermography for Instability Processes Assessment in the Rupestrian Monastery Complex of David Gareja (Georgia)

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The present paper describes the recent support activities implemented during the fall of 2018 in the David Gareja monastery complex area (South-eastern Georgia). During last decades, the growing cultural interest in the Georgian rock hewn monasteries founded in the sixth century has been constantly accompanied by conservation and management problems, due mainly to weathering and rocks collapses. In order to verify instability processes affecting the several monasteries in the area, detailed topographic surveys (Terrestrial Laser Scanner—TLS and Unmanned Aerial Vehicle-based Digital Photogrammetry—UAV DP) were performed jointly with Infrared Thermographic (IRT) analysis, geological and geomorphological field surveys. Geo-structural analysis was implemented in order to analyse the landslide types and processes, while kinematic analyses were performed in order to define the most frequent instability mechanism affecting the sites. IRT revealed thermal anomalies potentially connected to erosion, weathering and instability. The outcomes of the performed analyses highlighted that geo-structural setting, joint and stress released promotes rock instability processes in all the David Gareja monastery complex, representing a starting point for the implementation of a preliminary master plan based on low impact mitigation measures and monitoring systems.

Keywords: Cultural heritage, Landslides, Kinematic analysis, Infrared thermography

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Shallow Landslide Susceptibility Assessment in the High City of Antananarivo (Madagascar)

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The urban area of Antananarivo hosts the most important built Cultural Heritage sites, recently inscribed in the UNESCO World Heritage tentative list: the High City of Antananarivo, built on top of the Analamanga hill and encompassing the Rova royal complex together with several important Churches and Cathedrals. During the first months of 2015 the city was severely affected by geo-hydrological hazards due to heavy cyclonic rain, resulting in flooding in the Ikopa river plain area and widespread shallow landslides along the Analamanga hill slopes. This event caused thousands of evacuees and casualties, showing the vulnerability of the site to geo-hydrological hazards. Field data and remote sensing data interpretation were combined in order to produce a detailed geological-geomorphological map in order to understand the processes acting in the Analamanga hill area. With the aim of analyzing the landslide-prone areas with respect to the High City Cultural Heritage and structures a shallow landslide susceptibility map was also created. The obtained maps will provide management-planning tools to be used as a first step towards a risk reduction strategy in the High City UNESCO Core Zone and the surrounding Buffer Zone.

Keywords: Geomorphological mapping, GIS, Remote sensing, Cultural heritage, Landslides

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Thermo-Mechanical Cliff Stability at Tomb KV42 in the Valley of the Kings, Egypt

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The Valley of the Kings (or Kings' Valley, KV) in Egypt is surrounded by tall, subvertical cliffs of marl and limestones which are close to archaeological sites and visitor pathways. A previous analysis of the slope above the tomb KV42 entrance suggested that vertical rock discontinuities (i.e., tectonic joints and a lateral tension cracks) have a large impact on the stability of the cliff. The site at KV42 is being monitored with a weather station, a crack meter and a seismometer. Preliminary data analysis of temperature cycles suggests a correlation with cyclic crack aperture changes of a prominent tension crack in the cliff above KV42. Weather data from April 2018 to present helped in understanding the environmental conditions of the site. During a field campaign in April 2019, an infrared sensor was installed to systematically capture thermal infrared images of the slope above KV42. The thermal response of the rock slope measured by this sensor was used in correlation with the environmental conditions and the geomechanical response of tension crack. The in-situ data were used in this study to develop a thermo-mechanical numerical model in FLAC®, by inputting the thermal boundary conditions and geometry of the rock column, and to differentiate gravitational and thermally induced stress acting in the rock mass. Results showed that peak total displacements values are delayed with respect to peak values of rock temperatures, similar to the observations made in real measurements. The modelled rock temperatures are higher than the measured data by 3% in warm months and by 68% in cooler periods. The total displacement trend is similar to the measured data, however, the model underestimates the peak displacement by 0.2 mm, which is 34% lower than the measured data. The research forms the basis of an

approach to incorporate weather conditions into long-term stability modelling of rock masses.

Keywords: Environmental monitoring, Thermo-mechanical modelling , Infrared thermographic survey

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Collaboration in MHEWS Through an Integrated Way: The Great Efforts Contributed by Multi-stakeholder Partnership at National, Regional and International Levels

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In recent years, great progress has been made in the development of knowledge and practices related to the multi-hazard early warnings and in strengthening the related multi-stakeholder partnership. Global initiatives are gaining momentum to improve multi-hazard early warning systems (MHEWS) and so boost the resilience of the most vulnerable countries to extreme weather/water /geological, environment and health-related events and its impacts to the sustainability of social and economic development. However, understanding its interconnectivity and interoperability and developing impact-based and risk-informed methodologies in its integration in the all relevant hazard aspects are still needed to be strengthened. This article presents an overview of advances and challenges in multi-stakeholder partnership for improving MHEWS in an integrated way in order to better achieve the Target-G of the Sendai Framework on DRR, Paris Agreement on Climate Change and SDGs. We focus on major international cooperation and partnerships on MHEWS and its applications, but not limited to, the International Multi-Hazard Early Warning System Network (IN-MHEWS), Climate Risk and Early Warning Systems (CREWS), Regional Integrated MHEWS in Africa and Asia

(RIMES); and many specific MHEWSs interfaces, such as Global Disaster Alerting Coordination System (GDACS), Global Multi-hazard Alert System (GMAS), MeteoAlarm/Alert Systems, All Risk Integrated System TOwards Trans-boundary hoListic Early-warning—European Natural Hazards Scientific Partnership (ARISTOTLE-ENHSP), etc. as well as relevant multi-stakeholder partnership platforms to connect related MHEWS with its application networks between international organizations, governments, non-governmental organizations (NGOs), private sectors at regional and national levels, such as United Nations Disaster Assessment and Coordination (UNDAC), Global Water Partnership(GWP), Environment and Humanitarian Action (EHA) Network, Global network on Monitoring, Analysis, and Prediction of Air Quality (MAP-AQ), Public Health Emergency Operations Centre Network (EOC-NET), Humanitarian Networks and Partnerships Week (HNPW), and Forecast-based Financing mechanism and programme (FbF) etc. The further actions to facilitate UN Member States for improving its capacity in MHEWS partnership at national and local levels through strengthening multi-stakeholder partnership at international and regional levels are discussed and recommended in the conclusion and discussion.

Keywords: Impact-based forecasting and integrated risk management, Interactivity, Interoperability Multi-hazard early warning systems, Multi-stakeholder partnerships governance, Risk interconnectivity, Public and private partnership (PPP), And public and public partnership (PUP)

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Resilient Watershed Management: Landscape Approach to Climate Change and Disaster Risk Reduction

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Resilient Watershed Management differs from traditional approaches in that it incorporates climate change and natural disaster risk into the overall watershed management planning process. Underpinning these two attributes is its use of a landscape approach to natural resource management and risk mitigation, which factors in all aspects of land use and societal needs, from the highest snow mountains, to the middle hills, to the coastal plains. Most importantly, the umbrella under which all three concepts fall is the sustainable development of a watershed's inhabitants. Resilient Watershed Management also incorporates an integration of the physical and social sciences as fundamental to its operations, from the first analysis of stakeholder vulnerabilities to the baseline data required for the most meaningful monitoring and evaluation plan. The use of local knowledge within the planning process is also stressed. Case studies from FAO projects in Morocco and Pakistan provide evidence of the benefits of this approach. In both cases, the investment and objectives addressed land degradation while engaging the local communities and income generation. In Morocco, the project's objective was combating soil erosion and reducing the risk of flooding in overgrazed and eroded area. The investments included the improvement of irrigation systems, apple orchards, promoting income-generation activities, and enhancing the capacity of local institutions. In Pakistan, landslide stabilization was conducted through integrated and participatory watershed management. Activities included bioengineering and soil conservation measures, capacity development of stakeholders, strengthening natural resource management-based enterprises, and the improvement of local livelihoods. In both cases, the involvement of governmental institutions was key in ensuring the follow-up and replication of the projects in similarly affected areas. It is through adaptive management, the integration of key stakeholders and institutions,

and the recognition of the landscape as the unit of action, that these communities successfully enhanced their risk management.

Keywords: Resilience, Watershed, Risk, Landscape, Integrated management

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Integrating DRR into the Conservation and Management Mechanisms of the Internationally Designated Sites—View of IRDR

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Internationally designate sites (IDAs) refers to Biosphere Reserves (BR), World Heritage (WH) properties and Global Geoparks designed by UNESCO for global conservation of biological, cultural and geological diversities and sustainable use. The relevance of DRR in IDAs has been seen increasing due to the concern over climate change impacts and earthquake, landslides and volcano eruptions in recent years. What at stake are firstly about the conservation values of IDAs. It is also about safety of people, both living near IDAs and visitors, as most IDAs are also important tourism destinations. IDAs are thus highly relevant to SFDRR Priorities and Sustainable Development Targets. WLF4 in 2017 provided an important occasion to underscore landslide disaster risks in IDAs and the needs for ICL's global support to IDAs. Given disaster response in practice remains more a common approach in IDAs, 2018 Huangshan Dialogue, co-sponsored by UNESCO-HIST and IRDR, produced an initial set of recommendations for improvement. For better integration of DRR in IDAs practices, one needs also to look into the statutory instruments used in IDAs. In parallel, greater effort is required to further develop an international DRR initiative for IDAs, in order to facilitate research cooperation, data and knowledge sharing, multi-early warning and fast assessment, access to expertise and capacity building. All these are of interest of IRDR in pursuing a new partnership with UNESCO, ICL and others in its planned new DRR research agenda for 2030.

Keywords: Internationally designate sites, Disaster risk reduction, Partnership, IRDR, UNESCO, ICL

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Landslide Hazard and Risk Assessment for Civil Protection Early Response

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This paper presents a series of severe landslide disasters occurred in Italy, during which the local scientific community supported civil protection authorities in the management of the emergency responses. Depending on the event characteristics, scientific support focused on landslide mapping, damage assessment, monitoring, early warning, and designing of countermeasures. Relevant studies, published after the disasters and describing these activities, highlight that, in case of major events, the scientific community can provide a significant support in decision-making processes and intervention strategies, by means of multi-disciplinary skills, experience and resources. The Italian example of cooperation between the scientific community and civil protection authorities here described highlights as a knowledge transfer from theoretical frameworks to practical applications can optimize the disaster response operations. Even if this study focuses on the Italian situation, it may represents a starting point to evaluate the real contribution provided by landslide experts in disaster responses worldwide, for understanding weaknesses and strengths. In many countries, in fact, local authorities are not able to provide timely and effective responses also because of a lacking or insufficient support of scientists.

Keywords: Landslide disaster, Emergency response, Scientific support, Italy

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Size Matters: The Impact of Small, Medium and Large Landslide Disasters

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Owing to the nature of landslide triggering mechanisms, lack of realistic documentation on the impact of landslide disasters at global, national and subnational scales has existed for many years. Data from two sources was used to examine the discrepancies about the impact of landslide disasters by considering both, high magnitude-low frequency and high frequency-low magnitude events. Analysis of this landslide disaster data for thirteen countries (Argentina, Bolivia, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Mexico, Nepal, Nicaragua, Perú, Sri Lanka, and Venezuela) revealed larger differences than those previously reported. Variation among number of landslide disasters between databases was expressed in three orders of magnitude, whereas number of human losses differed in two orders of magnitude, and people affected in one.

Keywords: Landslides, Disasters, Database, Impact, DesInventar, EM-DAT

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Practices of Public Participation Early Warning System for Geological Hazards in China

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Early warning systems (EWSs) are the essential tools for disaster risk reduction and have been implemented in practices all around the world. The Chinese government, in consideration of its physical and social condition, developed the Public Participation Monitoring and Warning (PPMW) System as an affordable solution to reduce disaster risk. Governments steer the whole system, and residents are trained on how to identify, monitor, and escape from hazards to establish a PPMW network for early warning and emergency response. This system has been implemented in practice for more than twenty years and proved its efficiency, especially in terms of disaster mortality reduction in China. This article introduced its function and took Liangshan Prefecture to explain how the PPWM was set up and operated during the "719" Boli Landslide in 2018 at the community level to avoid casualties. The PPWM is one of the practices of the Chinese government to engage the public in disaster risk reduction, which can be an excellent experience to share with other less developed and populated countries facing similar disaster situations as China.

Keywords: Early warning, Public participation, Geological hazard, China

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Landslide geometry and activity in Villa de la Independencia (Bolivia) revealed by InSAR and seismic noise measurements

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Interferometric Synthetic Aperture Radar (InSAR) enables detailed investigation of surface landslide movements, but it cannot provide information about subsurface structures. In this work, InSAR measurements were integrated with seismic noise in situ measurements to analyse both the surface and subsurface characteristics of a complex slow-moving landslide exhibiting multiple failure surfaces. The landslide body involves a town of around 6000 inhabitants, Villa de la Independencia (Bolivia), where extensive damages to buildings have been observed. To investigate the spatial-temporal characteristics of the landslide motion, Sentinel-1 displacement time series from October 2014 to December 2019 were produced. A new geometric inversion method is proposed to determine the best-fit sliding direction and inclination of the landslide. Our results indicate that the landslide is featured by a compound movement where three different blocks slide. This is further evidenced by seismic noise measurements which identified that the different dynamic characteristics of the three sub-blocks were possibly due to the different properties of shallow and deep slip surfaces. Determination of the slip surface depths allows for estimating the overall landslide volume (9.18 · 107 m3). Furthermore, Sentinel-1 time series show that the landslide movements manifest substantial accelerations in

early 2018 and 2019, coinciding with increased precipitations in the late rainy season which are identified as the most likely triggers of the observed accelerations. This study showcases the potential of integrating InSAR and seismic noise techniques to understand the landslide mechanism from ground to subsurface.

Keywords: Compound landslide, InSAR, H/V method, Landslide triggers, Bolivia

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Early Warning Systems in Italy: State-of-the-Art and Future Trends

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Landslide risk in Italy is one of the highest worldwide. The strategy to face this problem largely relies on early warning systems. A national early warning system based on weather forecast is regulated by a national law, although each of the twenty regions composing Italy has a high degree of autonomy. For example, in Emilia-Romagna Region, rainfall data are statistically analysed and multiple values of standard deviation are used to define warning thresholds. On the other hand, a correct risk communication toward the population using appropriate means and content is necessary to make the warnings effective. Recently, a new possibility for regional scale, displacement-based early warning systems came to existence and is here presented.

Keywords: Early warning systems, Landslides, Sentinel-1, Rainfall thresholds, Risk communication

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Community-Based Landslide Risk Management in Contrasting Social Environments, Cases from the Czech Republic

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The contribution presents four cases illustrating advantages as well as flaws of community-based LDRR approaches under various environmental and social conditions. It shows that the individualization along with preferred competing interests (e.g. housing development) negatively affect LDRR at the community level. Nevertheless, even under unfavourable community conditions, its individual members may still effectively protect their interests involving the local state administrations into mitigation landslide risk, which they perceived as high. LDRR on the community level could be further hindered by legal fragmentation and institutional diversification, which could prevent implementation of desired mitigation measures due to unavailability of funds or missing definition of responsibilities. Nevertheless communities can overcome even such institutional obstacle, although it requires much larger collaboration involving other external actors (e.g. non-governmental organizations).

Keywords: Community, Landslide risk reduction, Citizen science

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Refinement Progresses on Freeway Slope Maintenance After a Huge Landslide Disaster

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After a huge landslide disaster, the maintenance refinement progresses on freeway such as emergency treatment, manual revision, establishment of management system and overall inspection are emphasized. The completely blocked traffic was opened after 55 days ongoing excavation and construction. The slope maintenance manual was totally revised based on the actual operation action. There are patrolling, periodical and special inspections. Some of the slope and the anchor inspection results are shown in the paper. All of grade A or B slopes have been upgraded to at least grade C (no obvious signs of instability) by the reinforcement method.The system is composed by lifecycle-based maintenance and management system, slope inspection operation system, slope information sharing platform and slope action management platform. All of the inspection and monitoring data are stored in the system. The data management time can be saved more than 30% and the inspection efficiency can increase about 50% by using the system. The freeway slopes are safeguarded from the results of overall inspection and restoration. The slope sorting results can help to control the maintenance sequence and budget planning.

Keywords: Slope maintenance management, Slope safety, Management system, Overall inspection

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Landslide Exposure Community-Based Mapping: A First Encounter in a Small Rural Locality of Mexico

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This research aimed to analyse the exposure of households and other buildings to landslides by means of community-based mapping in Huehueymico, a small rural locality of 884 inhabitants located in Teziutlán, Puebla, Mexico. Despite the severe impact of the disaster of October 1999 associated with rainfall induced landslides, there has been a lack of interest of local authorities to promote landslide disaster risk preparedness in rural isolated areas. Under such account, it is suggested that community-based mapping can be regarded as a very valuable alternative to enhance disaster risk education as a first encounter between residents and landslide disaster risk awareness. The methodology undertaken comprised the use of an unmanned aerial vehicle (UAV), in order to generate high resolution base maps, field evaluation of the conditions and state of conservation of the buildings, and a couple of workshops directed to undertake the community-based mapping. Results regarding the landslide exposure community-based map are presented in this investigation.

Keywords: Community-based mapping, Landslide exposure, Disaster risk, Uavs

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Co-Producing Data and Decision Support Tools to Reduce Landslide Risk in the Humid Tropics

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Rainfall-triggered landslides are increasing in the humid tropics, and Small Island Developing States are disproportionately affected. Frequent shallow slides in hillside cuttings along roads and in communities hinder sustainable development. Larger, less frequent storms cause hundreds of landslides that block lifeline roads, impede disaster response and reverse economic growth. Top-down Disaster Risk Reduction (DRR) policies and approaches aiming to transfer conventional landslide assessment science and engineering practices are not always suitable in these data- and resource-limited contexts. This paper recognises the emergence of co-production approaches as part of the resilience paradigm response to DRR science-policy-practice gaps. We present a case study from Saint Lucia, Eastern Caribbean, in which government engineers and policymakers have partnered with the authors to co-produce landslide hazard assessment data and prototype decision support tools to strengthen landslide hazard management along lifeline roads.

Keywords: Rainfall-triggered landslides, Small Island Developing States (SIDS), Knowledge co-production, Lifeline roads, Geotechnical data, Stochastic slope stability modelling

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ICT-Based Landslide Disaster Simulation Drill: Road to Achieve 2030 Global Commitment

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Information and Communication Technology (ICT) is an important driver for socio-economic innovation, and a promising tool for better managing future risk in a changing climate. ICT technology has been widely applied to support disaster management cycles (prevention/mitigation, preparedness, response, and recovery/rehabilitation). This paper presents a new approach based on inclusion of multi-stakeholders in strengthening community-based disaster risk reduction (DRR) in the urbanized region. We developed a functional framework to promote an ICT driven bottom-up DRR approach and increase coping with resilience capacity of vulnerable communities. This study was carried out based on the landslide that occurred on 28 November 2016 at Taman Idaman (Serendah, Selangor) with a potential effected 83,000 residents in the vicinity. We designed and implemented a disaster management training scheme based on a simulation drill

involving multi-stakeholders in the most urbanized state in Malaysia. The training scheme was established based on the metamodel based geospatial multi-disaster prototype system, which was later tested in the Full Scale Exercise (FSX) simulation drill. Remarkably the FSX drill was the first recorded landslide disaster simulation drill carried out at a district level characterized by ICT-Geospatial data in Malaysia. It was successfully organized with aims not only to improve the efficiency of the rescue effort, but also to enhance the community's participation in disseminating early warnings and to utilize an ICT enabler for building disaster resilient communities. We depicted 10 critical factors to design a landslide disaster simulation drill for supporting a local DRR resilience strategy. As a conclusion, an ICT-based landslide disaster simulation drill has potential to be up-scaled and replicated by empowering community knowledge, building capacity of local champions and promoting digital inclusivity towards assessing disaster risk and building resilient societies, in line with the 2030 global commitment in DRR.

Keywords: Disaster risk management, Landslide, ICT, Simulation dril,l Community-based disaster risk reduction

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A Preliminary Work of Safety Potential Analysis Model for Anchors Used on Freeway Slopes

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In Taiwan, the landforms are mainly dominated by mountains and hills. Thus, countless road sections of the freeways are impossible to avoid the state-of-the-practice problems such as slope cutting. In order to stabilize the freeway slope, ground anchor technique is often employed to improve the stability of cut slope. With the increasing service time of ground anchors, their performance on the freeway slopes is highly required to be assessed. There were many disasters on freeway anchored slopes in recent years, so ground anchor inspection has also received attention to a great extent. This paper introduces the concept of safety potential analysis and then utilizes the proposed model for an anchored slope. Specifically, the proposed safety potential analysis collects plain map, historical slope inspections, monitoring data, ground anchor inspections and maintenance practices, as well as further use the geographic information system to establish the proposed model. Finally, this paper provides the predicted result from safety potential analysis and suggests the dangerous area of the studied anchored slope to the government authorities for immediately response purpose.

Keywords: Anchor, Slope, Freeway, Safety potential analysis, Geographic information system

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Initial Experiences of Community Involvement in an Early Warning System in Informal Settlements in Medellín, Colombia

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The project Inform@Risk is developing a landslide early warning system in the informal neighbourhood or barrio Bello Oriente in the city of Medellín, Colombia. Settlements in an already unstable slope increase its instability even more due to several anthropogenic interventions. Since every step in the risk cycle includes human factors, this early warning system must be developed in accordance with and with the full involvement of the residents of the informal settlement. To achieve acceptance and even help from the population they need to be educated about the hazards and about the different aspects of a landslide and a warning system. In the project this education is carried out in several workshops, where the residents are informed, and community walks, in which they apply their new knowledge in the field. This cooperation will continue with the assistance of the residents in the field work and in integrating the early warning system into the barrio.

Keywords: Early warning system, Community participation, Informal settlements, Medellín (Colombia)

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Capacity Building and Community Preparedness Towards Landslide Disaster in Pagerharjo Village, Kulon Progo Regency of Yogyakarta, Indonesia

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In developing countries, promoting disaster knowledge for disaster mitigation and disaster risk reduction is at best when initiated from a local scale. The bottom-up approach in the landslide disaster management program in Indonesia could catch common awareness of the community for their living neighbourhood. Despite diverse characteristics of the communities, community-based mitigation may effective and often achieving capacity building and community preparedness towards disasters. Landslide disaster mitigation activities have been conducted in Pagerharjo Village, Samigaluh District, Kulon Progo Regency of Yogyakarta Province, Indonesia from April to October 2019. The activities are strongly involved in community participation in risk assessment, disseminating knowledge, establishing a task force team for disaster preparedness and emergency response, monitoring potential landslide disasters, as well as creating evacuation maps and standard operating procedures for evacuation. The main goals of these mitigation activities are well achieved: (1) locations of potential landslides in the village are identified; (2) capacity and preparedness of the community in Pagerharjo Village towards landslide disaster are successfully built through creating a simple risk and evacuation route map; (3) community participation in monitoring of slope mass movement is increased; (4) disaster mitigation knowledge to the community is well promoted, and (5) awareness of the importance of reforestation and slope protection of the area in Pagerharjo Village has become highly concerned.

Keywords: Landslide, Community participation, Preparedness and response team, Evacuation route map, Yogyakarta

The abstract is from the book "K. Sassa et al. (eds.), Understanding and Reducing Landslide Disaster Risk, Volume 1 Sendai Landslide Partnerships and Kyoto Landslide Commitment, pp 603-610

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Characterization and hydrological analysis of the Guarumales deep-seated landslide in the tropical Ecuadorian Andes

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The potential for landslides along the high sloped hills of the Eastern Andes chain provides challenges in planning and hazard mitigation especially in areas with hydropower dams and reservoirs. The objective of this study is to characterize, understand, and quantify the possible driving mechanisms underlying the Guarumales landslide located near the “Paute Integral” hydroelectric complex in Ecuador. Special attention is paid to the role of predisposing conditions and possible triggering factors such as rainfall and subsequent groundwater fluctuations, which may influence slope acceleration. We collected geological information from 12 cores, and data on surficial displacement, precipitation, evaporation, groundwater levels, and slope drainage. The geological interpretation of the landslide was revised based on the new drillings. Displacement data was collected using total station equipment with 6 and 5 seconds of precision. We performed a time-series analysis of measured groundwater levels and drainage data using transfer functions. The geology shows a locally complex system of colluvium deposits overlying a schist bedrock, reaching up to 100 m. Displacement rates are nearly constant over 18 years. Accuracy and time resolution of displacement data was too small to identify possible acceleration or deceleration in response to hydro-meteorological forcing. Groundwater and slope drainage showed a lagged response to rainfall. Finally, a conceptual model of the Guarumales landslide was developed, which may help to understand the other landslides in the area.

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On the importance of geological data for landslide risk reduction in Slovenia

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This study highlights the importance of geological data for landslide risk reduction in Slovenia. By using geological data at different scales and integrating them into landslide susceptibility models, we present a multiscale approach that can serve as an effective tool for risk reduction. Effective landslide risk reduction approaches consist of developing methods to identify landslide-prone areas and/or developing risk reduction approaches to mitigate landslide impacts in these areas. Landslide hazard, vulnerability, and risk classification must be at the core of any landslide management decision and, indeed, in any land use planning process on potentially landslide-prone lands. To date, most landslide hazard models have been based on geologic data obtained through field mapping, drilling, or outcrops, with the accuracy of these data dependent on the quality of the field investigation. Certain parameters must be considered when mapping geology, geologic landforms, and structures, with detail, accuracy, and precision being the most important. Similar multistep steps are required for drilling, sampling, testing, and extracting information from boreholes, which are one of the most important sources of information about subsurface geology and structure. Based on studies of archival data, boreholes are first plotted on maps and then located in the field by field inspection with the consent of the landowners. Boreholes provide a direct picture of the rock and soil components at depth. Boreholes also provide information on the depth of the underground water table, variations of different layers and their permeability, and the mineralogical and chemical composition of the rocks and their properties in terms of strength, landslide area, etc. The results of geological maps and boreholes are usually compiled and interpreted together with other advanced geodetic and geophysical techniques for landslide monitoring and spatio-temporal prediction of landslides to identify areas where landslides occur.

Keywords: landslides, geological data, mapping, monitoring, hazard

The abstract is from the One-Page Abstract of The Fifth World Landslide Forum, pp 9

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SATREPS project for Sri Lanka with regard to "Development of early warning technology of Rain-induced Rapid and Long-travelling Landslides"

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Influenced by the recent global climate change, extreme rainfall events have become more frequent worldwide and resultant hydro-meteorological hazards are creating more deaths and devastations. One of the most remarkable disasters of rain-induced rapid long-travelling landslides (RRLL) in Sri Lanka took place at Aranayake, 70 km east of Colombo in 2016 (JICA Survey Team 2016). The fluidized landslide mass ran over an about 2 km distance claiming the lives of 125 people. This tragic event has thus highlighted the importance of rational and scientific early warning and disaster management mechanisms even more than ever because the presence of these hidden unstable soil masses, as well as their run-out distances are very difficult to predict in advance, and once they start sliding, it is almost impossible to stop them. Both the National Building Research Organisation, Sri Lanka (NBRO) and the International Consortium on Landslides (ICL) have jointly compiled a research proposal within the framework of SATREPS, standing for "Science and Technology Research Partnership for Sustainable Development," a Japanese government program that promotes international joint research, and the 5-years SATREPS project for Sri Lanka with regard to "Development of early warning technology of Rain-induced Rapid and Long-travelling Landslides (Project RRLL)" has officially launched in 2020 in the wake of the COVID-19 pandemic. Though COVID-19 cases are yet soaring worldwide, we have implemented a greater part of our original plans remotely and smoothly thanks to the great bits of helps from officers in charge at JICA and JST. This article reports on the outline of the project including its goals, current development progress of individual technologies for the early warning system, etc.

Keywords: rain-induced rapid long-travelling landslide, SATREPS, early warning, Sri Lanka

The abstract is from the One-Page Abstract of The Fifth World Landslide Forum, pp 10

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Technology development of reliable rainfall prediction in mountain regions of Sri Lanka

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We develop a reliable rainfall prediction system to be incorporated with an early-warning system for rapid and long travelling landslides in Sri Lanka. The southwest region of Sri Lanka, where the south-western monsoon brings heavy rain between May to September, is our target region. We use a non-hydrostatic atmosphere-ocean-land coupled model named the Multi-Scale Simulator for the Geoenvironment (MSSG) (e.g., Takahashi, K. et al., 2007, 2013; Onishi, R, and Takahashi, K., 2012). We have implemented a new cloud microphysical parameterization that can consider the effect of atmospheric turbulence on rainfall generation processes (Seifert, A, and Onishi, R., 2016), which enables us to consider the impact of boundary layer turbulence on orographic precipitation (i.e, mountain rainfalls). We have confirmed that our prediction system can reproduce the heavy rainfall that induced the Aranayake landslide of May 2016 in Sri Lanka. We have also implemented the super-resolution prediction system (Onishi, R. et al., 2019), which utilizes the super-resolution mapping technology based on the deep convolutional neural network. We have shown that our system can produce rainfall predictions at the spatial resolution of 500m for the coming 24 hours within one hour at an ordinary workstation.

Keywords: numerical weather prediction, orographic precipitation, turbulent cloud, super resolution

The abstract is from the One-Page Abstract of The Fifth World Landslide Forum, pp 11

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Strategy for monitoring creeping movements of unstable soil masses triggered by heavy rain at pilot sites in tropical forested mountain

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The mountainous district in Sri Lanka is located in the tropical rain region, and many landslides triggered by heavy rains have occurred frequently. Especially, rain-induced rapid and long-travelling landslides can cause serious damage to regions. It is therefore necessary to clarify the landslide mechanism and develop the risk prediction technology for damage reduction. The soil water and groundwater condition have a great influence on the activity of high liquidity landslides. Therefore, it is important to clarify the groundwater characteristics of landslide-prone slopes in tropical rain forests under heavy rains. In this study, the observation system was designed to study the hydrological processes and landslide mechanisms. In this presentation, we introduce the overall plan of observation. The study sites are Athweltota and Aranayake in Sri Lanka. A monitoring system will be installed on the remaining soil masses immediately by the collapsed slope. In particular, the infiltration process will be a focus of observation during heavy rain seasons. Observation items are general weather, rainfall in the forest, soil moisture, groundwater level, surface displacement, and underground displacement.
Forests have special environmental conditions such as rainfall interception in the canopy, forest soil which has high water retention and permeability, and root system in the underground soil layer. Therefore, it is necessary to consider the rainfall infiltration processes different from those on the bare slopes. We conducted a preliminary study on the effect of forests on heavy rain infiltration on slopes, which can trigger landslides. Rainfall and soil moisture on the surface on the forest slope were observed in the heavy rainfall region of Japan. Changes in soil moisture during rainfall were compared before and after deforestation. It is clarified that the surface soil becomes dry before a rain, and that soil moisture content increases sharply during rainfall without rainfall interception after deforestation. In the future, we will examine the relationship between the infiltration of heavy rainfall on the forest slopes of tropical rainforests and landslides, referring to the preliminary study.

Keywords: landslide, groundwater, monitoring, tropical rain, Sri Lanka

The abstract is from the One-Page Abstract of The Fifth World Landslide Forum, pp 12

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Porewater pressure build-up of slopes subjected to different rainfall conditions by centrifuge modelling

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The occurrence of landslides possesses a high degree of unpredictability by nature since it involves many factors. Out of many, rainfall holds as the main triggering factor which causes landslides in particularly, natural slopes in countries all over the world. In general, landslide early warning systems use the combination of rainfall duration and rainfall intensity as two fundamental parameters to develop empirical relationships. These predictions show that high intensity – low duration rainfall to low intensity – high duration rainfall have the potentiality to trigger a landslide. In this study, an attempt has made to quantitatively demonstrate the behavior of soil slopes under four different rainfall intensities varying from high intensity to low intensity, trying to keep the same cumulative rainfall for all the cases. Geotechnical centrifuge modelling technique is used to conduct the experiments using an inflight rainfall simulator. Four identical slopes with shallow depth to bedrock are subjected to different rainfall conditions to discuss the effect of rainfall intensity, cumulative rainfall, and rainfall continuity to change porewater pressure variation during each case.

Keywords: landslides, slopes, rainfall infiltration, centrifuge modelling

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Early warning system against rainfall-induced landslide in Sri Lanka

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Landslide Early Warning System (EWS) plays a major role as a non-structural risk reduction method on rainfall-induced landslides and slope failures in Sri Lanka. In this regard, National Building Research Organisation (NBRO) is the authorized body for issuing landslide EW in the country. Warnings are based on predefined rainfall threshold limits and issued on a regional scale under three levels namely watch, alert, and evacuation respectively at 75 mm/day, 100 mm/day, and 150 mm/day or 75 mm/hours. The NBRO's automated rain gauges network comprising of 325 automated rain gauges established in the landslide-prone areas of the country is used to obtain real-time rainfall data based on which the early warnings are issued. Landslide Hazard Zonation Maps (LHZM) and site-specific landslide investigations that were already completed by NBRO are also important tools to identify the places needing to give special attention during the issuance of early warnings. Although the formal EW message is disseminated from the top national level up to the grass-roots level, the devasting landslide incidents that took place in the country in the recent past has taught that the warnings are not always relayed efficiently to vulnerable communities and often get neglected by the communities due to the generalized nature of the warning.

Therefore, as a practical solution to save more lives in line with four priorities of Sendai Framework for Disaster Risk Reduction 2015-2030, NBRO started implementing site-specific instrumentation based EW systems and the Community-Based Landslide Early Warning (CBLEW) approach for the identified landslide vulnerable communities in the country from 2016 onwards. The CBLEW approach is aiming to empower the communities and establish systematic preparedness plans for timely self-evacuation of communities in case of a landslide event. In this course, the communities are educated on preparedness and self-decision making based upon the rainfall data which could be obtained by manual rain gauges distributed in the village. However, fatal landslides/slope failures that keep happening in the county keeps reminding us about the existing need for a more sophisticated early warning system that is not limited to a generalized regional scale one, which consists of a balanced combination of each phase such as designing, monitoring, forecasting, and education.

Keywords: rainfall-induced landslide, rainfall threshold, early warning, community-based, Sri Lanka

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Strengthening non-structural measures for Landslide Risk Reduction in Sri Lanka – Achievement in Project SABO -

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Landslide is one of the most serious natural disasters in Sri Lanka. In the central and southwestern mountainous areas, landslides frequently occur in the monsoon period because of the fragile geology and steep topography. In addition, increasing exposure to the hazards due to rapid reclamation and development has been raising landslide disaster risks in urban and rural areas. National Building Research Organisation (NBRO) under the Ministry of Defense is the responsible agency for implementing landslide risk reduction measures both structural and non-structural in Sri Lanka. Based on the request from the Sri Lankan government in 2018, Japan International Cooperation Agency (JICA) launched a technical cooperation project, "Project for Capacity Strengthening on Development of Non-structural Measures for Landslide Risk Reduction (Project SABO)" aiming at 1) strengthening capacity on landslide hazard mapping and risk assessment, 2) improving landslide early warning system and 3) implementing land use regulation to prevent inappropriate reclamation and development in mountainous areas. In the project, the "Sediment Disaster Prevention Act" in Japan has been introduced to apply the landslide hazard zoning methods and the land use regulation/development standards in Sri Lanka. During the implementation of the project, however, a lot of adjustments were needed to apply those in Sri Lanka because of the different natural and social conditions, and legislation systems in both countries. Based on the series of discussions and trial and error approaches, finally, the methods, criteria, and risk-based land-use regulations have been compromised, and the comprehensive Sediment Disaster Risk Reduction Plans (SDRRPs) were developed in the selected pilot sites in cooperation with relevant stakeholders such as Disaster Management Center, Urban Development Authority, and Local Authorities.

Keywords: SABO, landslide, non-structural measures, JICA, Sri Lanka

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Role of Disaster Management Center on Landslide Risk Management

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Impacts of extensive and intensive types of disasters have been identified as one of the serious threats to sustainable development in Sri Lanka. Frequent disasters of the country are associated with hydro meteorological-related hazards such as floods, droughts, landslides, high winds, etc. As per the DesInventra data published by the Disaster Management Center (DMC) and all other data available, the highest number of deaths and economic loss have been recorded under landslides. DMC, being the mandated organization, for guiding, facilitating, coordinating, and implementing disaster risk management to ensure safer Sri Lanka while facilitating to achieve the sustainable development goals, landslide risk management has been identified as one prime area that needs to be addressed holistically and urgently.

DMC has taken milestone steps on landslide risk management addressing the four priority areas of Sendai Framework for Disaster Risk Reduction (SFDRR), together with the National Building Research Organization (NBRO), which has been identified as technical agency for landslide monitoring and mitigation. Landslide risk management has been included into National Disaster Management Plan (NDMP) and National Emergency Operation Plan (NEOP) as one of the major strategic area and has taken initiatives to mainstream landslide risk reduction into development sectors such as road construction, housing development and tourism development etc. Complementing with technical guidance, the information provided by the NBRO on landslide monitoring and warning, DMC has initiated numerous programmers at the community level enabling the public to obtained information on landslide risk, disseminate early warning messages to the vulnerable communities, enhance capacities and capabilities of vulnerable communities on community-level landslide monitoring using manual rain gauges and observing changes in the surrounding environments with the support of the national and local level stakeholders. Analysis of the achievement of landslide risk management of the country, strengthening landslide risk governance to manage landslide risk, and investing landslide risk for resilience have been identified as areas to be reinforced in the future to achieve resilience in 2030.

Keywords: Landslide, Disaster Risk Reduction, Sri Lanka

The abstract is from the One-Page Abstract of The Fifth World Landslide Forum, pp 16

Theme 2 From Mapping to Hazard and Risk Zonation

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Landslides across the USA: occurrence, susceptibility, and data limitations

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Detailed information about landslide occurrence is the foundation for advancing process understanding, susceptibility mapping, and risk reduction. Despite the recent revolution in digital elevation data and remote sensing technologies, landslide mapping remains resource intensive. Consequently, a modern, comprehensive map of landslide occurrence across the United States (USA) has not been compiled. As a first step toward this goal, we present a national-scale compilation of existing, publicly available landslide inventories. This geodatabase can be downloaded in its entirety or viewed through an online, searchable map, with parsimonious attributes and direct links to the contributing sources with additional details. The mapped spatial pattern and concentration of landslides are consistent with prior characterization of susceptibility within the conterminous USA, with some notable exceptions on the West Coast. Although the database is evolving and known to be incomplete in many regions, it confirms that landslides do occur across the country, thus highlighting the importance of our national-scale assessment. The map illustrates regions where high-quality mapping has occurred and, in contrast, where additional resources could improve confidence in landslide characterization. For example, borders between states and other jurisdictions are quite apparent, indicating the

variation in approaches to data collection by different agencies and disparity between the resources dedicated to landslide characterization. Further investigations are needed to better assess susceptibility and to determine whether regions with high relief and steep topography, but without mapped landslides, require further landslide inventory mapping. Overall, this map provides a new resource for accessing information about known landslides across the USA.

Keywords Landslide mapping, Inventories, Susceptibility, Incidence, National map, United States

The abstract is from the Landslides journal “Landslides 17, 2271–2285 (2020)”.

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Landslide Recognition and Mapping for Slope Disaster Risk Reduction and Management

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Understanding of landslide phenomena and mapping has advanced technically, as have the tools and related theory. The change began during the international decade for Natural Disaster Reduction launched by the United Nations in 1990. The utmost importance of these issues worldwide has clarified business solutions for disaster prevention by the United Nations World Conference on Disaster Reduction in 2015. Here, an improved understanding of landslide recognition and mapping serve as fundamental ways to both reduce and prevents disasters. Naturally for engineers and researchers, recognition and mapping must benefit in both capacities. However, a question remains as to the ability for everyone to understand the results, such as with a map. Whenever a disaster occurs, disaster victims claim due to “not understand that a disaster could occur here”. During such times, engineers, clients, and local residents must aim to increase the understanding and use of maps for slope disaster risk reduction (SLOPE DRR). This keynote lecture introduces examples in connection with the circumstances of understanding and mapping.

Keywords: Landslide mapping, Risk evaluation, Sensing tool, Site prediction, Slope DRR

The abstract is from the book “F. Guzzetti et al. (eds.), Understanding and Reducing Landslide Disaster Risk, Volume 2 From Mapping to Hazard and Risk Zonation, pp 9-31

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New Landslide Inventory Map of the Sudetes Mountains (South-Western Poland)

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The paper presents the new landslide inventory map in the Sudetes Mountains (NE part of Bohemian Massif) in south-western Poland. The inventory is based on the remote sensing method—analysis of the digital elevation model (from LiDAR data) and topographic maps. The information from published papers, geological maps and field works were also used. The results contain a characterization of the study area by the number of landslides and index of landslide occurrence for each mesoregion. Moreover, a preliminary analysis of landslide distribution in relation to the geology and major tectonic zones of the Sudetes was made.

Keywords: Landslide, LiDAR, Lower, Silesia, Bohemian, Massif

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Gullies as Landforms for Landslide Initiation—Examples from the Dubračina River Basin (Croatia)

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One of the remedies for reducing the negative effects of landslide activity is landslide mapping. Landslide detection, carried out by using historical data analysis, stereoscopic photo interpretation and/or field works, is expensive, time-consuming and requires expert knowledge and experience. Automatic approaches for landslide detection can provide benefits such as increased efficiency and reduced costs and time. Many attempts have been made to automate the process of landslide identification but the key information for this process is provided by the high-resolution Digital Elevation Model (DEM) delivered from Airborne Laser Scanning (ALS) data. Having considered this, the objective of this study is to utilise the Object-Oriented Approach (OOA) and DEM for the detection of landslides. In this study, we use the results archived from Pawluszek et al. (ISPRS Int J Geo-Inf 8:321, 2019). The challenges and opportunities of automatic approaches are discussed, based on an investigation conducted in an area heavily affected by landslides. The study area is located close to Rożnów Lake, in Poland and stands out by various land uses. The automatic detection results achieved (OA = 85% and K = 0.6) indicate that there is a huge potential in automatic approaches. However, these approaches face difficulties in landslide detection due to the smoothing of typical landslide features. This situation appears for old landslides and landslides located in areas of active agricultural treatments. Besides the fuzzy delineation of the landslide extent, landslide amalgamation in the OOA results can be observed. Thus, automatic approaches still need to be developed and improved. At the current stage of the development, automatic approaches cannot replace validation based on field reconnaissance but can support an interpreter in their work.

Keywords: Gully erosion, Historical landslide inventory, Historical gully inventory, LiDAR derivatives, Visual interpretation, Dubračina River Basin, Vinodol Valley

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Can Repeat LiDAR Surveys Locate Future Massive Landslides?

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This study examined a topographic indicator of a massive landslide that occurred in 2011 in the Kii Peninsula, Japan. Assuming that the slope was deforming slowly based on surface roughening before the event, a roughness filter, the standard deviation of the slope angle for 3·3 cells on a 1 m digital elevation model (DEM), was used as a measure of change in the ground surface and calculated using light detection and ranging (LiDAR) data for 2006 and 2010. The images produced from the survey data showed that a major crack had already developed between a wide ridge and a lower undulating patch on the slope that subsequently became the head of the slide. The cells in which the standard deviation increased by 0.39–2.32 between the surveys formed a group of ripple-like features clustered in the area. The results indicate that repeat LiDAR surveys can help identify slopes in imminent danger of sliding based on the location of progressive surface roughening.

Keywords: Gully erosion, Historical landslide inventory, Historical gully inventory, LiDAR derivatives, Visual interpretation, Dubračina River Basin, Vinodol Valley

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Developing Recognition and Simple Mapping by UAV/SfM for Local Resident in Mountainous Area in Vietnam—A Case Study in Po Xi Ngai Community, Laocai Province

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Laocai is one of the provinces of northwestern Vietnam that is at high risk of landslide. Typical natural features of this area are hilly terrain, complex geology, and tropical monsoon climate with large annual average precipitation. People of ethnic minorities in the area up to now still affected by natural disasters. They desperately need appropriate tools for identifying and responding to this disaster. This study is a test fand quick landslide inventory map-making based on the application of modern technologies such as UAV/SfM to the building up of landslide identification and distribution maps in combination with checking and revising by site survey with the participation of local people for an area of Po Xi Ngai village, Lao Cai province. By recognizing the landslides on 3D images of the area in conjunction with the fieldwork checking, this method is expected to give local people the knowledge of landslide identification to develop the prevention and mitigation strategies by their capacity.

Keywords: Landslide, Simple mapping, UAV/SfM, Local resident, Mountainous area, Vietnam

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Landslide Activity Classification Based on Sentinel-1 Satellite Radar Interferometry Data

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Kosice basin located in the Eastern part of Slovakia heavily affected by landslides was studied using radar data from Sentinel-1A satellite. Existing landslide inventory activity map was reassessed using processed data from Sentinel-1A radar mission acquired between December 2014 and May 2017. PS InSAR technique was used for generation of landslide displacement permanent scatterers inside the landslide area, where average LOS velocity was applied for assessment of landslide activity in the form of thematic map. Using alternative method a LOS deformation velocity vectors were transformed into the slope direction generated from DEM resulting in kSLOPE velocity data used for alternative classification map. This was possible thanks to availability of radar data from both acquisitions (ascending and descending) on the studied AOI. Comparison of both methods showed increase in number of landslides classified as active on behalf on medium active class when kSLOPE transformed data were used, resulting in more comprehensive activity classification map. The transformation of velocity vector vLOS must be, however, used with caution, due to variable sensitivity of radar data in different directions with regard to the satellite path.

Keywords: Sentinel-1A, Landslide activity, Monitoring, Radar interferometry, Kosice basin

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Damming Predisposition of River Networks: A Mapping Methodology

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Landslide dams may collapse within few hours/days after their formation resulting in destructive flooding wave. Due to the limited time available since their formation, forecasting tools able to assess the damming susceptibility over large areas are more advisable for prevention and setting up mitigation measures. A semi-automated GIS-based methodology is proposed in this work to map the spatial damming predisposition over large areas, to analyse consequence and risk scenarios. The procedure is based on a morphological index that use a statistical correlation between morphometric parameters to spatially assess the chance of a river obstruction through the reactivation of an existing landslide. This damming mechanism were tested on the Arno River basin (9116 km2) in Italy, where about 30,000 landslides are mapped. The highest mountain ridges in the Eastern part of the area resulted as the most susceptible to damming in the basin. The concentration of the historical landslide dams endorses the results for this basin.

Keywords: Landslide dams, Susceptibility, Natural hazards, GIS

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Maximum Likelihood Classification method for detection of litho-geomorphological units in the Vipava Valley, SW Slovenia

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Various types of mass movements occur in a geologically and geomorphologically diverse setting in the Vipava Valley (SW Slovenia). These comprise various types of landslides, creep, and Quaternary slope deposits of carbonate blocks and recent scree deposits. In the valley, Mesozoic carbonate are overthrusted on Paleogene flysch (alternations of mostly sandstones and marlstones), resulting in steep slopes and mass movements. Our study is based on the automatic supervised maximum likelihood classification of various lithogeomorphological units including slope deposits, alluvial deposits, steep carbonate cliffs, flysch, two carbonate plateaus, and Quaternary deposits. Several polygons were used for training and consequently the method was applied to automatically classify the complete study area into the above mentioned six litho geomorphological units. For input layers, we used data for elevation, slope, terrain ruggedness index (TRI), and curvature. Results show that the method is generally suitable for classification of the litho geomorfological units including slope deposits. Comparison with a more detailed map, comprising mapped various mass movements indicates that the method correctly predicts high Trnovo plateau carbonates, steep carbonate slopes, translational carbonate blocks, and fossil rock avalanche deposits and alluvial deposits, but however is not able to clearly distinguish between flysch and more recent slope deposits of gravel and breccia due to their similar elevation, TRI, and slope values. The Slano blato mudflow and Stogovce landslide are not recognized. Therefore, this automatic classification can be carefully used to create a general guidance map of general occurrences of litho - geomorphological units including slope deposits before the field mapping, with the aim of delineation of slope deposits so they can be further studied in detail later in the field. Nevertheless, such a map cannot be used as a direct substitute map for the geological and geomorphological map obtained in the field due to impossibility in distinguishing among the units with the same properties.

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Landslides Triggered by the September 6th 2018 Hokkaido Eastern Iburi Earthquake □Topographic and Geologic GIS□LP Analyses

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An intensive earthquake (M6.7) on September 6th 2018 triggered total more than 10,000 landslides in the Eastern Iburi area, Hokkaido, Japan. The landslides claimed 36 lives on the foot of the slopes. We interpreted the landslides using Ortho Image by Geospatial Information Authority(GIA), Japan and Chibouzu (CBZ) developed by Shin Engineering Co. Ltd., and classified three types of the landslides: 1) Spoon Type(S), 2)Planar Type(P) and 3) Jisuberi Type(J). And then, we analyzed them using GIS the relationship between the landslide frequency, and the topography and geology composed of volcanic pumice/ash fall deposits and underlain by Miocene sandstone and mudstones. As the results, we revealed that the elevation of the landslide area ranges from 100‐200m, the slope gradients for the landslides show peaks at 20o‐30o before the earthquake, however, it shifted to 25o ‐35o after the earthquake, and that most of the shallow landslides (S and P Type) in the northwest area, occurred from the air fall pumice/ash deposits derived from Tarumai Volcano (ca: 9,000 yBP) and Eniwa Volcano (ca: 20,000 yBP) and we found that the deep‐seated landslides (J Type) occurred as dip‐slipping along the stratum dipping of the Miocene formations in the southeast areas. Namely, this shows the same tendency as the old landslide distribution. In addition, we now attempt to establish a simulation model of the large‐scale landslide using high resolution LP Scanner.

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Landslides Along Halong-Vandon Expressway in Quang Ninh Province, Vietnam

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This paper presents a preliminary study on landslides along Halong-Vandon expressway in Quang Ninh province, Vietnam through detailed site surveys, soil testing and analysis of collected data including geology, geomorphology, rainfall and project documents. The results show that landslides occurred at 44 locations from June to August in the 2017 and 2018 rainy seasons. Shallow debris slides were dominant on cut slopes along the expressway, accounting for 35 cases. Rainfall with moderate to high intensity in a short period was the landslide triggering factor while slope cutting for road construction was the main preparatory factor of the landslides. A detailed rainfall analysis presented that the cumulative event rainfall of 3 days ago was likely sufficient to saturate the soils and forming a landslide. In addition, the improper geological investigation and calculation of safety factors played a significant contributing factor, which has become a critical issue in the Halong-Vandon expressway project. These findings highly agreed with those examined in a selected landslide case at the Km 27 + 950 location.

Keywords: Landslides, Characteristics, Mechanism, Cut slopes, Rainfall, Halong-Vandon

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Roughness analysis of the fossil landslides surface in the Vipava Valley, SW Slovenia

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The aim of the study is to analyse the geomorphological characteristics of sedimentary bodies of Podrta gora and Gradiška gmajna fossil landslides and some smaller gravitational bodies Stara baba, Veliki strel, Klapačiše and Zagriža, where we have roughly identified two main types of movement: structurally conditioned movement and movement originating from gravitational slope processes. In addition to material properties, the level of surface roughness also depends on the depositional processes of the slope deposit. These were formed by complex sedimentary events and are intertwined in the geological past. Geomorphometric analysis revealed some specific features concerning the structure. The most distinctive geomorphological element is the downward gravitational movement of the huge carbonate block along the Predjama fault, located in the hinterland of the fossil landslides, and the high intensity of the slope processes of the Podrta gora and Gradiška gmajna landslides in this area. The results suggest that the whole area could be a part of a large deep-seated landslide of a carbonate massif along the old fault structures.

Keywords: fossil landslide, geomorphology, geological setting, deep-seated landslide

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Mapping landslides at a nationwide scale using InSAR: the Norwegian Ground Motion Service

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Large rock avalanches represent one of the most significant risks to lives and infrastructure in Norway. Catastrophic failures of unstable rock slopes have occurred several times in the last century in Norway, with fatal consequences. Therefore, the Government of Norway aims to systematically map and classify all unstable slopes in Norway for their hazard and risk. With over 300,000 km^2 of sparsely populated, mountainous landscape, earth observation plays a crucial role in this task.

Between 2009 and 2018, the Geological Survey of Norway (NGU) systematically acquired Radarsat-2 images over the most landslide-prone areas of the country. Using InSAR software developed by NORCE, NGU processed these data to produce regional ground motion datasets. These proved invaluable for identifying unstable slopes. Nonetheless, these datasets had limitations. For example, with Radarsat-2's 24-day repeat cycle, at most 5 or 6 snow-free images could be acquired for any given area each year. And even though we acquired over 800 scenes each year, only select areas of the country could be prioritised. Fortunately, these problems were soon to be solved by the Copernicus Sentinel-1 satellites.

In 2016, NGU, the Norwegian Space Agency and the Norwegian Water and Energy Directorate set about developing the Norwegian Ground Motion Service (InSAR Norway). Operated by NGU, the service runs on a high-performance computing cluster (HPCC) using software developed by NORCE and PPO.labs. By processing over 4000 Sentinel-1 images per year, velocities for over 5 billion measurement points are provided, with complete deformation time series. Launched in November 2018, the service provides government, industry, scientists, and the general public with a consistent free and open InSAR based ground motion data source. The data are publicly available in a web browser interface, with tools for simple data analysis and

download.

Ground motion maps are used to identify moving slopes, which are then assessed to determine the primary process driving the movement. Since the release of the first national dataset, over 100 new unstable rock slopes have been identified. During the hazard and risk classification stage, movement rates are fed into a semi-quantitative assessment process. Thanks to the high latitude of Norway and the wide satellite ground track, most points on the ground are covered by between four and six independent datasets. These can be combined for interesting sites to estimate two-dimensional displacement vectors, given the appropriate local constraints on movement direction. These, combined with extensive field investigation, are used to determine possible failure scenarios and assign hazard and risk values to each.

InSAR also plays a role within our permanent monitoring of medium- and high-risk unstable mountain slopes. Such unstable slopes are equipped with snow protected corner reflector (CR) networks. Currently, over 20 slopes are monitored throughout the year, with displacement data being updated biweekly.

Keywords: InSAR, Landslide, Copernicus, Sentinel-1

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The Effective Surveyed Area. Uncertainty reduction in field work based landslide inventories

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Geomorphological field mapping is a conventional method used to prepare landslide inventories; however, the approach is typically hampered by the accessibility and visibility during the field campaigns along the study area. This results in a non-homogeneous survey of the territory, which lead to uncertainties respect to the area that was actually observed and mapped. To date, landslide absence has been typically assumed in non-surveyed regions and this assumption can have relevant effects in all the derivative products such as landslide susceptibility models. In order to overcome such methodological uncertainty we present the new release of r.survey.py, an open source GIS tool that allows the delineation of the portion of the area that was actually surveyed (or which can be surveyed in the future), also called the Effective Surveyed Area (ESA). Defining the ESA by means of the simple viewshed area respect to the paths traveled during the field-mapping is not enough; ESA is the area in which an object (a landslide) of a given area is considered visible, and hence mappable. So, having more accurate information about the real observed area can help to manage field-based landslide information avoiding uncertain assumptions. This communication shows the details about the usage of r.survey.py and proposes an approach for the optimal selection of the parameters controlling the ESA delineation. The method was tested in Gipuzkoa Province (Basque Country), north of the Iberian Peninsula, where digital elevation models of different ground resolution were available and a field-based landslide survey was performed.

Keywords: landslide inventory, field-based data, landslide susceptibility model, effective surveyed area

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Use of InSAR at multiple spatial and temporal scales to reveal landsliding mechanisms

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Interferometric synthetic aperture radar (InSAR) on terrestrial, aerial, and satellite platforms often provides spatially extensive landslide kinematic data. The persistent Slumgullion landslide in Colorado, USA has been studied for more than a century, and recent studies have benefited from InSAR measurements from these 3 platforms. Results illustrate utility of InSAR for landslide studies. InSAR provides only line-of-sight displacement data, and while satellite-based InSAR generally provides near-weekly data, the line of sight may not relate well to slide movement. Some satellites may be tasked more frequently, however, with look angles aligned with slide movement. Such tasked and untasked satellite-based studies revealed Slumgullion's general kinematics and seasonal changes in speed likely caused by pore-water pressure variation. Aerial-based studies of the slide involved multiple flight paths to provide three-dimensional displacement data with higher spatial and temporal resolution than satellite studies. Aerial studies well-revealed the slide's 11 primary kinematic elements, their internal speed consistency, and abrupt landslide and element boundaries suggestive of displacement along faults. Aerial studies also revealed seasonal differences in relative element speeds likely resulting from variable timing of pore-pressure change, and variable sensitivity of landslide elements to precipitation, possibly due to slide depth variation. Terrestrial InSAR provides the greatest temporal resolution (minutes) and can be aligned with slide movement, but shadowing by topography and vegetation can hinder spatial coverage. At Slumgullion, terrestrial studies revealed hourly upslope and downslope propagation of sub-mm movements and that in-phase movement of all elements resulted in faster overall slide movement. Results suggest that minor pore-pressure change along shallow parts of lateral slide boundaries instigated speed change, and that rapid movement caused strengthening of landslide boundaries and consequent deceleration. Hence, InSAR can rapidly characterize landslide kinematics and assist studies of landsliding mechanisms, with the InSAR platform largely determining the data utility.

Keywords: InSAR, Slumgullion, landslide, kinematics, landslide mechanisms

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Landslide susceptibility assessment in complex geological settings: sensitivity to geological information and insights on its parameterization

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The literature about landslide susceptibility mapping is rich of works focusing on improving or comparing the algorithms used for the modeling, but to our knowledge, a sensitivity analysis on the use of geological information has never been performed, and a standard method to input geological maps into susceptibility assessments has never been established. This point is crucial, especially when working on wide and complex areas, in which a detailed geological map needs to be reclassified according to more general criteria. In a study area in Italy, we tested different configurations of a random forest–based landslide susceptibility model, accounting for geological information with the use of lithologic, chronologic, structural, paleogeographic, and genetic units. Different susceptibility maps were obtained, and a validation procedure based on AUC (area under receiver-operator characteristic curve) and OOBE (out of bag error) allowed us to get to some conclusions that could be of help for in future landslide susceptibility assessments. Different parameters can be derived from a detailed geological map by aggregating the mapped elements into broader units, and the results of the susceptibility assessment are very sensitive to these geology-derived parameters; thus, it is of paramount importance to understand properly the nature and the meaning of the information provided by geology-related maps before using them in susceptibility assessment. Regarding the model configurations making use of only one parameter, the best results were obtained using the genetic approach, while lithology, which is commonly used in the current literature, was ranked only second. However, in our case study, the best prediction was obtained when all the geological parameters were used together. Geological maps provide a very complex and multifaceted information; in wide and complex area, this information cannot be represented by a single parameter: more geology-based parameters can perform better than one, because each of them can account for specific features connected to landslide predisposition.

Keywords: Susceptibility, Random forest, Comparison, Sensitivity, Geology, Lithology

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An expert‐based Landslide susceptibility assessment on city scale level with limited data-an example from Kuala Lumpur City

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Kuala Lumpur City suffers from frequent landslides, but many of them are related to human activity and human construction works. A literature review showed that most reported landslides occur in cut slopes, road embankments, highways and other man‐made slopes. Also many landslides are associated with ex‐mining activities and hillside or hill slope development. In the frame of the international project "Disaster Resilient Cities ‐ Forecasting Local Level Climate Extremes and Physical Hazards for Kuala Lumpur", funded by MIGHT (Malaysia) and InnovateUK, a consortium of 10 Malaysian and 6 UK partners, a landslide susceptibility map was developed for Kuala Lumpur. To achieve this, landslide inventories and numerous thematic maps were provided by the Malaysian project partners. Considerable inherent uncertainty in the data provision, pertaining to inconsistency in data capture and spatial resolution in both the landslide point data and,.. the distribution of superficial deposits, weathering grade and composition of the bedrock material, alluvial deposits, material in the ex‐mining areas and distribution artificial soils for KL city was identified at an early stage in the project . Two different approaches to susceptibility mapping were trialled.Colleagues from the University of Malaya tested a bivariate statistical analysis, as described by Brabb (1972) and Van Westen (1994). After workshop and roundtable discussions with project partners and Malaysian experts, it was decided to include 7 different factors in the analysis, which include Distance to Road, NDVI, Surface Material, distance to lineament, Elevation, slope gradient and roughness. These factors were classified, combined with part of the landslide inventory data and weighted to produce the final susceptibility map. Finally the map was validated by using the other part of the landslide inventory data. British Geological Survey (BGS) colleagues focuses more on the potential causal factors, with subsequent use of the landslide inventory to check whether the defined areas of susceptibility show landslides. This methodology

aligns with parts the BGS GeoSure methodology, a deterministic / heuristic approach, where different aspects are weighted and factored according to their potential impact on landslide susceptibility. The main principle behind this approach is the development of an expert based method, that allows the Malaysian experts to adapt and change according to their knowledge and expertise, but also to update the map, when changes occur (like changes in morphology, land□use etc.). The available landslide records were not used to develop the models, but were used for comparison and checking. The procedure involved dividing the landslide susceptibility work into three blocks, considering morphometric, anthropogenic and lithological attributes. For the morphometric analysis only the high resolution DTM was used and thus the data uncertainty is very low. The analysis around anthropogenic attributes includes factors like land□use and land□use change, distance to roads and land□disturbance and has a higher degree of uncertainty due to the available information. In contrast to this, the geology/ lithology analysis contains numerous assumptions and speculations as no spatial near surface information for KL were available. Thus, this analysis include a higher degree of uncertainties. For each attribute, a susceptibility map was created by using an index matrix based on an expert□based weighting. In a final step, these maps were all combined into one final susceptibility map. The outputs of the two different susceptibility methodologies were compared and analysed. The statistical approach provided a more "conservative" result, i.e. it shows a bigger area of high and very high susceptible areas and smaller areas of low susceptible areas. For the visualisation, BGS developed a viewer where the different susceptibility maps, together with other hazards, like atmospheric, karst and flood hazard are shown. This viewer is just an exemplar and will be accessible via the BGS website in the future

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Landslide Susceptibility Mapping by Interpretation of Aerial Photographs, AHP and Precise DEM

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Aerial photo interpretation which make us realize the nature of landforms is strong tool to detect landslide prone area, even though precise DEM becomes to be available. Combination of above two methods is important to prepare landslide susceptibility map (LSM). Scale of landslide susceptibility map (LSM) varies according to the objectives of the projects. Landslide inventory of small scale is useful for nation wide planning. While AHP method is suitable for LSM of middle scale, 1/20,000–1/50,000 by aerial photo interpretation to nominate landslide susceptible area. Landslide susceptibility mapping of large scale for implementation of landslide prevention work or installation of observation equipment requires ground truth and comprehensive evaluation combined with AHP. Bell-Shape Index provide us the convenient criteria to evaluate landslide susceptibility in high relief mountain region, assessing overburdened mountain profile in high relief area.

Keywords: Landslide susceptibility mapping, Aerial photo interpretation, AHP, Precise DEM, Bell-shape index

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New Data on Geological Conditions of Landslide Activity on Vorobyovy Gory (Moscow, Russia)

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Landslides developing on the high slope of the Vorobyovy Gory in the right side of the Moskva River valley form one of the largest landslide massifs in Moscow (Russia). Based on the newly obtained data it was detected: firstly, the territory involved in landslide processes on the Vorobyovy Gory is characterized by much larger values, both in area and in depth, than it was previously assumed. In the head part, where the displacement zone is located at depths of 80–100 m, the deformations, confined to the lower part of the Jurassic deposits, have a block character. Secondly, we can speak of a combined mechanism for the development of a large-scale landslide massif "Vorobyovy Gory", which includes plastic flow with the formation of a ridge compression, collapse with tipping, block displacement and other types of deformations. Also it is possible to distinguish both primary and secondary displacements. According to correlation of Callovian-Oxfordian deposits the new sliding surface position is detected.

Keywords: Largest landslide, Sliding surface, Combined mechanism of displacements

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Impact of Agricultural Management in Vineyards to Landslides Susceptibility in Italian Apennines

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Cultivation of grapevines in sloping soils is very widespread all over the world, representing also a fundamental branch of the local economy of several hilly zones. Vineyards can be managed in different ways especially in the inter-rows. These management practices may influence deeply soil properties and grapevine root development. Therefore, this work aims to analyze the effects of different agronomical practices of inter-rows on soil properties, grapevine root systems and proneness towards shallow landslides. We focused on traditional agricultural techniques of tillage and permanent grass cover as well as the alternation of these two practices between adjacent inter-rows. The research was conducted in several test-sites of the Oltrepò Pavese, one of the most important Italian zones for wine production in northern Italian Apennines. Among the examined soil properties, soil hydraulic conductivity was the most influenced one by different soil management practices. Regarding the features of the grapevine root system, vineyards with alternation management of inter-rows had the highest root density and the strongest root reinforcement. As a consequence, slopes with medium steepness were unstable if inter-rows of vineyards were tilled, while vineyards with permanent grass cover or alternation in the inter rows promoted the stability of slopes with higher steepness. The results of this study yielded important information to establish land use managements acting as mitigation measures for shallow landslides susceptibility.

Keywords: Vineyard, Soil, Root, Shallow landslides, Failure probability, Land management

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Landslide Susceptibility in Two Secondary Rivers of La Ciénega Watershed, Nevado de Toluca Volcano, Mexico

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Unstable areas along first-order tributary rivers and meander bends developed in volcanic poorly consolidated materials such as lahars, pyroclastic flows, and pumice fall deposits are common in Mexico. The present research is based on studies of the stream system of La Ciénega watershed on the eastern flank of Nevado de Toluca volcano, Mexico. The watershed is prone to landslides due to its climatic, topographic, geomorphologic, and geologic conditions that predispose the study area to episodic landslides and debris flows. Landslide volcanoclastic sediments are dragged by the streams and torrents during the rainy season and create a hazardous situation for people living along the stream system. Our work is focused on two secondary rivers located ian the southern portion of La Ciénega watershed. In both tributaries, a detailed landslide inventory and a geomorphological map were carried out to determine the landslide susceptibility by landforms. The results show that debris slides are the most frequent processes along the two secondary rivers, and three landforms out of fourteen have the highest landslide susceptibility. In these landforms, factors such as steep slopes, geological faults, and hillslope morphology influence the abundance and distribution of landslides.

Keywords: GIS, Landslide inventory map, Landslide susceptibility, Landforms, Nevado de toluca volcano

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An Ordinal Scale Weighting Approach for Susceptibility Mapping Around Tehri Dam, Uttarakhand, India

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The landslides are natural hazards, which cause damage to both property and life every year, especially in the Himalayas. Detailed studies of landslide susceptible areas are instrumental in getting fast and safe mitigation actions and doing future planning for any construction work. The study area lies under the Lesser Himalaya in the Tehri-Garhwal region of Uttarakhand, India. This area consists of weak and unstable lithology, highly fragile rocks due to the complicated tectonic settings; consequently, landslide movement is a common phenomenon in the area. We have used several landslide controlling factors such as slope, lithology, thrust buffers, relative relief, land use land cover, lineaments, and stream buffer in order to generate a susceptibility map. We have prepared these parameters from geological (structural and lithological) maps, Landsat TM, and ASTER GDEM data and field investigation data. We have integrated the data based on the ordinal scale weightage rating technique to generate the landslide susceptibility index (LSI) values. The LSI frequency distribution is divided into five zones (i.e., very low, low, moderate, high, and very high susceptibility) based on the geometric interval as well as the standard deviation to enhance the classes with minimal frequency. These zones account for 3.30%, 20.88%, 47.99%, 41.13%, and 1.83% of total area respectively. Furthermore, the final susceptibility map is validated using the field data of landslide occurrences, which depicts that more than 50% of landslides occur in very high and high zones. These zones lie in the north-eastern side of the Tehri reservoir, which is traversed by North Almora Thrust (NAT), while just 16% of landslides have fallen in low and very low susceptible zones.

Keywords: Landslide susceptibility zonation (LSZ), Ordinal weighting scheme, Garhwal himalaya, Landslides

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Potential Analysis of Deep-Seated Landslides Caused by Typhoon Morakot Using Slope Unit

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Taiwan is prone to landslide hazard due to fragile geological conditions, frequent earthquakes, and heavy rainfall in the monsoon seasons. The severe rainfall often caused deep-seated landslides. This study utilized the slope unit and discriminant analysis to assess the deep-seated landslide potential in four sub-basins in the Namasia area, Kaoshiung City. The deep-seated landslides were mapped using LiDAR data and aerial photos of the study area. Delineation method of the slope unit was developed, and the resulting slope units consisted well with boundaries of deep-seated landslides. Typically, one deep-seated landslide enclosed one to few slope units. The assessment model was constructed using discriminant analysis on two sub-basins, C and D, with slope angle, aspect, height, and area as causal factors. The model was validated and provided good accuracy for the fitting and validation data. The model was then adopted to assess the landslide potential and moderate results were obtained. Differences in property distributions among sub-basins and choice of factors could cause some discrepancy in assessment results. The potential maps of the study were developed accordingly, and good to moderate results were obtained.

Keywords: Deep-seated landslide, Potential analysis, Slope-unit, Discriminant function

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Landslide Susceptibility Assessment Using Binary Logistic Regression in Northern Philippines

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In a landslide prone area in mountainous northern Philippines, landslide susceptibility using binary logistic regression was investigated. Landslide data were randomly divided into training and validation sets using 80% and 20% proportions, respectively. A detailed logistic regression procedure was applied and presented herein. Nine landslide conditioning factors were used. Based on the coefficients obtained, the most influential factors were NDVI followed by land use/land cover, slope aspect, lithology and slope angle. Distance to lineament, distance to road, plan and profile curvature showed no influence in the model generated. Training and validation accuracy were good, amounting to 91% and 86%, respectively. Using training data, 80%, 11%, 5%, 2% and 2% of the landslides were associated with the very high, high, moderate, low and very low susceptibility classes, respectively. Using validation data, the proportions were 82%, 10%, 5%, 3% and 0%, respectively. The strong influence of NDVI affirms its major role in modelling landslide susceptibility. It supports the strong potential of revegetation of precarious slopes in complementing ongoing structural slope stabilization and rehabilitation measures.

Keywords: Landslide susceptibility, Binary logistic regression, Landslide, Philippines

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Landslide Hazard Mapping of Penang Island Malaysia Based on Multilayer Perceptron Approach

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Landslide is one of the natural disasters in Malaysia. It causes property damages, infrastructure destruction, injuries and causalities. Landslide hazard mapping is one of the efforts to identify the landslide prone areas with the purpose of reducing the risk of landslide hazards. In this paper, landslide hazard map of the study area, Penang Island Malaysia, is produced using artificial neural network model. Penang Island dataset is collected and its data samples are used to train the artificial neural networks. This study deals with the hidden layer of ANNs. The number of hidden neurons in hidden layer is one of the important parameters of the neural network. Although the hidden layer is not interacted with the external environment but it has tremendous influence on the final output. The different number of hidden neurons of artificial neural networks applied on landslide data produce landslide hazard maps with distinct accuracies and computation time. Finally, Receiver of Characteristics curve is applied on whole Penang Island dataset to validate the accuracy and effectiveness of trained artificial neural model.

Keywords: Landslide hazard map, Artificial neural network, Multilayer perceptron, Receiver of characteristics

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Landslide Susceptibility Mapping Based on the Deep Belief Network: A Case Study in Sichuan Province, China

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Landslides dataset of Sichuan Province in China, containing 1551 historical individual landslides, is a result of two teams' effort in the past few years, based on which landslide susceptibility can be mapped. Considering complex internal relations among the triggering factors, logistic regression (LR) and shallow neural networks, such as back propagation neural network (BPNN), are often limited. In this paper, we make a straightforward development that the deep belief network (DBN) based on deep learning technology is introduced to map the regional landslide susceptibility. Seven key factors with respect to geomorphology, geology, and hydrology are considered, and a DBN model containing three pre-trained layers of Restricted Boltzmann Machines (RBM) by stochastic gradient descent (SGD) method is configured to obtain the landslide susceptibility. In the receive operator characteristic (ROC) analysis, comparing DBN with LR and BPNN shows that DBN has a better prediction precision, with lower false alarm rate and fake alarm rate. This research will contribute to a better-performance model for regional-scale landslide susceptibility mapping, in particular at the area where triggering factors show complex relation and relative independence.

Keywords: Landslide, Susceptibility mapping, Deep learning, Deep belief network, Sichuan area

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A Comparative Study of Deep Learning and Conventional Neural Network for Evaluating Landslide Susceptibility Using Landslide Initiation Zones

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Considerable efforts have achieved to comprehend where seismically triggered landslides may occur because they are a disastrous hazard with an extraordinarily risk component in tectonically active mountainous areas. The objectives of this research are to investigate and compare two advanced artificial intelligence models (AI), i.e., artificial neural network (ANN) and deep learning (DL) techniques to evaluate susceptible zones using landslide initiation zone polygons (i.e., scarp areas). For this, a comprehensive landslide inventory map comprising of the representative of the landslide scarp, which is constructed using high resolution aerial photographs and Lidar digital elevation models (Lidar DEM) for the 2018 Hokkaido earthquake-affected sites. Afterward, 11 causative factors were prepared, including seismic, topographic, and hydrological factors. Our results show that DL has better predictive performance than the traditional ANN obtained model. Furthermore, the importance of factor ranks indicates that topography has played the leading role in the landslide occurrences. The DL model shows a promising way for rapid response in the field of landslide hazard mitigation.

Keywords: Deep learning, Scarp, Landslide susceptibility, Artificial intelligence, Lidar DEM

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Landslide Susceptibility Assessment by Ensemble-Based Machine Learning Models

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Slope failures are among the most hazardous natural disasters, causing severe damage to public and private properties. Casualties owing to landslides have been growing in many areas of the world, especially since the increase of climate changes and precipitations. To this, decision-makers need trustworthy information that may be employed to decide the spatial solution plans to protect people. Statistical landslide susceptibility mapping is facing a constant evolution, especially since the introduction of Machine Learning algorithms (ML). A new methodology is here presented, based on the ensemble of Artificial Neural Network, Generalized Boosting Model and Maximum Entropy ML algorithms. Such an approach has been used in Cinque Terre National Park (Northern Italy), severely affected over the years by landslides, following precipitation events, causing extensive damage in a World Heritage Site. Nine predisposing factors were selected and assessed according to the knowledge of the territory, including slope angle, aspect angle, planform curvature, profile curvature, distance to roads, distance to streams, agricultural terraces state of activity, land use and geological information, whilst a database made of ca. 400 landslides was used as input. Four different Ensemble techniques were applied, after the averaging of 150 stand-alone methods, each one providing validation scores such as ROC/AUC curve. Therefore, the results obtained through Ensemble modeling showed improved values, confirming the reliability and the suitability of the proposed approach for decision-makers in land management at local and regional scales.

Keywords: Landslide, Machine learning, Cinque terre, Susceptibility, Spatial distribution model, Ensemble model

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Overcoming Data Scarcity Related Issues for Landslide Susceptibility Modeling with Machine Learning

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Landslide susceptibility maps can be a useful tool to support holistic urban planning in mountainous environments. Data-driven methods for landslide susceptibility modeling work well even in data scarce areas, and there is an increasing relevance of machine learning methods that help analyze efficiently large and complex datasets. In this contribution we present some of our study examples to show how data quality, quantity, complexity, and preparation can have major effects on the outcomes of landslide susceptibility modeling. The aforementioned aspects are too often neglected in spite of their relevance, both in data scarce, but also data rich areas. We also use these examples to discuss the way we evaluate landslide susceptibility models, as the spatial performance of landslide susceptibility maps often differs from the mathematical performance. We finally discuss the necessity of standards for input data, modeling results and result communication to improve the usability of landslide susceptibility models in urban planning.

Keywords: Landslide susceptibility, Data quality, Machine learning

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Practical Accounting for Uncertainties in Data-Driven Landslide Susceptibility Models. Examples from the Lanzhou Case Study

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Modeling of a complex environment is inevitably associated with uncertainties arising from the model design or data errors. In the uncertainty assessment, the bias (related to accuracy) and the random error (related to precision) are distinguished. Recent reviews of case studies, which used data-driven methods for landslide susceptibility assessment (LSA), indicate a general lack of appropriate evaluation of uncertainties. In this paper, we discuss practical techniques to account for uncertainties in LSA, relying majorly on the examples from the project “Landslide Hazard and Risk Assessment for Lanzhou” (LHARA).

Keywords: Uncertainty, Random subsampling, Landslides, Data-driven, Susceptibility

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Assessment of Shallow Landslides Susceptibility Using SHALSTAB and SINMAP at Serra Do Mar, Brazil

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The Serra do Mar mountain range in Brazil is highly susceptible to shallow landslides initiation, due to its relief and high rainfall index. The aim of this study is the application and comparative performance analysis of SHALSTAB and SINMAP in the landslide susceptibility assessment of the Perequê watershed at the Serra do Mar escarpments. The application of physically based models is an objective method used in landslide susceptibility to predict slope failure under different geotechnical scenarios, supporting hazard assessment studies. Model calibration is based on the landslide scars inventory of the 1985 and 1994 events, while topographic parameters are DEM sourced and geotechnical parameters obtained from soil samples. Using performance classifiers based on a contingency table to assess model performance, the results indicate that SHALSTAB is the best-fit model at the chosen scale due to higher accuracy and higher concentration of scars in unstable areas (>62%). SINMAP was less accurate, also exhibiting higher false positive results and lower density of landslides scars in unstable areas. For future studies, the compartmentalization of the study area according to geology is suggested as an improvement in the representativeness of modeling results.

Keywords: Shallow landslides, SHALSTAB, SINMAP, Performance assessment, Serra do mar

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Regional Slope Stability Analysis in Landslide Hazard Assessment Context, North Macedonia Example

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This paper is representing a successful application and comparison of heuristic and deterministic landslide hazard assessment modelling. The advantages of deterministic model, which quantify hazard more plainly and more transparently, are herein emphasized, as they are usually better accepted by potential end users, i.e., decision makers. However, applying deterministic model on large scale is always challenging due to data shortage and uncertainty. Presented example appears to be applicable in road management, i.e. assessment of landslide hazard exposure of the road network. The case study involved Polog region in North Macedonia, modeled for two types of landslides by two different models. The first included shallow translational sliding mechanism and implementation of SINMAP model, while the second included flow mechanism and implementation of RAMMS model. Both models resulted in concurrent map products, suitable for further use in road network decision making. The latter was identified particularly useful when it can be back analyzed on the basis of recent real flow example with sufficient documentation, such as examples from Polog region in 2015 when massive failures occurred following rainstorm and flooding. In comparison to conventional heuristic map which was created in previous research for the same area, the new maps were more difficult to parameterize, with sufficient certainty, so back analysis is a very useful convenience of this particular case study. In conclusion, regional scale deterministic landslide assessment is desirable tool for standard applications in planing and decision making, but it is also recommendable to use it in combination with expert-driven heuristic outputs.

Keywords: Landslide hazard, SINMAP, Regional scale, North Macedonia

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Evaluation of Secondary Landslide Susceptibility for the Rescue Activity Using LiDAR UAV Data

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On April 11th, 2018, a large-scale landslide occurred in Yabakei Town, Nakatsu City, Oita Prefecture, Japan (Yabakei landslide). The characteristic of the Yabakei landslide is that occurred without any special causes such as rainfall and earthquakes. In this research, we analyzed the LiDAR UAV data (Nakanihon Air Service Co., LTD.) measured immediately after the Yabakei landslide, and considered the evaluation of secondary landslide susceptibility during the rescue activities. And I considered the cause of the time lag landslide which occurred without any special causes based on the features of Yabakei landslide. I thought that the main cause was groundwater.

Keywords: Secondary landslide susceptibility, The time lag landslide, Rescue activity, LiDAR UAV

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Methodology for Landslides Assessment Causing River Channel Obstructions and the Consequent Water Shortage in Rural Communities

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Landslides are considered one of the natural hazards that cause the most significant losses worldwide. In countries like Colombia, landslides events cause the highest number of deaths and economic losses and are related to river flooding caused by landslides in basins. This paper presents a methodology to assess the associated risk with landslides in water supply basins. The hazard is assessed considering probabilistic methods that include the effects of rainfall and earthquakes. Furthermore, this study assesses the probability that a sliding mass reaches riverbeds forming a natural landslide deposit known as landslide dam (LD), calculating the probability of obstructions in its channel. Besides, damage degree (DD) or vulnerability is assessed using damage curves based on the obstruction height of the stream channel. This methodology is based on probability methods, such as the first order second moment method (FOSM) and the point estimate method (PEM). As study case, this methodology was applied in the La Liboriana River basin, in the southwest of Colombia, where morphodynamic and hydrometeorological conditions have generated several natural disasters that have left dead, injured and damage to the infrastructure. The model results show a high coincidence of affected areas with landslides according to the inventory of events in the study zone, with areas of high probability of failure predicted by the proposed model, indicating its coherence to identify areas to be studied with more detail.

Keywords: Landslide, Landslide dam, River channel obstruction, Water shortage

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Landslide susceptibility assessment in a tropical scares-data region of the Colombian Andes

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Landslides triggered by rainfall are one of the most frequent causes of natural disasters in tropical and mountainous countries such as Colombia. However, landslide susceptibility assessments are often limited due to the scarcity of reliable observations and available information, particularly in remote high-mountain regions. Although Colombia has a tropical and mountainous terrain dominated by landslide prone regions, it has little available data for landslide susceptibility assessments. This study presents the application of a logistic regression model to assess landslide susceptibility in the Liboriana catchment. The basin is composed of a tropical inaccessible terrain in the northern Colombian Andes where, on May 18th, 2015, more than 40 landslides and a subsequent flash flood and debris flow killed 104 inhabitants. The applied approach is based on free access remote sensing tools used to determine and complete the missing landslide causative factors. To select key factors related to landslide occurrences, the prediction and success performances of the susceptibility maps for each combination of landslide causative factors were estimated using Receiver Operating Characteristics (ROC). The results show that only three factors produced the best prediction accuracy. All the factors were obtained using free remote sensing tools, indicating that they can provide adequate information to achieve a successful initial approach for landslide susceptibility assessments in complex terrains such as the study area. However, ancient shallow landslides are not included in the landslide inventories, which reduces the prediction capacity of the statistical models to shallow landslides triggered by rainfall

Keywords: Scarce data region; remote sensing; logistic regression; landslide susceptibility; tropical and complex terrains

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Concerns Over Reliable Earthquake-Induced Landslide Hazard Assessment: Developing Sophisticated Geotechnical Databases and 3D Landslide Inventories

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Despite recent advances in earthquake-triggered hazard evaluation, there is still a disparity between probability models and their derived maps, and actual events. Hence, as a strong earthquake drives slope failure event, professionals need to reassess their hazard zonation models in the affected region.

This paper scrutinises the reliability of geological datasets and landslide inventories used in hazard zonation models. The data has traditionally been presented in conventional geological maps and implemented in numerical form by geotechnical engineers. The study is carried out in an earthquake-prone mountainous region of Central Alborz, Iran; a popular tourist destination. The research utilises a newly designed GIS workflow, 3D satellite imagery, re-derived landslide inventories and geotechnical test results from inside the landslides to integrate and update existing datasets. The updated geotechnical database shows the relative depreciation of shear strength in old and existing landslide zones.

The resulting seismic landslide hazard assessment reveals an increase in the number of extracted landslides and their subsequent volume of the displaced material, compared to existing assessment for the same region. This evidence confirms our belief that inventory databases should be updated with modern 3D imagery, and that geotechnical sampling arrays should be designed in areas proximate to the existing landslide and the surface of rupture zones.

Keywords: earthquake-induced landslide, Central Alborz Mountains

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Modeling of Landslide Susceptibility in a Part of Abay Basin, Northwestern Ethiopia based on Bivariate and Multivariate Statistical Methods

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The study area in northwestern Ethiopia is one among the foremost landslide-prone regions, which is characterized by frequent high landslide occurrences. Preparing a landslide susceptibility mapping is vital to manage the landslide hazard and reduce loss of lives and damages of properties. Geographic information system (GIS)-based frequency ratio (FR), information value (IV), certainty factor (CF), and logistic regression (LR) methods were applied. The landslide inventory map is ready from historical records and Google Earth imagery interpretation. Thus, 717 landslides were mapped, of which 502 (70%) landslides were used to build landslide susceptibility models, and the remaining 215 (30%) landslides were used to model validation. Eleven factors like lithology, land use/cover, distance to drainage, distance to lineament, normalized difference vegetation index, drainage density, rainfall, soil type, slope, aspect, and curvature were evaluated and their relationship with landslide occurrence was analyzed using the GIS tool. Then, landslide susceptibility maps of the study area are categorized into very low, low, moderate, high and very high susceptibility classes. The four models were validated by the world under the curve (AUC) and landslide density. The results for the AUC are 93.9% for the CF model, which is best than 93.2% using IV, 92.7% using the FR model, and 87.9% using the LR model. Moreover, the statistical significance test between the models was performed using LR analysis by SPSS software. The result showed that the LR and CF models have higher statistical significance than the FR and IV methods. Although all statistical models indicated higher prediction accuracy, supported their statistical significance analysis result (Table 5), the CF model for regional land use planning, landslide hazard mitigation and prevention purposes comparatively better follows the LR model.

Keywords: landslide, susceptibility, geographic information system, certainty factor, frequency ratio, information value, logistic regression, Ethiopia

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Theoretical Framework for Estimating the Annual Probability of Occurrence of Landslides

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Risk assessment of constructed facilities and infrastructure exposed to landslides requires an estimation of the occurrence probability of a slide event during a reference time period, for example the annual probability of a residential building being impacted by a mass gravity flow. The paper describes the procedures developed in recent landslide risk assessment studies for the estimation of the temporal probability in two situations: 1) When there is a clear trigger for initiating the slide, and 2) When there is evidence of slide activity, but no obvious trigger for slide initiation. In the first situation, the assessment of temporal probability requires a probabilistic description of the frequency and intensity of the trigger(s) releasing the slide and a probabilistic model for calculating the response of the slope to the trigger. Using these models, the probability of a mass gravity flow impacting the installation(s) should then be computed for all relevant scenarios and return periods in order to derive the annual or lifetime probability. However, analyzing all possible scenarios and return periods is time-consuming and impractical. The paper presents a simplified procedure and demonstrates its application through a case study for earthquake-triggered landslides. In the second situation, where it is difficult to identify the trigger(s) initiating the slide, one must rely on the identification and dating of recent (in the geological sense) slide events in the area and/or database of regional slide events. The dating results and other relevant geological evidence are then integrated into a Bayesian framework to establish the annual probability of slope instability.

The paper presents the theoretical framework and example calculations for both situations. The example calculations are from recent offshore geohazards studies and they will demonstrate the application of the methods presented in the paper.

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Multi-scale Landslide Hazard Assessment using Remote Sensing Data

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The global coverage and temporal frequency provided by satellites offers a unique opportunity to evaluate landslide hazards at a variety of spatial scales from more localized landslide mapping to global situational awareness. These data can be particularly impactful in remote areas where extreme rainfall coupled with complex terrain drives widespread hydrometeorological hazards that can result in cascading impacts. Defining when and where satellite-derived data and model products are relevant is largely contingent on the spatiotemporal sampling, the hazard characteristics and the needs from the research or applications community.

The Landslide Hazard Assessment for Situational Awareness (LHASA) model leverages satellite precipitation, soil moisture, and snow information along with more static variables including topography and lithology to provide near real-time assessment of potential rainfall-triggered landslide hazards around the world. The newest version of this model, Version 2.0, uses machine learning techniques with a range of landslide inventory data to better relate the contributing variables to observed landslide processes throughout the world. In order to provide more advanced information on landslide hazards, a precipitation forecast product has also been incorporated within this framework. Additional exacerbating factors for rainfall-triggered landslides, including recent burned areas and earthquakes, are also being incorporated into the LHASA suite of tools to better characterize the underlying drivers of landslide hazard. Finally, within areas of higher hazard, landslide exposure is estimated based on population and road networks. The LHASA model and its components are open source and the model results and suite of information is being provided routinely at

https://landslides.nasa.gov/viewer. Results of the new LHASA Version 2 modeling framework suggest improved performance relative to the previous version of this model. The LHASA framework is also being implemented in the Mekong Region as well as being tested over High Mountain Asia. In this presentation we present the LHASA modeling framework and provide examples for how satellite data is being applied to map and model landslide hazard and exposure processes with the goal of supporting landslide hazard response, mitigation and planning.

Keywords: remote sensing, landslide hazard assessment, exposure analysis

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Global debris flow susceptibility, current and future impact, based on climate and urbanization trends

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Debris flows, and landslides in general, are worldwide catastrophic phenomena. Fatal landslides are most prevalent in densely occupied urban centers, so as world population and urbanization grow in magnitude and geographic coverage, we realize the need to extend our focus, research, and modeling to a continental and global scale at present and projected into the future.

Climate and aridity may experience major changes in magnitude and geographic extent in the future. These changes may impact soils (thickness, type, composition), landforms, landcover and other environmental factors which influence the potential for debris flows.

In this study historical events are modeled with environmental factors to determine those with the highest significance to debris flow events, globally. These factors are used to define areas globally with the highest debris flow potential and susceptibility today and projected into the future. Based on projected climate and urbanization trends worldwide, a spatial analysis is developed of the future societal vulnerability impact, intersections of high debris flow susceptibility and urbanization.

Keywords: Landslide, susceptibility zonation, climate change

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Evaluating the Terrain Susceptibility to Mass Movements

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The variability of landslide phenomena in terms of types, velocity and size makes it difficult to establish a unique methodology for the definition of landslide susceptibility and different approaches are proposed in the literature for the prediction of landslide occurrence. In addition, the extent of the study area and the characteristics of the available data may influence the selection of the susceptibility models. For these reasons, landslide susceptibility studies described in the literature use different modelling approaches adopting a variety of mapping units and thematic information. In this chapter, we first use a database of 565 articles from a recent systematic review of the literature to illustrate and describe a synthesis of relevant information on landslide susceptibility modelling and terrain zonation. We then present examples of susceptibility zonation prepared at four different scales: (i) continental (Europe), (ii) national (Italy), (iii) sub-national (Umbria Region, Italy), and (iv) catchment scale (Collazzone area, Italy), using different data types and resolutions, different mapping units, and various statistically-based modelling approaches. We use these four examples to provide our reflections on proprieties of the geo-environmental data and on the main characteristics of the modelling approaches at different scale. We conclude with few steps that could become a starting point for the discussion and definition of a standard for statistically-based landslide susceptibility methods and zonation.

Keywords: Landslide, susceptibility zonation, statistical model

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Data-driven Modelling of the Spatio-Temporal Probability of Occurrence of Shallow Landslides with the Integration of Satellite Data

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Rainfall-induced shallow landslides affect buildings, roads, facilities, cultivations, causing several damages and loss of human lives. It is necessary assessing the most prone zones in a territory where these phenomena could occur and the triggering conditions of these events. The spatial and temporal probability of occurrence of these phenomena is generally estimated through physically-based models, that quantify the hydrological and the mechanical responses of the slopes according to particular rainfall scenarios. Whereas, they are limited to be applied in a reliable way in little catchments, where geotechnical and hydrological characteristics of the materials are homogeneous. Data-driven methods could constraint these, when the predisposing factors are combined with triggering factors of shallow landslides to allow these methods to estimate also the probability of occurrence and, then, the hazard. This work presents the implementation of a data-driven model able to assses the spatio-temporal probability of occurrence of shallow landslides in large areas by means of a data-driven model. The models are based on Multivariate Adaptive Regression Technique (MARS), that links geomorphological, hydrological, geological and land use predisposing factors to triggering factors of shallow failures. These triggering factors correspond to soil saturation degree and rainfall amounts, which are available thanks to satellite measures (ASCAT and GPM). The methodological approach is testing in different catchments of Oltrepò Pavese hilly area (northern Italy), that is representative of Italian Apeninnes environment. This work was made in the frame of the project ANDROMEDA, funded by Fondazione Cariplo.

Keywords: Shallow landslides; Data-driven model; Remote sensing; Rainfall; Soil moisture

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Introducing the climate component into landslide susceptibility mapping

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Intense rainfall and snowmelt are commonly recognized predisposing and triggering factors for shallow landslides. Due to climate change, their frequency and magnitude could vary, thus modifying soils response. Therefore, their inclusion in planning tools becomes fundamental. The aim of our study was to derive a susceptibility model adaptable to climate changes, through the inclusion of the above-mentioned climate factors. We selected the territory of the Mont-Emilius and Mont-Cervin Mountain Communities (Aosta Valley, northern Italy) as study area. To define the summary variables, we investigated the relationships between landslide occurrences and meteorological events (reference period 1991-2020), firstly recognized on ground-station data and following (ongoing activity) on gridded data. For landslide susceptibility mapping, we set up a Generalized Additive Model to evaluate both the variables statistical significance and physical plausibility. We optimized a model including classical predictors (relief, geology, land use) and climate variables. We validated the optimized model through a k-fold cross-validation and evaluated the performance through contingency tables and area under the receiver operating characteristic curve (AUROC). Also, we investigated variable importance through the decrease in explained variance. The climate variables that resulted statistically and physically significant are the effective annual number of rainfall events with intensity-duration characteristics above a defined threshold (EAT_{ean}) and the average number of snow melting events occurring in a hydrological year (ME_n), derived from snow water equivalent data. In the optimized model, together they accounted for 5% of the model deviance. The inclusion in the susceptibility model of EAT_{ean} and ME_n brought to an increase of the true positive rate and AUROC of 2.4% and 0.8%, respectively. Also, it caused a transition of susceptibility class in 11.0% of the modelling area. The k-fold validation confirmed the statistical and physical significance of the meteorological variables in 74% (EAT_{ean}) and 93% (ME_n) of the fitted models. Our findings stress the utility of these variables in improving the performance of susceptibility models and making them adaptable to climate changes.

Keywords: intense rainfall, snowmelt, snow water equivalent, generalized additive models, Alps

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The role of climatic predictors for non-stationary rockfall susceptibility modelling

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The overarching goal of the study was to develop a rockfall susceptibility model that included the climate component. The territory of the Mont-Emilius and Mont-Cervin Mountain Communities (Aosta Valley, northern Italy) was selected as study area. The first part of the study was organized as follows: (i) identification of climate indices related to rockfall occurrence, namely EWI, effective water inputs (including rainfall and snow melting), WD, wet-dry episodes and FT, freeze-thaw cycles using ground-station data (reference period 1990-2018); (ii) definition of empirical critical thresholds for each climate index; (iii) calculation of the mean annual threshold exceedance for each index, both for station data, with a consequent regionalization, and for gridded data of P and T (hourly resolution). The second part of the study comprised: (i) the evaluation of a visibility mask to reduce the rockfall inventory bias; (ii) the set-up of a rockfall susceptibility model by means of Generalized Additive Models, including both topographic, climatic (in the form of threshold exceedance frequency, alternatively using station and gridded derived predictors) and additional snow-related predictors (from a SWE weekly gridded dataset); (iii) the validation of the optimized model through a k-fold cross-validation and the evaluation of its performance in terms of area under the receiver operating characteristic curve (AUROC); (iv) the investigation of variable importance through the decrease in explained deviance (mDD%) and analysis of their physical significance in the model. The key results were: (i) the use of climate predictors (both station-derived and gridded-derived) resulted in an improvement of the model performance (AUROC up to 3%) in comparison to the topographic-only model; (ii) the climate predictors with the strongest physical significance were EWI and WD, with a mDD% varying from 5% to 10% each; (iii) the effect of FT was masked by elevation. Our findings demonstrated that the inclusion of climate processes as non-stationary predictors (i.e., considering climate change) could be a valuable approach to derive rockfall susceptibility future scenarios.

Keywords: Rockfalls, Generalized additive models, effective water inputs, freeze-thaw cycles, wet-dry episodes.

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Probabilistic modeling of rockfall source areas

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Rockfalls are the most frequent and dangerous instability phenomena in mountainous areas, causing high economic and social damages. Rockfalls are triggered by complex instability mechanisms and the source areas are controlled by environmental factors like geology, the presence of discontinuities and slope angle. Modeling rockfall phenomena is complex and requires diversified input including parameters controlling the boulders trajectories and the source areas identification. In the Canary Islands, the steep topography and the geological complexity influence the activation of slope dynamics and the occurrence of slope failures. In particular, rockfalls are very common and they represent a major threat to society, costing lives, disrupting infrastructures and destroying livelihoods. In 2011 the volcanic crisis in El Hierro Island triggered numerous rockfalls that affected the road network causing a great social alarm. After the recent event, we have attempted to identify rockfall source areas using different approaches including probabilistic modeling. The probabilistic approach applies a combination of multiple statistical models and requires a map of the observed source areas as dependent variable and a set of thematic information as independent variables (e.g., morphometric parameters derived from DTM, lithological information that considers the mechanical behavior of the rocks). For the purpose, we have identified various scenarios selecting different training and validation zones and evaluating for each scenario the associated errors. The maps resulting from the models, provide for the whole El Hierro Island, the probability of a pixel being a source area and can be used as input for the rockfall modeling.

Keywords: Rockfall, Source area, Probabilistic approach, Statistical models, Susceptibility

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Introducing Land Surface Temperature in Susceptibility Modeling

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The effect of climate change on slope stability patterns and trends has been the object of extensive research. Susceptibility modeling is a first step to understand the spatial distribution of landslides on the basis of geomorphic, tectonic, hydro-climatic, geotechnical, and other factors. Temperature-related variables have often been excluded from modeling – even in studies accounting for climate change – in favor of better recognized controls, summarized by precipitation-related and vegetation-related variables. In other words, temperature has only been considered to exert an indirect control thus far, at least in temperate climates. On the other hand, numerous experiments as well as field data demonstrate that temperature plays a major (and direct) role in many soil and rock hydro-mechanical processes and properties. Changes in these properties (e.g., stiffness, viscosity, void ratio, permeability), in turn, can condition the stability of slopes. Here, we present two case studies: (i) a field experiment in which locally-measured trends of Land Surface Temperature (LST) were related the strength of a rock outcrop; and (ii) a catchment-wide study in which the role of LST was evaluated through a slope unit-based susceptibility modeling of an area undergoing a rapid evolution of landslide activity in a post-seismic context. We demonstrate that, in both cases, LST plays a significant role, and argue for its inclusion in modeling approaches, also with the aim of better relating field variables with the underlying thermo-hydro-mechanical processes controlling slope stability.

Keywords: landslide, susceptibility, climate change, temperature, LST

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Dynamic Landslide Hazard Assessment by Matrix Combination of Soil Water Index and Landslide Susceptibility Map

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To effective management of landslide hazard, both of direct and indirect factors inducing landslide should be considered. In Korea, landslide early warning system based on soil water index (SWI) and landslide susceptibility map (LSM) are used as hazard map considering direct and indirect factors, respectively. Recently, the necessity of dynamic landslide hazard assessment by coupling them is emphasized because of the increase of extreme storm event, such as a long rainy season in 2020. In this study, we used several matrixes to combine SWI and LSM, and these matrixes were applied to the 2017 landslide occurred in Cheonan-si to assess its dynamic hazard. As the result, the dynamic landslide hazard map based on matrix combination showed higher accuracy then static landslide susceptibility map. Moreover, because SWI are provided based on 1-hour rainfall prediction, dynamic hazard of landslide in near future can be estimated. This result implies that matrix combination of SWI and LSM can be used for the efficient landslide disaster prevention during rainy season.

Keywords: landslide susceptibility map, early warning system, soil water index, matrix approach

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Landslide Size Distribution Characteristics of Cretaceous and Eocene Flysch Assemblages in the Western Black Sea Region of Turkey

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The main purpose of the study is to determine the general characteristics of the landslide sizes observed in Cretaceous and Eocene aged flysch assemblages at the Western Black Sea region of Turkey by using magnitude and frequency relations. For this purpose, the magnitude and frequency relations were investigated by considering power-law scaling characteristics of the geological formations. The probability distributions were also examined by considering Double Pareto and Inverse Gamma distribution models. According to the power-law relations, the rollover effects were observed at 0.047 and 0.048 km2, and the fractal dimensions of the distributions were obtained as −1.97 and −1.41 for Cretaceous and Eocene flysch assemblages, respectively. Considering the probability distributions, the best-fits were acquired from the models Double Pareto with three parameters estimated by maximum likelihood estimation for Cretaceous flysch and Kernel density estimation for Eocene flysch. When we compared these results with the results of a study carried out in the same flysch but in another sub-catchment, it is concluded that rollover effects and fractal dimensions may not be generalized, that means, the parameters may differ site to site depending on not only spatial resolution but also morphological, climatic, and anthropogenic features of the region in concern, and conversely, landslide size distributions fit Double Pareto distribution models in general.

Keywords: Cretaceous flysch, Eocene flysch, Landslide size distributions, Western Black Sea region of Turkey

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A Statistical Exploratory Analysis of Inventoried Slide-Type Movements for South Tyrol (Italy)

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Landslides of the slide-type movement represent common damaging phenomena in the Italian province of South Tyrol. Up to January 2019, the landslide inventory of the province lists 1928 accurately mapped landslides that required intervention by e.g. the local road service or the provincial geological survey. Thus, this landslide data set mainly includes events that caused damage. The aim of this contribution was to investigate and critically interpret statistical associations between the inventoried slide-type movements and a variety of spatial environmental variables. The assessment of conditional frequencies and the discriminatory power of single variables revealed conditions that are typically present at landslide mapping locations, e.g. topography, land cover, rock types, and proximity to infrastructure. A critical interpretation of the statistical results highlighted the need to consider the landslide data origin (i.e. background information) in order to avoid misleading statements and wrong inferences. The findings of the here presented work show that the availability of detailed landslide information does not always ensure that valid process-related conclusions can be drawn from subsequent statistical analyses (e.g. identification of important landslide controls). Despite considerable methodical advancements in the field of statistical data analysis and machine learning, we conclude that the principle 'correlation does not necessarily imply (geomorphic) causation' remains of particular relevance when exploiting available landslide information.

Keywords: Landslide inventory, South Tyrol, Exploratory data analysis, IFFI, Sampling bias, Susceptibility
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Assessing Landslide Volume for Landform Hazard Zoning Purposes

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We model the relationship between surface area and volume of landslides caused by rain, together with a geomorphologic analysis of 15 landforms to characterize slope instability. The use of this method allows a better understanding of the landslide susceptibility along homogeneous units. The analysis is supported by Geographic Information Systems (GIS) to create a comprehensive method for landslide volume estimation for each landform. This approach is applied to the Río Chiquito-Barranca del Muerto watershed on the south flank of Pico de Orizaba volcano, Mexico. The watershed is prone to gravitational processes because highly weathered volcanic and sedimentary deposits that are affected by extreme seasonal precipitation and deforestation. In the area, more 600 landslides have been mapped and grouped into the landform units. Representative landslides in the watershed were measured in detail with differential GPS and a drone to establish an empirical relationship between landslide area and volume. This relationship expressed as a power law is used to estimate the potential contribution of material delivered from each volcanic and sedimentary landform.

Keywords: GIS, Landslide inventory map, Landslide volume, Drone, Power law

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Empirical Relationships to Estimate the Probability of Runout Exceedance for Various Landslide Types

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Estimating the potential runout distance of a landslide and it associated impacted area is an important component of landslide hazard and risk analysis. This can be done using empirical; or physics-based runout analysis methods. The current study uses the empirical method by compiling previously published international examples of landslide runout and unpublished New Zealand landslides triggered by recent earthquakes and rainstorm events. The results are presented in a series of ΔH/L versus volume plots for different landslide types, substrate (glacier versus unglaciated), and triggers (earthquake versus rainfall). The plots contain superimposed probability of runout exceedance lines. The results from this study provide landslide researchers and practitioners simple tools to conduct a forward-looking empirical-probabilistic runout analysis for debris avalanches, debris flows, and rock avalanches. The methodology presented is appropriate for a regional-level assessment or scoping-level site-specific assessment to identify areas warranting more detailed work. Applications and limitations of empirical-probabilistic runout methods are also discussed.

Keywords: Runout, Travel distance, Probability of runout exceedance

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Rapid Sensitivity Analysis for Reducing Uncertainty in Landslide Hazard Assessments

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One of the challenges in assessing temporal and spatial aspects of landslide hazard using process-based models is estimating model input parameters, especially in areas where limited measurements of soil and rock properties are available. In an effort to simplify and streamline parameter estimation, development of a simple, rapid approach to sensitivity analysis relies on field measurements of landslide characteristics, especially slope and depth. This method is demonstrated for a case study in Puerto Rico where widespread destruction resulted from tens of thousands of debris flows induced by Hurricanes Irma and María in Puerto Rico in 2017. The approach can be applied to estimation of shear strength as well as hydrologic parameters that control infiltration and flow of water in the subsurface and ultimately the timing of landslides resulting from heavy rainfall. Results narrow the possible range of cohesion and friction parameters as well as hydraulic conductivity and other soil water parameters by counting the fraction of field observations that can be explained by each combination of parameters. For cases studied in Puerto Rico, the method identified combinations of cohesion and friction values that explain more than 80–90% of observed landslide source areas.

Keywords: Hazard assessment, Debris flows, Puerto rico, Sensitivity analysis

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Applying Debris Flow Simulation for Detailed Hazard and Risk Mapping

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For houses situated in mountainous regions, evacuation routes during sediment disasters are limited. Thus, in the event of heavy rainfall, it may be difficult for inhabitants to evacuate from disaster areas. Therefore, it is important to understand the risk distribution before debris flow disasters in order to determine safe evacuation planning. Debris flow simulations are useful for the determination of hazard and risk mapping. When considering debris flow behavior and conducting debris flow simulations, there are two critical factors with respect to the debris flow flooding and deposition processes, namely, the scale of debris flow and landform conditions. The focus of this study was on various resolution digital elevation model (DEM) landform data in Japan. Simulations were performed for a residential area in Hiroshima, which was subject to debris flow events in 2014. Based on a comparison of the simulation results obtained using DEM data with a mesh resolution of 5 m, as sourced from the Geospatial Information Authority of Japan, and the results using high-resolution light detection and ranging (LiDAR) DEM data, the houses can be considered to describe the influence area and high risk region situated near the valley exit, in addition to locally dangerous areas and movement of debris flows on roads. To achieve a detailed hazard and risk mapping and determine safe evacuation routes and shelters, the application of high-resolution LiDAR DEM data and consideration of houses is critical.

Keywords: Debris flow, Simulation, Hazard and risk mapping, Digital elevation model (DEM)

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Debris-Flow Peak Discharge Calculation Model Based on Erosion Zoning

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Earthquakes trigger large numbers of landslides that provide abundant material for rainfall-induced debris flows and hence increase the frequency and magnitude of post-quake debris flows. A physically-based model incorporating a quantitative function of how much landslide deposit transforms into debris flows is developed to calculate debris-flow peak discharge by dividing a catchment into non-erosion, hydraulic erosion, and gravitational erosion zones. The model was implemented with a distributed hydrological computation program, and applied to Qipan catchment that was strongly influenced by the 2008 Wenchuan earthquake and where the debris flow peak discharge in 2013 was more than 10 times that before the earthquake. Remote sensing images and digital elevation model (DEM) data were used to obtain the spatial distribution of the earthquake-induced landslides. In situ tests were conducted to measure the hydrological parameters of the landslides. Comparisons of field survey and simulation results were carried out to verify the model validity. At 14 cross-sections, the peak discharge errors range from 3 to 20%. Moreover, the error of the inundation area is 2.1%, which suggests that the model is highly applicable to hazard mapping.

Keywords: Debris flow, Peak discharge, Earthquake-induced landslides, Distributed hydrological computation

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Rainfall-Induced Lahar Occurrences Shortly After Eruptions and Its Initiation Processes in Japan

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This study examined the eruption magnitude and timing of lahar occurrences in recent eruptions in Japan. The volcanic deposition status and rainfall in time series were investigated for lahar frequent occurrences shortly after the eruption. The purpose of this study was to clarify the lahar initiation process and characteristics triggering rainfall during periods of approximately one month from the main eruption. Of the nine eruptions in Japan in recent years, lahars frequently occurred due to airborne tephra shortly after the eruption in three cases: the Usu 1977 eruption, Unzen 1990 eruption, and Miyakejima 2000 eruption. For each eruption case, the eruption transition and the occurrence/non-occurrence of lahar are summarized. The primary lahar was initiated in the range of 11–26 mm of hourly rainfall, i.e. “triggered rainfall”. After the primary lahar, subsequent lahars were generated with smaller rainfall of less than 10 mm per hour due to the accumulation of volcanic falls and changes in the hydrological regime associated with the preceding rainfall. The existence of “triggered rainfall” is due to the change of unstable sediment that produce initiation conditions. Furthermore, compared to debris flows generated by factors outside the volcanic eruption, the rainfall related to lahar in relatively short durations or at a lower rainfall intensity is also characterized.

Keywords: Lahar, Debris flow, Rainfall intensity, Volcanic falls, Volcanic hazards, Disaster mitigation, Japan

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Spatiotemporal Assessment of Geological Hazard Safety Along Railway Engineering Using a Novel Method: A Case Study of the Sichuan-Tibet Railway, China

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The Sichuan-Tibet Railway in China is the significance for the long-term development of “The Belt and Road”. However, railway engineering reshapes the landscape it passes through and consequently influences the geological hazard safety. Because of a paucity of previous studies involving this factor, in the present paper, we make a novel development in our previous study that a novel index system, notably from the spatiotemporal aspect. Meanwhile, the effect of railway construction is proposed for geological hazard assessment. Different from regional or site assessment, the concept of the line element is introduced, and the geological hazard safety along Sichuan-Tibet Railway is comprehensively evaluated using matter-element extension model (MEEM), gray correlation model (GCM), and support vector machine (SVM). Meanwhile, the receiver operating characteristic curve (ROC) analysis demonstrates that the method performs better than the method without considering the construction factor or temporal factor. The finding highlights that the construction factor and temporal factor play an essential role in the assessment of geological hazard safety along the railway.

Keywords: Geological hazard, Sichuan-tibet railway, Safety assessment, Construction factor, Spatiotemporal factor

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Slope Stability and Landslide Hazard in Volubilis Archaeological Site (Morocco)

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Volubilis is the most important and famous Roman archaeological site in Morocco. Despite it represents the well preserved archaeological city in Morocco, the site shows a serious marks of soil instability affecting some ancient buildings and mosaics. From geological point of view, Volubilis is located mainly on Miocene marls at mid slope of Zerhoune hill. A field study showed obvious geotechnical instability consisting meanly of a superficial gravitational creep. This landslide phenomenon affects here and there the precious Roman mosaics, and threatens to ruin ancient house walls, especially in northern city. Spatial statistics have led to describe and quantify the inclination of walls as instability index of soil movement, and to map vulnerable zones. The Miocene marls mineralogical composition, determined by X-Ray Diffraction analysis show that the clay fraction is dominated by the Smectite mineral which has high swelling potential. In order to realize an advanced diagnosis of soil instability, geotechnical characterization of Miocene marls has been conducted to assess their mechanical behaviour as expansive soils.

Keywords: Slope stability, Landslide hazard, Geotechnical behavior, Volubilis Morocco

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Landslide Timing in a Changing Tropical Environment: the North Tanganyika-Kivu Rift region, Africa

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Understanding when landslides occur and how they evolve is fundamental to grasp the dynamics of the landscapes and anticipate the dangers they can offer up. However, knowledge on the timing of the landslides remains overlooked in large parts of the world. This is particularly the case in regions where infrastructures are weak or absent and data scarcity is common. Many populated regions of the tropics stand out as such places, despite being affected by high and increasing landslide impacts. There, persistent cloud cover, rapid natural vegetation regeneration, cultivation practices and deep weathering further challenge the harvest of timing information. We present key findings on the characterisation of the timing of the landslides in the North

Tanganyika-Kivu Rift region in Africa, a changing tropical environment lacking baseline studies where population density is high and on the rise. From an inventory of more than 15000 landslides with various timing accuracy (from daily to thousands of years), we identify causes and triggers of the slope instabilities in a context of important human-induced landscape changes. The interaction between uplift associated with the continental rifting in the region and fluvial incision, deforestation, and urban growth are key elements that are considered in our analysis. This is achieved through a holistic approach that combines field work, optical and SAR/InSAR satellite remote sensing, time-series analysis, UAS image acquisition, historical photograph processing, citizen science and geomorphic marker understanding.

Keywords: landslide inventory, causes and triggers, environmental change, hazard assessment, remote sensing

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Slope Hazard and Risk Mapping Project (PBRC)—An Overview of Disaster Risk Reduction Initiative

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Extreme climate, rapid urbanisation, and environmental degradation substantially increase our exposure and vulnerability to natural hazards and disaster risk in a developing tropical country. Therefore, it is crucial to address the issues and possible solutions related to the natural hazards in an objective and quantitative manner. The Slope Hazard and Risk Mapping Project (Projek Penghasilan Peta Bahaya dan Risiko Cerun, PBRC) is the first Malaysia initiative that tackles the issues of area-based landslide hazard and risk with the use of multi-sensory Light Detection and Ranging (LiDAR) technology, supported by many expertise and disciplinary partners. This project is one of the action plans formulated under the National Slope Master Plan (NSMP) 2009–2023 to reduce risk and build the resilience of nations and communities to disasters. It involves comprehensive methodology framework and operational needs driven by modern and advanced geospatial technology. The model has been formulated and evaluated with the complexity of risk scenarios in this knowledge driven project. Slope instability problems in the urban, mountainous, and tectonic landscapes are considered, and their spatial information is crucial for regional landslide assessment. This project established standard procedures with optimal parameterisation for susceptibility, hazard, and risk assessment in the selected regions. It also put forth the critical and practical framework, ranging from updating landslide inventory to mitigating landslide risk as an attempt to support the establishment of a comprehensive disaster risk management in Malaysia. The PBRC project is a great example of producing hazard and risk maps that follow international standards and meet the need of multi- sectoral agencies. It is a practical and evidence-based guidance to support implementation, ensure engagement by stakeholders, and strengthen

accountability in disaster risk reduction. The developed methods can be used to assess tropical landslide geomorphology in an objective, reproducible, and quantitative manner.

Keywords: Disaster risk reduction, Slope hazard and risk mapping, LiDAR

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Risk-Informed Land Use Planning for Landslide Disaster Risk Reduction: A Case Study of Cameron Highlands, Pahang, Malaysia

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The 2030 Agenda for Sustainable Development Goals (SDG) has recognized the urgent need to reduce the risk of disasters in a changing climate. With complexity and interaction of human, economic and political systems, risk becomes increasingly systemic. Therefore, it requires concerted and urgent effort to reduce it in an integrated way. This paper describes a new insight into risk-informed development planning in Cameron Highlands (Pahang, Malaysia), the most populated and economically developed mountainous area in Malaysia. We compiled landslide inventories dated since 1961 coupling with the historical records, and national landslide hazard risk mapping project resulted in 1842 landslides. We found that several landslide hotspots contain more than 10 landslides/km2. Most of the study area was marked as very high to high hazard (38.96%). The GIS-based spatio-temporal assessment indicated about 10.0% and 0.4% of land use changes for the period 2003–2015 and 2015–2018, respectively. Spatial analysis of landslide hazard indicated a positive correlation with land use changes. This study review of 100-year trends in land use changes (1930–1960, 1960–2003, 2003–2015, 2015–2030) indicates that anthropogenic activities dominantly affected by physical development and agriculture activity contributed significantly towards environmental degradation in a populated highland area. Since the urbanization rate in Malaysia is expected to increase up to 85% with 46.1 million people in 2040, integration of Disaster Risk Reduction (DRR) and resilience is critical in all sectors. As a conclusion,

this research provides a significant input for developing local DRR and resilience strategies, as one of seven global targets of the Sendai Framework for Disaster Risk Reduction 2015–2030.

Keywords: Landslide inventory, LiDAR technology, Hazard assessment, Land use changes, Risk-informed sustainable development

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Landslides in Steep-Slope Agricultural Landscapes

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Agricultural landscapes cover a significant part of the Earth. In floodplains, we can find large areas dedicated to intensive agriculture. However, also on hills and mountains, agricultural activity can be relevant from the socio-economic point of view. Nowadays, such areas are increasingly under threat because of global environmental changes. Widespread growing rainfall aggressiveness due to climate change, in addition to land abandonment, lack of structural maintenance, and in some cases unsuitable agronomic practices are exposing steep-slope agricultural landscapes to increased hazard of landslides. A suitable hazard assessment and zonation of these phenomena would help better management of such agricultural landscapes. The purpose of this article is to provide an overview of this relevant problem focusing on (i) the contribution of remote sensing technologies (e.g., LiDAR and UAV photogrammetry) in mapping the investigated processes, and (ii) discussing advances and limitations of susceptibility modelling.

Keywords: Landslide, Remote sensing, Modelling, Landscape, Agriculture

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From Satellite Images to Field Survey: A Complete Scheme of Landslide InSAR Monitoring

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The free availability of Sentinel-1 satellite radar images, combined with the wide-area coverage, the huge benefits-cost ratio, the short revisiting time and the non-invasiveness allows a continuous monitoring of ground displacements. In Italy, Sentinel-1-based continuous monitoring activities are operating in three regions and a possible chain for a practical use of satellite images for local authorities and civil protection operators is presented. A continuous monitoring is set up through the systematic collection of imagery and the repeated processing of each new pair acquired. The Persistent Scatterers (PS) resulting from such chain are subsequently analyzed by means of a data-mining algorithm for highlighting the points with relevant trend variations in the time series. In this way, a huge amount of data and wide areas may be monitored and temporal changes due to various phenomena could be assessed in a short time. The highlighted points, taking advantage of the surrounding PS data, are thus interpreted and classified according to a list of possible causes (e.g. accelerations of landslide or subsidence phenomena). The most relevant cases are notified to local authorities as potential active hazardous phenomena to be verified by means of field survey. A supporting scheme for the operative chain is here proposed and two case studies are presented. This operating workflow is intended to represent a standard procedure which could be applied on a national scale, aiming at the real-time monitoring of hazardous scenarios, and may be used as a guide for civil protection procedures for the risk reduction in large areas.

Keywords: Sentinel-1, InSAR, Monitoring, Landslides, Preliminary risk assessment, Field survey

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Slope Disaster Risk Reduction Map as a Communication Tool for Community Based DRR in Japan and Vietnam

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The need to reduce the damage of local residents who are direct victims of natural disasters has long been pointed out. In recent years, disasters of an unexpectedly large scale occur frequently, and it is not possible to protect local communities and human lives simply by taking disaster prevention measures. In order to mitigate disasters, it is necessary to build voluntary disaster mitigation measures by residents. However, local residents have not accurately acknowledged and understood disaster risks existing in the region. Through this report, we have discussed the significance of the process of creating a communication base DRR map jointly by the community and engineers in order to realize “local residents’ understanding of regional disaster risks". Specifically, we have introduced how a slope disaster risk map should be, the flexibility and ease of acquiring necessary data in the present age, the actual work progress and results, etc., using examples from Japan and Vietnam.

Keywords: Landslide mapping, Slope DRR, Local resident, Communication base mapping, Japan, Vietnam

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People Vulnerability to Landslide: Risky Behaviours and Dangerous Conditions by Gender and Age

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Landslides are frequent and destructive geo-hydrological events that cause harm to people every year worldwide. We used a catalogue on 1039 landslide fatalities, occurred in Italy in the 50-year period 1970–2019, to determine the dependence of the fatalities on gender, age and circumstance of death. The updated version of the Italian landslide fatalities catalogue includes information on the exact time of the occurrence of the fatal landslide events and the circumstances of death. Possible relations between time of the day and fatalities occurrence are analysed. Males landslides fatalities occurred frequently outdoor, along roads mainly involving drivers or passengers travelling in vehicles, indicating a specific dangerous death contingence preferentially occurring in daylight. Conversely, female landslide fatalities occurred more frequently indoor. To consider the demographic and socio-cultural changes over time, we performed a temporal analysis splitting the catalogue into three overlapping subsets 30-year each. In the three time periods, we estimated the expected fatalities by gender and age, using national census data and a multinomial distribution. Such estimates were compared with the observed landslide fatalities distribution. We identified the age categories over or under represented when the observed fatalities were respectively higher or lower than the modelled expected deaths. The analysis shows that for all the periods landslide male fatalities compared to the female ones are significantly higher than those expected by census data, indicating both a diverse propensity towards the risk taking and a different degree of exposure between males and females.

Keywords: Loss of life, Landslide fatalities, Landslide mortality, Statistical approach, Gender and age analysis

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Using Mixed-Methods to Understand Community Vulnerability to Debris Flows in Montecito, CA

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More communities around the world are living in hazard-prone areas. These communities are susceptible to natural hazards and negative impacts, which can be mitigated by adopting Disaster Risk Reduction measures that take into account an assessment of vulnerability. However, vulnerability studies can be limited and often do not take a spatio-temporal approach. In this study, we applied a spatio-temporal approach to the case of Montecito, CA, in order to better understand the variables that make a community vulnerable and to identify those who are the most vulnerable. In 2018, Montecito was heavily impacted by debris-flows resulting in material and human losses. Our results showed that informal workers, residents of voluntary evacuation areas, and renters were most vulnerable, and the main aspect that contributed to their vulnerability was a lack of understanding of debris-flow risk. Moreover, local authorities failed to use historical data to communicate and educate the community before the event to reduce the overall community vulnerability and rebuilding process is changing the community vulnerability.

Keywords: Montecito, Debris-flows, Vulnerability, Mixed-methods, Spatio-temporal

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Innovation in Analysis and Forecasting of Vulnerability to Slow-Moving Landslides

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The analysis of consequence induced by landslides to the built environment is a key step in the landslide risk management process. For this purpose, a thorough knowledge of both the landslide mechanisms and the behaviour/characteristics of the exposed elements turn out to be crucial. Currently, scientists and technicians have access to unprecedented big data sources that provide a variety of useful information on landslide-affected areas. With reference to slow-moving landslides, this paper presents some case studies of an ongoing research aimed at defining and testing original procedures pursuing the exploitation of innovative monitoring/surveying techniques for the analysis and forecasting of vulnerability of buildings and roads.

Keywords: Slow-moving landslides, Vulnerability, Damage, Remote sensing, DInSAR

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On the Use of UAVs for Landslide Exposure of Households: La Gloria Neighbourhood, Teziutlán, Puebla

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Owing to landslide susceptibility of pyroclastic deposits, coupled with high vulnerability and exposure, the Sierra Norte de Puebla region, in Mexico, is characterised by significant levels of landslide disaster risk. This study aimed at evaluating landslide exposure of households in La Gloria neighbourhood, Teziutlán, Puebla, an area that was severely affected by the disaster of October 1999. The methodological approach comprised three stages: (1) definition of the parameters used for developing the landslide exposure index; (2) aerial survey using a drone; and, (3) elaboration of the landslide exposure map. According to the produced landslide exposure map, 57% of the households are in areas of high level of exposure, whereas 32 and 11% are in moderate and low exposure zones, correspondingly.

Keywords: Landslide, Exposure, UAV, Households, Disaster risk, Teziutlán

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Site-Specific Risk Assessment of Buildings Exposed to Rock Fall in India—a Case Study

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Rock falls are the most common type of fast- moving landslide where rock fragments fall (bounces or slides or rolls) freely from a cliff face having little or no shear displacement, thereby posing serious threat to life and infrastructure. In order to prevent these accidental happenings, assessment of site-specific risk becomes essential. The specific risk (RS) is useful in assessing risk due to site-specific landslide in a particular area at a particular intensity. In the present study, landslide risk (rock fall risk in this case) has been assessed spatially as a function of physical vulnerability (PV) and proximity (Prox) of the buildings from site-specific rock fall zone and drainage channels associated with them by using a semi-quantitative approach in a GIS platform. The site-specific risk exposed to rock falls has further been classified into three classes to determine the severity of risk level as low, medium and high. These site-specific risk classes will be useful in taking appropriate protection measures such as bolts, nets, removal of unstable blocks, simple light fences, buttress walls. The proposed methodology has been presented as a case study in a rock fall prone region of Chamoli District, Garhwal Himalayas of India.

Keywords: Rock fall, Site-Specific risk, Physical vulnerability

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The Advanced Method for Detecting Geotechnical Risks of Landslide Failures by Surveying Historical Surface Deformation and Underground Water

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On April 11th 2018, a landslide failure occurred suddenly at Yabakei town, Oita, Japan without any rainfall or earthquakes. To carry out an experimental trial for forecasting such a sudden disaster, we applied the SqueeSARTM time series analysis to detect historical surface movements in Yabakei and searched spring water in moving areas by using a thermography camera on a drone. As a result, surface water flows were found in the most of moving areas by thermographic observation. Also, we confirmed spring water in the all moving areas by the optical survey. This means that the integration of SqueeSARTM and thermographic observation is a powerful means to extract dangerous areas where a sudden landslide failure would occur even if there are no clear predictive phenomenons. For detecting geotechnical risks, it is important to focus on both historical surface deformations and underground water.

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Quantitative analysis of the consequences induced by slow-moving landslides to a road network in southern Italy

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This abstract synthetizes the results of a research aimed at estimating – on a quantitative basis and at large scale – the consequences associated with direct damages induced by slow-moving landslides to a road network. The applicability of the newly conceived procedure, rigorously framed in the risk theory, is tested with reference to a case study of the Campania Region (southern Italy) for which the slow-moving landslide inventory, the graph of the road network (divided into primary and secondary), remote sensing data and multi-temporal information on the damage severity level are available. The obtained results are expressed in terms of repair costs, over given periods, of the primary road network considering that it is already damaged. The Monte Carlo probabilistic method is then applied to both the primary and secondary networks (no damage data are available for the latter) to identify the road sections that primarily require risk mitigation measures (this is of particular concern for decision-makers) or for which the severity level of the most likely damage is such as to determine the greatest increases in travel time (this is of particular concern for road users). Finally, the main outcomes are discussed, highlighting the original and innovative aspects of the work done, the positive impacts on the decision-making processes (e.g., in selecting the most adequate intervention categories and their scheduling), the future developments (including applications at detailed scale for the correct design of interventions).

Keywords: slow-moving landslide, road, consequence, Monte Carlo method

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Landslide Scenario in North Eastern Region of India and Associated Challenges

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North Eastern Region (NER) of India consists of 8 states, namely, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. Almost entire NER is susceptible to landslides except the plain areas of Assam, Manipur and Tripura. Physiographically NER is a part of Extra-Peninsula of India and of geologically recent origin, having exposed rocks from Archaean to Quaternary ages. These diverse geological settings make the terrain susceptible for landslides. While, intense and/or prolonged monsoonal rainfall and seismic activities are the landslide trigger. Anthropogenic factors have a role in accelerating the issue. Moreover, NER is one of the most seismically active regions in the world.

Mostly deep-seated landslides are responsible for disrupting transportation network for longer duration while shallow slides are common in urban areas affecting settlements. Further, the cost of landslide damage keeps on increasing drastically as the pace of urbanization intensifies on the geologically sensitive slopes. Decadal population growth in a range from 12.36% to 27.82% is observed in NER from 2001 to 2011 (Census 2011) and it is increasing. Moreover, frequent disruption of connectivity along road corridors and railway tracks for longer spells causes shortages in supply of essential commodities other than inconvenience to travelers. Siltation of rivers, as well as damming of rivers causing impoundment of water and subsequent dam burst also pose indirect threat to the society. In 2020, post monsoon, total 52 casualties are reported from different parts of NER. Although the dimension of landslides is small, fatality rate and loss of property is high in urban areas.

However, efforts are being made by various organizations/ institutes to prepare large-scale susceptibility maps, followed by vulnerability and risk assessment, estimation of rainfall threshold for early warning apart from site specific studies to help concerned disaster management authorities.

Keywords: Landslides, Earthquakes, Rainfall, Geology, NER India

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Population vulnerability assessment and its effect in landslide risk mapping – The case of Angra dos Reis, Rio de Janeiro, Brazil

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Landslide risk results from the combination of three components: hazard, the exposed population and their vulnerabilities. Vulnerability is related to community conditions that render it susceptible to the damaging effects. Therefore, landslide risk mapping must not only focus on the physical aspects of the landslide (hazard), but also on vulnerability among exposed populations to the potential process, practice not commonly followed, which may compromise the efficiency of disaster risk management policies. This work presents a method to evaluate vulnerability, combine it with hazard and exposure to define the risk degree and to assess the effect of including vulnerability in comparison with the method which does not consider this risk component. The method was applied to the municipality of Angra dos Reis in Rio de Janeiro State, Brazil. The data for evaluation of each risk component sourced from the census information and hazard mapping. The method includes procedures for spatial compatibilization of the three components, definition of values for each one and how they are combined. The results indicated that vulnerability has a significant influence on risk estimation in the study area – 60% of risk sectors had their ratings altered after consideration of this component, corresponding to 58% of the total area mapped, in which 43% of the population lives.

Keywords:, risk mapping, vulnerability, GIS, census, risk zonation

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Theme 3 Monitoring and Early Warning

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Defining Kinematic and Evolutive Features of Earth Flows Using Integrated Monitoring and Low-Cost Sensors

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Mid to long-term monitoring of earth flow displacements is essential for the understanding of their kinematic features, process dynamic and evolution, and designing of mitigation measures. This paper summarizes methods, results, and interpretations of monitoring activities carried out between 2006 and 2020 at three earth flow sites in southern Italy characterised by structurally and lithologically complex slopes: (1) the Montaguto, (2) the Mount Pizzuto, and (3) the Pietrafitta landslides. By integrating traditional monitoring techniques and specifically developed low-cost sensors, kinematic and evolutive features of the three earth flows were analyses allowing detailed reconstruction of the relationship among basal-slip surface geometry, deformation styles and pattern, geomorphic structures, movement velocity and sediment discharge during ordinary and extraordinary movements. Final results highlight that earth flows are composed of distinct kinematic zones with characteristic longitudinal velocity profiles. Velocity variation along a kinematic zone, which is controlled by the basal and lateral geometry of the slip surface, is consistent with the distribution of structures on the ground surface of the flows, reflecting stretching and shortening of material during movement. Seasonal movements characterized by alternation between relatively slow persistent movement and acceleration are induced by material recharge passing through each kinematic zone and depends from this amount. Finally, it is empathised the use of low-cost sensors for displacement monitoring associated with traditional instrumentations, which give the advantage to obtain multiple stations distributed over large areas and reduce the cost of expensive monitoring campaigns.

Keywords: Earth flow, Kinematic, Displacement, Evolution, Monitoring, Low-cost sensors

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Monitoring of Thermoelastic Wave Within a Rock Mass Coupling Information from IR Camera and Crack Meters: A 24-Hour Experiment on "Branická Skála" Rock in Prague, Czechia

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Results from a 24-hour time-lapse IR camera monitoring experimental study performed on a rock mass in the city of Prague are presented. The thermal images were processed and analysed. Acquired temperatures were coupled with information from crack meters monitoring of an unstable block. It has been shown that it is feasible to directly observe the thermoelastic wave on the monitored block. Correlations of movements with monitored temperatures showed that the rock surface temperature is not the only variable that influences thermally-induced movements. The movements are probably controlled more by the overall air/rock mass temperature rather than maximum and minimum peaks. However, for better understanding of this phenomena, we suggest monitoring for a longer period including measurement of temperatures inside the rock mass.

Keywords: Thermoelastic wave, Rock mass monitoring, IR camera, Crack meters, Branická skála, Czechia

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Field testing innovative differential geospatial and photogrammetric monitoring of a slow-moving landslide, south-central British Columbia, Canada

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We present a novel approach to continuously monitor very slow-moving translational landslides in mountainous terrain using conventional and experimental differential global navigation satellite system (d-GNSS) technologies. Field testing undertaken at Ripley Landslide, near Ashcroft in south-central British Columbia, Canada, demonstrates the applicability of new geospatial technologies to monitoring ground control points (GCPs) and railway infrastructure on a landslide with small and slow annual displacements (<10 cm/yr). A radio-frequency “mobile” d-GNSS network, satellite interferometric synthetic aperture radar (InSAR) and unmanned aerial vehicle (UAV) photogrammetry all record increased landslide activity and ground displacement in late winter and early spring. During this interval, river and groundwater levels are at their lowest levels, while ground saturation rapidly increases in response to the thawing of surficial earth materials, and the infiltration of snowmelt and runoff occurs by way of deep-penetrating tension cracks at the head scarp and across the main slide body. Our research provides vital information for government agencies, national railway companies, and other stakeholders to understand geohazard risk, predict landslide movement, improve the safety, security, and resilience of Canada's transportation infrastructure; and reduce risks to the economy, environment, natural resources, and public safety.

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The Role of Measure of Deep-Seated Displacements in the Monitoring Networks on Large-Scale Landslide

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The aim of this research is to obtain a hydro-geomorphological and geotechnical model of the Arzeno and Prato di Reppia large scale landslide for the geo-hydrological risk management. Arzeno and Reppia are typical rural villages built in historical times at about 600 m a.s.l. near the main watershed, in the Entella river catchment (Ligurian Apennine): this is a very common situation in the Ligurian hinterland, where large landslides represent about 15% of the territory. For decades, there have been reports of slope instability phenomena in the villages of Arzeno and Prato di Reppia, which are outlined by several indirect kinematic indicators (mainly damage on buildings and infrastructures). In order to improve the comprehension of the landslide kinematic and the consequences on buildings and infrastructures, in 2017, a drill survey was carried out: one inclinometer case with robotized system and one piezometer with pressure transducer for continuous measurement have been installed in Arzeno. One inclinometer case and one piezometer case have been installed in Prato di Reppia village. The monitoring activities show a complex situation for the studied large-scale landslide: an evolution of the slope instabilities in several compartments with different kinematics and hydrogeological set-up is recognized, as well as a good convergence between satellite, GPS and inclinometric monitoring data.

Keywords: Deep-seated ground deformations, Monitoring network, InSAR

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LiDAR and UAV SfM for landslide monitoring

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Landslides are natural processes, widespread across landforms and climatic zones, that are controlled by river incision or sea level fluctuations. While landslides are shaping the earth surface and have their role across the geospheres of the Earth System, in relation to humans and societies, landslides are natural hazards (although there also cases when landslides were beneficial to human society), that pose risks to life and infrastructures. Through land surface changes and induced climatic changes, humans also act as drivers of landslides, especially along roads. The study of the characteristics and dynamics of landslides, both in the past and nowadays is important for their forecast. LiDAR topography is one of the main sources of information about the spread and for the mapping of landslides at hillslope and regional scale. For site specific studies Structure from Motion of UAV acquired images represents a game changer in topography acquisition for landslide studies due to low-cost and the rapidity of surveying. While these technologies were proven for reconnaissance studies, the future achievements should focus on monitoring approaches, both technological or algorithmic. The monitoring can be performed pre-event, during the event, but is also important for the post-event period. Technologic achievements are related to the development of new systems that can provide automatic solutions to topographic acquiistion. Algorithmic achievements are related to algorithm building/testing for semi or fully automatic landslide recognition, point cloud generation, point cloud or DEM matching for change detection. Machine learning algorithms are provisioned to be game-changers in the field of landslide recognition from high-resolution topography.

Keywords: landslides, LiDAR, UAV, Structure from Motion, Digital Elevation Model

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Recent Developments in Photomonitoring

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The use of photos is today a common practice for landslide mapping and monitoring. Aerial pictures have been used for geomorphological and landslide mapping since the ’30s and dates back to the ‘60s the first application of time-lapse topography for multitemporal landslide characterization. From ‘80s are also available the first scientific papers showing the application of ground based time-lapse photography for continuous monitoring of landslides. However, an incredible revolution has been achieved with the advent of digital photography in the late ’80s early ’90s, the first high resolution (sub-metric) satellite missions in late ’90s and early 2000s and more recently the fast growth of UAV (Unmanned Aerial Vehicle) allowing for repeated flights. This large availability of images, supported by increased power computation, has let image processing discipline to become relevant also in landslide mapping and monitoring science. Today, multi-temporal scenes collected at different times over the same area can be processed taking advantage of techniques such as Change Detection (CD), Image Segmentation (IS), Image Classification (IC) and Motion Estimation based, for instance, on Digital Image Correlation (DIC) and Optical Flow (OF) algorithms, thus allowing the monitoring of changes and displacements at sub-pixel detail. Furthermore, different kind of images can be used ranging from the traditional Optical images to InfraRed and Microwaves derived images (e.g. Synthetic Aperture Radar (SAR) images). Recent studies are also demonstrating the capability of these techniques to measure displacements up to 1/100 pixel precision and to provide time series of displacement if long stacks of images are used.
Photomonitoring approached based on Digital Image Correlation and, even more, Optical Flows algorithms are not affected by aliasing and phase ambiguity issues for large displacements, thus being complementary to Interferometric SAR techniques.

Keywords: landslides, displacement, digital image correlation, satellite, UAV

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Geophysical Monitoring of Landslides: State-of-the Art and Recent Advances

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Geophysical monitoring of landslides has developed strongly in recent years with the use of electrical resistivity imaging on the one hand, and the application of techniques based on continuous seismic recordings on the other hand. The paper resituates these developments within the general framework of the application of geophysical methods to landslides and focus on the definition of relevant geophysical parameters that can be precursors to activation or reactivation phases. Four recent case studies from the literature illustrate the potential and limitations of geophysics for landslide monitoring. Development prospects, especially for integration into early warning systems, are discussed.
Keywords: Geophysics, Monitoring, Early warning, Resistivity, Seismic

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Recent Advances in High Spatial Resolution Geophysical Monitoring of Moisture-Induced Landslides

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Time-lapse geophysical methods are increasingly used to monitor unstable slopes prone to hydrological destabilisation. Geophysical methods are well suited to this purpose due to the high spatiotemporal resolutions at which monitoring data can be acquired. In particular, geoelectrical and seismic approaches are shown to be particularly beneficial for identifying variations in landslide systems at high spatial resolutions. The integrated use of these approaches, which are sensitive to closely inter-related hydrogeological features and processes driving moisture-induced slope instabilities, can reveal the evolving properties of subsurface materials as they move toward failure. Here, we highlight recent advances in high spatial resolution geophysical monitoring with examples from the Hollin Hill Landslide Observatory, a slow-moving, clay-rich, moisture–induced landslide located in North Yorkshire, UK. We present the details of different high spatial resolution geophysical monitoring arrays deployed at the site, including electrical resistivity, seismic refraction, self-potential, and passive seismic, and consider their relative benefits and weaknesses. Focusing on electrical resistivity and seismic refraction monitoring data, we demonstrate how the integrated analysis of time-lapse data can be used to better understand the key hydrogeological features and processes leading to slope failure.

Keywords: Geophysics, Monitoring, Early-warning, Geoelectric, Resistivity, Seismic, Refraction

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Characteristic Analysis of the Nayong Rock Avalanche Based on the Seismic Signal

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A rock avalanche that destroyed 23 houses and killed 35 people occurred on 28 August 2017, Nayong, SW China. Combined with the dynamic parameters from seismic signal inversion, a discrete element model, MatDEM was used to determine the kinematic behaviour of the rock avalanche. By comparing the velocity evolution process of numerical simulation with that of seismic signal inversion, we are able to find the best fitting parameters. The dynamic process obtained by modelling was compared with the frequency distribution spectrum of the nearest seismometer, showing that the dynamic process is in good agreement with those parameters inverted from seismic signals. The simulation results show that the movement process lasted for nearly 40 s, with a maximum speed of 40 m/s. The selected models and parameters contribute to explain the dynamic processes of similar rock avalanche more accurately and are of considerable significance to the hazard prediction in karst area.

Keywords: Rock avalanche dynamics, Avalanche seismology, Time-series analysis, Discrete element method, Model calibration

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Rockfall detection, localization, and early warning using micro-seismic monitoring

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Rockfall risk is usually characterized with high velocity, lack of noticeable forerunners, abrupt collapse, complex mechanism, and high frequency of occurrence. It has a relatively high potential vulnerability against people and communication routes and difficult in prediction. Based on a rock slope monitoring case study (Torgiovannetto, in central Italy) and an artificial released rockfall test, this study proposes a framework of rockfall early warning using micro-seismic monitoring that includes rockfall detection, classification, and localization. In that framework, STA/LTA was suggested for seismic detection considering the stable processing and good performance, but the methods of waveform template matching and cross-correlation are still good future approaches when the template waveform is found. A three-step classifier was introduced to integrate and classify seismic events from all components into a 'final' detected event type that represent that monitored by the network. Seismic polarization was priory suggested for localization taken the advantage of automatic process, compares to the method of arrival times, even though the seismic wave phases (P wave and S wave) are not completely understand and more studies are needed to validate seismic polarization. Arrival times, in fact, is more reliable than seismic polarization if the accuracy in the arrival times picking is improved or more stations are employed. Based on the studies of Voight, Fukuzono and Amitrano, a seismic quantity of accumulated energy of rockfall was proposed for rockfall early warning. With this framework, the rockfall occurrence frequency in the monitoring period was ex-posted, and the slope rockfall susceptible area was extracted by localizing all the rockfalls detected in the monitoring period. Moreover, a seismic quantity, the accumulated energy of rockfalls, was defined to perform rockfall (both rock mass fall and rock avalanche) early warning. The presented seismic monitoring framework provides a new route on rockfall monitoring, covering the shortages of displacement monitoring in subsurface and abrupt collapse. Knowing the time and location of a failure could be helpful for transportation line emergency organization, such as activate traffic lights and close roads.

Keywords: Rockfall detection, seismic monitoring, rockfall classification, rockfall localization, early warning system

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Electrical Resistivity Tomography (ERT) Based Investigation of Two Landslides in Guizhou, China

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On 28th June 2010 and 23th July 2019, two long runout landslides occurred in the Guizhou province, Southwest China. These two catastrophic events have a runout distance > 1 km and an estimated maximum velocity > 40 m/s and caused mass casualties in the local area. To investigate the spatial distribution of deposits and better understand the local geological settings of these two landslides, geophysical surveys, including electrical resistivity tomography (ERT) and borehole tests were carried out in this study. The ERT results of the Guanling landslide are roughly consistent with the borehole data, indicating the validity of inversion images. Also, due to the surface and underground river channels, the lithological boundaries of the Shuicheng landslide determined through ERT was not very pronounced. Nevertheless, the location of river channels and deposit characteristics investigated in situ are in rough agreement with the inversion results of ERT. It is expected that the results from the ERT survey are beneficial for the mechanism analysis of these two long runout landslides and proposing more appropriate actions for the landslide mitigation activities.

Keywords: Electrical resistivity tomography, Borehole, Guanling landslide, Shuicheng landslide, Subsurface investigation

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Vibration of Piled Rocks—Which Rock Can Be Removed?

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To identify rocks which can be taken from rock-mound without disturbing stability of other rocks, vibration characteristics of rocks in mound were investigated by measuring vibration of each rock in an artificial mound. A mound of sand stone rocks of randomly-shaped, length 30–40 cm was constructed on the ground and was subjected by artificial vibration. The vibration of rock on the top ("free rock") and that of a rock supporting the top rock ("supporting rock") were measured. Their characteristics showed that the dominant frequency was different; 40–50 Hz for the free rock and 50–60 Hz for the supporting rock. After changing the free rock to a supporting rock by means of leaning another rock on it, the dominant frequency became to 50 and 60 Hz. It is considered that waves of frequency range of 40–50 were amplified in the free rock in test conditions of this paper. According to these findings, the authors discussed about possibility of identify free rocks from supporting rocks by vibration characteristics.

Keywords: Vibration, Microtremor, Test Rescue, Rock mound

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Multiinstrumental Monitoring Network Slopenet - New Advances

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In 1980ies, the department of engineering geology began to build a monitoring network for observation of movements of selected landslides. Since that time, the network has developed into a multiinstrumental, wide-spread system for overall observation of landslides, monitoring not only movements, but also climatic, underground and hydrologic conditions related to the slope activity: the Slopenet. Currently, the network consists of 15 sites across the Czech Republic, and includes various types of landslide sites, unstable rock monitoring sites as well as rock faces disintegration sites. The instrumentation differs depending on the character of the site, observed process(es) types and purpose of the monitoring. Traditionally, most of the sites are instrumented with the TM-71, a highly precise 3D crack gauge developed at the department. Aside from that, the movements are observed by various dilatometers, steel tape extensometers, geodetic surveying and levelling.

During the recent years, Slopenet monitoring network was upgraded by installation of innovative, often automatized, monitoring devices measuring activity of slope processes, climatic parameters, hydrological conditions and soil changes, aiming to collect more thorough data on the slope processes preconditioning and triggering events. The new development of the TM-71 device lead to designing an automatized version, where a specialized computer controls the data collection, storage and transmitting. Further, the new equipment includes a multiparametric column combining piezometric and inclinometer readings (CSG), automatic RC TL-ERT across distal part of a complex landslide (GF Instruments), or automatic stations with soil, water and air sensors. The rockfall sites are monitored with crack gauges (Geko) and temperature sensors (EMS) set in insulated chambers along a 3 m borehole and combined with IR surveying. The newest contribution to the network is the development of custom, low-cost phase GNSS devices for slow displacement measurements.

The Slopenet network combines the advantages of long-time monitoring with the advantages of new types of data from innovative, sometimes custom-developed methods. This not only brings some interesting results, such as observation of propagation of landslide activity and its linking with preconditioning of the environment, but also allows testing and improving of the newly developed monitoring designs.

Keywords: landslide monitoring, TL-ERT, inclinometry, 3D monitoring, Cereniste, Central Europe

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Slope Instabilities Analysis and Monitoring of Aizawl Landslide, Mizoram, Northeast India

Laldinpuia

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The geotechnical investigations and monitoring of landslides are carried out at Zuangtui locality, Aizawl to assess the instability of the slope and rate of movement. Geologically, the study area belongs to the Middle Bhuban Formation of Surma Group (Lower Miocene to Quaternary), the main rock type is argillaceous shale. The study area experienced a rotational type of movement from 1987, affected road subsidence, damage of buildings, and electric power station. Representative rock samples are analyzed and studied using XRD (X-ray Diffraction) to know the exact geochemical nature. Observed clay minerals, montmorillonite and kaolinite may play roles for subsidence. The rate of movement is regularly monitored using a borehole extensometer, crack meter and total station. It shows that slight movement, but no related to rainfall during the monitoring period. A deterministic method, the Limit Equilibrium Method (LEM) employed for finding factors of safety to propose proper mitigation measures. The observed factor of safety is 1.5 to 1.6 based on Fellenius, Bishop's Simplified, Janbu's simplified, Spencer's and GLE/ Morgenstern methods. Reducing driving forces by proper surface and sub-surface drainage system with benching, strengthening check dam, and reinforced concrete cement retaining wall for increasing resisting force are suggested.

Keywords: Aizawl, Borehole extensometer, Crackmeter, LEM, XRD, Zuangtui

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Debris Flow Detection Using a Video Camera

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The early warning of natural hazards is an important issue that was raised by the 2015 Sendai Framework for Disaster Risk Reduction. However, early warning systems need complimentary monitoring systems that themselves may be combined with automatic identification and prediction systems. For debris flows, once a disaster has been confirmed to have occurred in an upstream area, early warning of the hazard further downstream may be predicted with relatively good accuracy in time and space. In this study, we use video cameras to identify the arrival times of debris flows using a simple average grey-level method. We show that this method can automatically detect the arrival of debris flow events. This method is tested with both real events video and indoor experiments during the night with moonlight only illumination. All tests have an error of less than 1.3 s. The method is fast and therefore ideal for real-time monitoring and warning.

Keywords: Debris flow, Camera, Monitoring

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Comparison Between PS and SBAS InSAR Techniques in Monitoring Shallow Landslides

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The main aim of this study is to compare the two commonly used multi-temporal interferometric synthetic aperture radar (InSAR) techniques, i.e. permanent scatterers (PS) and small baseline subset (SBAS), in monitoring shallow landslides. PS and SBAS techniques have been applied to ascending and descending Sentinel-1 SAR data to measure the rate of surface deformation and the displacement time series in the Rovegliana area (NE Italian pre-Alps) from 2014 to 2019. As expected, PS results cover only urban areas, while those obtained by SBAS cover up to the 85% of the investigated area. Velocity maps obtained by the two techniques show that some sectors of the investigated slope are affected by active shallow landslides which threaten the stability of buildings, walls and road network. The comparison between ascending and descending velocity maps along the satellite line of sight reveals the presence of a horizontal component in the east–west direction which is consistent with the landslide kinematic. The analysis of the displacement time series shows that, in the case of linear deformation trends, PS and SBAS results are similar, whereas, in the case of high oscillations and non-linear behavior, SBAS technique can provide a better estimation of the displacements. Besides, SBAS provides smoother and less noisy displacement time series. However, both the techniques showed their high capability in monitoring the evolution of the landslides, which is crucial for the implementation of effective risk prevention and mitigation strategies. To deep investigate the differences between the two techniques, other geomatic methodologies, based on global navigation satellite system and terrestrial laser scanning, should be used.

Keywords: DInSAR techniques, PS, SBAS, Sentinel-1, Shallow landslides, Pre-alps, Italy

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Towards managing debris channel risks to infrastructure: understanding debris processes using remotely sensed data.

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In mountainous environments around the world, the transfer of debris from catchments by hydrogeomorphic processes is a common occurrence. These gravity-driven transport processes, which range from debris floods to debris avalanches, have an impact on landscape evolution and present a natural hazard to human settlements and industrial facilities. Of particular concern are debris flows, which are defined as a rapid movement of a saturated, poorly sorted mixture of clastic and organic materials in a steep channel. Long runout distances and poor temporal predictability make debris flows one of the most destructive and dangerous natural hazards.

The most significant contributor to debris-flow occurrence is a supply of readily erodible material, often created by rockfalls and landslides. The spatial distribution and total volume of storage are also critical factors controlling the initiation location, predominant flow type, and termination location of debris-flow surges. Therefore, there is a current need to be able to systematically incorporate the processes and timeframe that recharge debris to the channel into monitoring and characterization of debris flow hazards.

In this work, the authors present the terrestrial laser scanning (TLS) data that has been collected in the White Canyon, British Columbia, Canada. The TLS dataset spans almost a seven-year study period collected at monthly to quarterly intervals, providing the basis for analysis of debris transfer processes occurring on the slope. Rockfall activity has been linked to in-channel stored sediment volumes to characterize the channel recharge processes on this active slope. The overall goal of this work is to gain a better understanding of debris channel recharge processes, in order to advance the practices of natural slope mitigation planning and ongoing control, to protect the safety of the workers and integrity of infrastructure.

Keywords: TLS, debris flow, point clouds

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Remote sensing monitoring of landslides along highway in Guozigou Valley, China

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The highway in Guozigou Valley plays very important role in Xinjiang, China and even in Central Asia, especially under the strategy of the Belt and Road. It is the corridor of energy, material, economic and cultural exchange, etc., between Yili and other countries of China and Central Asia. But, due to climate change in recent years and its own special environment geological conditions, landslide, collapse, debris flows and other geological disasters are frequently occurred along the highway, and which cause great damages to peoples' life and properties. In this study, two period China's GF-2 HD satellite data (GF-2, GF represents GaoFen, meaning "high resolution" in Chinese) were used to monitor the geological disasters along the G30 highway of Guoziguo Valley. GF-2 is the first China's civil optical remote sensing satellite with the resolution of being superior to 1 m which is researched and developed by China independently. The remote sensing processing software ENVI5.2 was used to process the data. The roadside landslide, road collapse, roadbed broken and debris flows on road along the G30 highway in Guozigou Valley due to the heavy rain on May 10, 2016 were identified through GF-2 data. There were three places of road-fall, eight places of debris flows and two places of landslides along the around 35 km distance of highway after the heavy rain. The area of road damaged by those geological disasters were calculated. The GF-2 data meet the data requirements for monitoring highway geological hazards and it presents all the disasters along the road clearly and accurately. This kind of high spatial resolution satellite data can monitor highway geological disasters and provide reference data and guidance for highway maintenance.

Keywords: Highway Geological disaster, GF-2, ENVI 5.2, Guozigou, Debris flow, Road Collapse, Landslide

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Sentinel-1 landslides detection: the Granada coast

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The new European round Motion Service (Copernicus) opens a new perspective in the use of Satellite Synthetic Aperture Radar Interferometry (InSAR) products. Moreover, the start-up of new constellations with systematic acquisition policies and free data access like Sentinel-1, is increasing the interest in these techniques. In this context, not only the scientific community, but also the administrations and the authorities will deal more and more with InSAR displacement maps. Considering the huge amount of information, and the difficulties of analysis and interpretation, it is necessary to go towards semi-automatic tools and methodology to improve the operational use of this maps by users involved in territorial and risk management. Here we propose a set of tools and methodologies to detect and classify Active Deformation Areas, and to map the potential damages to anthropic elements, based on the differential displacement. We present the results achieved in the coast of Granada, which is strongly affected by slope instabilities. The methodology is applied at a regional scale and allows to go to a detailed local scale of analysis. The presented results have been achieved within the framework of the Riskcoast Project (financed by the Interreg Sudoe Program through the European Regional Development Fund (ERDF)).

Keywords: Sentinel-1, Active Deformation Areas, Landslides, InSAR

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Landslide Dynamic Deformation Monitoring with Sequential Least Squares Based SAR/InSAR techniques

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The catastrophic landslide disasters occur frequently in Karst mountainous regions, Yunnan-Guizhou Plateau, China due to vulnerable geological environment and underground mining activities. Therefore, the deformation monitoring of the potential unstable slopes is critical to the research on their failure mechanism and early warning. For this purpose, we take two mining sites with different deformation characteristics in Guizhou Province to retrieve and monitor their surface deformation by using synthetic aperture radar (SAR) offset tracking method and SAR interferometry techniques. In two sites, both two dimensional deformation time series are estimated by fusing ascending and descending SAR datasets. Meanwhile, to update the surface deformation dynamically, the sequential least squares norm is applied based on the small baseline SAR pairs. Finally, the triggering factors and failure modes of two landslides are discussed. For the first case, the Zongling landslide, a mining-induced and with small-gradient deformation landslide, is studied. We firstly retrieve the two dimensional deformation time series in east-west and vertical directions by fusing L-band ALOS/PALSAR-2 C-band Sentinel-1A/B with different tracks from May 2017 to December 2019. Then the spatiotemporal characteristics are uncovered and explained in terms of local topography, stratum and rainfall.
For the second case, the Jianshanying landslide, a mining-induced and with large-gradient deformation landslide, is studied. The two dimensional surface deformation time series from 2017 to 2020 is firstly estimated by combining ascending and descending ALOS/PALSAR-2 imagery based on sequential complex least squares norm. Then, the spatiotemporal characteristics of this landslide is analyzed in terms of local topography, rainfall and underground mining. Finally, we conceptualize the landslide failure mode for the Jianshanying landslide.

Keywords: SAR interferometry, SAR offset tracking, two dimensional deformation, sequential least squares norm, mining-induced landslides

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Definition and First Application of a Probabilistic Warning Model for Rainfall-Induced Landslides

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A methodology for the definition and the performance assessment of a probabilistic warning model for rainfall-induced landslides is proposed and tested in a study area in northern in Italy. To this aim, a database of 513 landslides triggered by rainfall in the period 2010–2018 and satellite-based rainfall data are used. It is worth mentioning that both landslide records and rainfall measurements used for this study are open-access datasets available online. The methodology developed herein can be summarized into several successive steps. First, an automated algorithm is applied for reconstructing the rainfall conditions responsible for the documented landslides in the area of analysis, as well as the rainfall conditions that did not result in any landslide. Then, the conditional probabilities of landslide occurrence are calculated using a two-dimensional Bayesian analysis, differentiating between single landslide events (SLE) and areal landslide events (ALE). Subsequently, several thresholds at different conditional probabilities are evaluated, and different combinations are selected for the activation of two warning levels. For each rainfall combination, the issuing of warning levels is computed by comparing the conditional probability of landslide occurrence with the pre-defined warning level thresholds. Finally, the optimal thresholds combination to be employed, i.e. the one providing the best model performance in terms of success and error indicators, is selected using performance indicators derived from a 3 by 3 contingency table.

Keywords: Landslide, Rainfall, Early warning, Probabilistic analysis, TRMM, Franeitalia

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Establishment of an Integrated Landslide Early Warning and Monitoring System in Populated Areas

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In this work a complete permanent system of timely landslide warning and monitoring in Greece is presented. This system is the first that is designed for a densely residential and mountainous environment. Since 1960's several instability phenomena have been recorded in one of the most traditional settlements in Greece, Metsovo, Region of Epirus. The last major landslide event occured in 2010–2011, and lead to serious damages on the construction and infrastructure within the settlement. The wider geological regime consists of Olonos-Pindos formations with the main appearance of the flysch one of the most critical landslide prone geological formations in Greece. The combinational use of dynamic geotechnical and satellite research methods is discussed as part of this study. In addition, one of the main goals of this investigation is to combine long term monitoring of the parameters connected to the landslide activity with the observation of the landslide kinematics in real time for the planning and realization of a Landslide Early Warning System (LEWS) in Greece.

Keywords: Greece, Real-time, Monitoring, Landslide early warning systems (LEWS)

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An Integrated WebGIS System for Shallow Landslide Hazard Early Warning

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The landslides are considered as one of the most dangerous natural disasters and can cause catastrophic influence on society. Therefore, improving the effectiveness of landslide early warning systems is an urgent requirement. The heavy and/or prolonged rainfall is the main factor that has triggered most of the landslide events. In this study, we propose the integration of a geotechnical model—LS-RAPID and a hydrological model—RRI in a WebGIS system to enhance the accuracy and efficiency of shallow landslide hazard early warning for a small basin in Ha Long City, Vietnam. LS-RAPID model is applied to determine potential landslide hazard areas and RRI model is employed to identify subsurface water levels. The system utilized real-time rainfall data from an automatic weather station and forecasted rainfall data from the GFS server as input data for the RRI model running inside the WebGIS server. By combining simulated results from LS-RAPID and RRI models, the integrated WebGIS system allows predicting the occurrence of landslide hazard in both location and time. With the ability to deliver highly accurate results in a short time, the system can be very helpful for the authorities at all levels in making early landslide hazard warnings that mitigate disasters in mountainous areas.

Keywords: WebGIS, Landslide hazard, Subsurface water, LS-RAPID model, RRI model, IDV

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The Value of Soil Wetness Measurements for Regional Landslide Early Warning Systems

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Current regional landslide Early Warning Systems (LEWS) are typically based on rainfall data and rarely use soil wetness information in spite of the direct relationship between soil wetness and landslide triggering. This is partly due to the limited availability of soil moisture measurement networks and the lack of experience in interpreting such data. Here we show how soil wetness measurements could be exploited for LEWS in a region (or country) with variable topography and soil composition. In particular, we highlight the relevance of (steep) topography for the soil wetness observations and its significance for the interpretation in regard to landslide criticality. To this end, a field study has been set up and is currently running in a landslide-susceptible region of central Switzerland (Emmental) where different soil wetness measurement methods are compared on a flat and a steep meadow site. First results suggest that in spite of noticeable topographical effects on soil drying and wetting the informative value of these data for LEWS is not very different for sloped and flat locations. Based on these findings and a comprehensive analysis of the co-occurrence between soil wetness indicators and shallow landslides across Switzerland we attribute soil wetness measurements a significant value for landslide early warning and encourage a wider incorporation of such data in existing warning systems.

Keywords: Soil moisture, Landslide early warning, Monitoring systems

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Technical Concepts for an Early Warning System for Rainfall Induced Landslides in Informal Settlements

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In developing and emerging countries informal settlements often develop uncontrollably around major cities. In mountainous regions these low-income settlements frequently are situated in areas subject to high landslide risk. An intermediate solution to reduce landslide risk for the inhabitants is the installation of a landslide early warning system. The Infom@Risk project is developing a socially integrated cost-effective landslide early warning system, that specifically addresses the complex spatial and social conditions of informal settlements. This paper discusses some of the technical concepts implemented in the planned early warning system, such as a low-cost LoRa wireless geosensor network, the measuring system “Continuous Shear Monitor” and the methods to be used in data analysis.

Keywords: Landslide early warning system, Geosensor network, Continuous shear monitor, Informal settlement

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Development of Landslide Early Warning System Based on the Satellite-Derived Rainfall Threshold in Indonesia

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Landslide is a common natural disaster occurring in Indonesia during the rainy season from November to February. Attempts have been made to develop an early warning system based on the rainfall derived from satellite observation. It is essential to verify the accuracy level of the rainfall threshold in predicting the occurrence of rainfall, causing landslides and non-landslides to model the lower limit that can be used as an early warning device of the landslides. In this analysis, modelling was carried out with an empirical (intensity—duration/ID) approach using 220 data of rainfall that triggered landslide with satellite-based TRMM in Indonesia territory. The intensity and duration of antecedent rainfall were utilized in rainfall threshold modelling. The rainfall threshold was validated with ROC analysis. This method used seven statistics indices and ROC curve to determine the accuracy rate of the rainfall threshold. The results showed empirical equation $I = 7.83D^{-0.328}$ within the interval time 2–18 days. The results of the analysis of the ROC on the rainfall threshold indicate that the model has a good accuracy rate and can be used in an early warning system of landslide even though it still has a fairly high error rate.

Keywords: Rainfall, TRMM, Threshold, Warning system

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Presenting Some Successful Cases of Regional Landslides Early Warning Systems in China

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The early warning of landslides is crucial for risk management and reduction. However, it is challenging due to the complex nature of landslide behaviours and failure mechanisms. Generally, landslides undergo a certain period of evolution from deformation to failure, and own obvious three-stage deformation phases of creep slope failure. Most of landslides own obvious sudden characteristics, such as rockslide, avalanche, and loess flowslide, which are object of this study. In this paper, an early warning systems for regional landslides and a comprehensive warning model are established, taking into account deformation rate threshold and the improved tangent angle as the early warning parameters. A four-level early warning criterion is proposed. Once the early warning parameters exceeded default thresholds, relevant local authorities and scientists could immediately receive the warning information released by the 3D WebGIS-based platform. It is the 11 times our early warning system successfully forecasted landslides in four different regions since its implementation in 2017. Here, we present three typical cases of successful early warning from these three different regions and timely evacuation in advance. It could take a reference and applicable for other cases globally.

Keywords: Slope monitoring, Early warning system, Real-time, Successful early warning

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Towards an Early Warning System for Instable Slopes in Georgia: The Large Tskneti-Akhaldaba-Landslide

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In June 2015 a flash flood caused by a failure of a natural dam originated by a hazardous debris flow in the Vere valley hit Georgias capital Tbilisi. 23 persons lost their lives and property damages were USD 24 mio. Along with the planning of the reconstruction of two destroyed roads an early warning system shall be developed an implemented for the safe use of the new roads. Therefore, some detailed geological investigations were carried out or are still in progress. This includes detailed engineering-geological mapping, hazard and risk mapping, geophysical measurements as well as planning and execution of exploration boreholes. Furthermore, a setup of a multi-sensor network was designed and is already installed in large parts. First data is providing some evidence of geological, hydrogeological and geotechnical setting in the Tskneti region as well as the occurring deformation. Further monitoring combined with numerical modelling will ultimately lead to the implementation of an early warning system, which is the main goal of this research. This paper tries to give an idea of the general geomorphological and geological setting as well as the occurring processes. It shows, the setup of the monitoring system and how it already delivers safety relevant data.

Keywords: Early warning system, Rock slide, Geomorphology, Monitoring network

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An EWS of Landslide and Slope Failure by MEMS Tilting Sensor Array

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A low-cost and simple method of monitoring rainfall-induced landslides is proposed, with the intention of developing an early-warning system (Uchimura et al. 2015). Surface tilt angles of a slope are monitored using this method, which incorporates a Micro Electro Mechanical Systems (MEMS) tilt sensor and a volumetric water content sensor. In several case studies, the system detected distinct tilt behaviour in the slope in pre-failure stages. Based on these behaviours and a conservative approach, it is proposed that a precaution for slope failure be issued at a tilting rate of 0.01°/h, and warning of slope failure issued at a rate of 0.1°/h. The development of this system can occur at a significantly reduced cost compared with current and comparable monitoring methods, which such as extensometer or borehole inclinometers. Increasing the number of installed sensors, thus increasing the accuracy of the early warning thresholds and predictions, so that given the cost reduction, slopes can be monitored at many points, resulting in detailed observation of slope behaviours, but the potentially large number of monitoring points for each slope does induce a financial restriction. Therefore, the selection of sensor positions needs to be carefully considered for an effective early warning system. These case studies will henceforth be helpful in determining the installation of the sensor array of early warning system.

Keywords: Landslide, Slope failure, Early warning, MEMS tilting sensor

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Standards for the performance assessment of territorial landslide early warning systems

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Landslide early warning systems (LEWS) can be categorized into two groups: territorial and local systems. Territorial landslide early warning systems (Te-LEWS) deal with the occurrence of several landslides in wide areas: at municipal/regional/national scale. The aim of such systems is to forecast the increased probability of landslide occurrence in a given warning zone. The performance evaluation of such systems is often overlooked, and a standardized procedure is still missing. This paper describes a new Excel user-friendly tool for the application of the EDuMaP method, originally proposed by (Calvello and Piciullo 2016). A description of indicators used for the performance evaluation of different Te-LEWS is provided, and the most useful ones have been selected and implemented into the tool. The EDuMaP tool has been used for the performance evaluation of the "SMART" warning model operating in Piemonte region, Italy. The analysis highlights the warning zones with the highest performance and the ones that need threshold refinement. A comparison of the performance of the SMART model with other models operating in different Te-LEWS has also been carried out, highlighting critical issues and positive aspects. Lastly, the SMART performance has been evaluated with both the EDuMaP and a standard 2 × 2 contingency table for comparison purposes. The result highlights that the latter approach can lead to an imprecise and not detailed assessment of the warning model, because it cannot differentiate among the levels of warning and the variable number of landslides that may occur in a time interval.

Keywords: Landslide early warning systems, Rainfall thresholds, Performance, Duration matrix, Statistical indicators, Landslides, Territoria

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Application and verification of a multivariate real-time early warning method for rainfall-induced landslides: implication for evolution of landslide-generated debris flows

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Landslide early warning systems (LEWS) can be categorized into two groups: territorial and local systems. Territorial landslide early warning systems (Te-LEWS) deal with the occurrence of several landslides in wide areas: at municipal/regional/national scale. The aim of such systems is to forecast the increased probability of landslide occurrence in a given warning zone. The performance evaluation of such systems is often overlooked, and a standardized procedure is still missing. This paper describes a new Excel user-friendly tool for the application of the EDuMaP method, originally proposed by (Calvello and Piciullo 2016). A description of indicators used for the performance evaluation of different Te-LEWS is provided, and the most useful ones have been selected and implemented into the tool. The EDuMaP tool has been used for the performance evaluation of the "SMART" warning model operating in Piemonte region, Italy. The analysis highlights the warning zones with the highest performance and the ones that need threshold refinement. A comparison of the performance of the SMART model with other models operating in different Te-LEWS has also been carried out, highlighting critical issues and positive aspects. Lastly, the SMART performance has been evaluated with both the EDuMaP and a standard 2×2 contingency table for comparison purposes. The result highlights that the latter approach can lead to an imprecise and not detailed assessment of the warning model, because it cannot differentiate among the levels of warning and the variable number of landslides that may occur in a time interval.

Keywords: Landslide early warning systems, Rainfall thresholds, Performance, Duration matrix, Statistical indicators, Landslides, Territoria

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LandAware: a new international network on Landslide Early Warning Systems

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Early Warning Systems (EWS) are important non-structural mitigation measures designed and used to avoid and/or minimize the impact posed by hazards on humans. They are often a cost-effective mitigation measure to adopt, and sometimes they are the only suitable option to manage the risk posed by natural hazards (Glade and Nadim 2014). UNISDR (2009) defines EWSs as a “set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to act appropriately and in sufficient time to reduce the possibility of harm or loss.” Landslide Early Warning Systems (LEWS) are specifically designed to monitor, forecast, and analyze conditions that could trigger one or more landslides, at a scale (local, regional, national, global) defined by system managers. The aim is, as for any EWS, saving human lives by issuing timely warnings and/or initiating other appropriate landslide risk mitigation actions. The design, implementation, management, and validation of LEWS are topics that are drawing increasing attention in the scientific and technical literature (e.g., Intrieri et al. 2013; Stähli et al. 2015; Fathani et al. 2016; Sättele et al. 2016; Calvello 2017; Piciullo et al. 2018; Pecoraro et al. 2019; Guzzetti et al. 2020), highlighting several theoretical and practical complexities.

Many recent international initiatives have been highlighting the importance of EWSs for disaster risk reduction purposes. The European Climate Adaptation Platform (http://climate-adapt.eea.europa.eu/) states “Early warning systems can enhance the preparedness of decision-makers and private individuals for climate-related natural hazards and their readiness to harness favourable weather conditions.” Goal no. 13 “Take urgent action to combat climate change and its impacts” of UN Agenda 2030 for sustainable development (http://sustainabledevelopment.un.org/post2015/transformingourworld) includes “Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.” One of the seven global targets of the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR 2015) is “substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030.” Concerning landslides, the important role played by LEWSs has been highlighted by the ISDR-ICL Sendai Partnership 2015–2025 (https://wlf5.iplhq.org/isdr-icl-sendai-partnerships-2015-2025/) and, more recently, by the Kyoto 2020 Commitment for Global Promotion of Understanding and Reducing Landslide Disaster Risk KLC2020 (Sassa 2019; Sassa 2020), in particular within the priority action no. 1 “People centered early warning,” and the priority action no. 3 “Technologies for monitoring, testing & early warning.”

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The Development of TDR-integrated landslide Early Warning System

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The automatic monitoring systems are gradually concerned for disaster prevention in Taiwan recently. Time Domain Reflectometry (TDR) is one of the valuable techniques for landslide monitoring. It is a passive-based monitoring method that provides multi-functions, such as water level, bridge scour, landslide, and suspended sediment concentration (SSC), based on a single TDR device via a multiplexer. In addition, the Real-Time Kinematic (RTK) based single-frequency GNSS sensor can provide the center-meter resolution capability for the surface displacement and direction of the landslide. Thus, this study tends to integrate the low-cost monitoring device with single-frequency GNSS and tri-axis accelerometer for surface displacement monitoring, and the TDR for sub-surface monitoring. Consequently, the proposed monitoring system can provide diverse monitoring data at the field-side and have three redundant thresholds for early warning of the landslide. Furthermore, the Open Geospatial Consortium (OGC) provided SensorThings API, a standardized definition for the sensor description, observed position, and observed feature. Because it is based on JSON and Restful protocols, the content of SensorThings API is lighter and more flexible than Sensor Observation Service (SOS). Besides, it realizes data interoperable way by providing web service. Thus, this study further improved the middleware between SOS and the existing TDR monitoring platform by providing TDR heterogeneity data interoperability via SensorThings API.

Keywords: Time Domain Reflectometry (TDR), landslide, Early Warning System

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What Hydrological Information Should We Include in Landslide Hazard Assessment and Early Warning Systems?

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Landslides are irregularly occurring natural hazard causing extensive direct and indirect damage, economic disruption and loss of life and affecting the most vulnerable groups in society above average. Naturally induced landslides are characteristically triggered by pore pressure rise due to earthquakes and precipitation events. Although (co-)seismic landslides are often disastrous, the assessment of landslides and their Early Warning Systems (EWS) merely focus on precipitation induced landslides on a regional scale.

The precipitation triggered landslides are geomorphological processes which are intertwined with the hydrological system. On a given slope, it is the highly non-linear interplay between precipitation and snow melt infiltration, water storage at various depths and dynamic subsurface drainage that determines whether a slope destabilizes or not. This dynamic hydrology of filling-storing-draining, in combination with the geotechnical boundary conditions of the slope (slope geometry and material strength parameters) steers the timing of the potential landslide initiation.

Historically the focus on regional landslide EWS has been on shallow landslides and debris flows using statistical (empirical) methods. The shallow landslides are known to be strongly linked to major precipitation or snow melt events. In such cases, the time scale of the landslide trigger is very close to the time scale of the meteorological event. This has led to the successful development of meteorological thresholds, in various forms, to predict landslide initiation at the regional scale. Concurrently, it has been recognized that not every major precipitation event triggers a landslide highlighting the importance of pre-event conditions. These so-called antecedent wetness conditions, or hydrological causes, essentially prolong the time scale of setting a slope to fail. Pragmatically, this could be incorporated in the regional landslide threshold by defining seasonal meteorological thresholds or approximated using antecedent precipitation information. Still, the meteorological thresholds suffer from too high rates of false alarms reducing the systems reliability.

Defining hydrometeorological thresholds to incorporate both cause (long time scale) and trigger (short-time

scale) has been cumbersome due to the limited access of measured hydrological information, i.e. time series of stored subsurface water. However, in recent time, the data availability has grown exponentially, especially remotely sensed information but also in-situ data, accelerating the development of hydrometeorological thresholds for regional landslide EWS. The scientific opening that is unfolding is that it is not the absolute water storage that is most essential but the relative, so time series. This can be time series of in-situ measured soil water content or regional groundwater levels, but also remotely assessed and partly modelled soil water storage. Interestingly, regional rainfall runoff models can give valuable time series on antecedent subsurface hydrological conditions constraining landslide initiation thresholds. This not only improves EWS thresholds for shallow landslides and debris flows, but in combination with e.g. remotely sensed surface displacement, allows developing regional EWS for deep-seated, reactivating slope deformations as well. These thresholds can be empirically of using deep-learning mathematical techniques. Results of using hydrometeorological thresholds are promising and indicate more stable, reliable, landslide EWS.

Keywords: Landslide hydrology, Early Warning Systems; Hydrometeorological thresholds

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Global Standard for Landslide Early Warning System

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Landslides occur in different topographic and geologic settings and cause great socio-economic losses. This research describes the current progress of a mitigation effort in terms of the implementation of a monitoring and warning system against landslide disasters. An adaptive and sustained landslide early warning system (LEWS) has been implemented in several prone areas in Indonesia and Myanmar, including the establishment of collaboration among the authorities, universities, private sectors, and communities. In order to guarantee the effectiveness of LEWS, the developed system should be simple to operate and appropriately installed in the most suitable sites, incorporating technical and social approaches. The implementation of early warning systems is in line with the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030. One of the four priorities of the Sendai Framework for Action emphasizes the improvement of preparedness in response to a disaster by carrying out a simple, low-cost early warning system and improving its dissemination. A new standard for community-based landslide early warning systems has been promoted to the International Organization for Standardization (ISO) by Universitas Gadjah Mada, in corporation with the Indonesian Standardization Agency (BSN) and the National Disaster Management Agency (BNPB). This standard has been published as ISO 22327:2018. The standard serves to empower individuals and communities who are vulnerable to landslides to act in sufficient time in appropriate ways to reduce the possibility of injuries, loss of life and damage to property and the environment. Recently, a global standard for multi-disasters early warning system has been published as ISO 22328-1:2020. Further action is to promote the other EWS standards for flood, tsunami, volcanic eruption, and other disasters.

Keywords: landslide vulnerability, multi-hazards, community-based, socio-technical approach

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Need for Information Disclosure of Landslide Early Warning Systems

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Slope disasters such as landslides often occur in rural areas, and the same is true for expressways in Japan.
After the landslide occurs, we vary surveys and field observations using measuring instruments to analyze the mechanism and determine the effectiveness of countermeasures. We also construct and operate the landslide early warning system to ensure the safety of local residents and public infrastructures. These are paid by the public sector, including the national and local governments.
The landslide early warning system is an automated system that monitors various types of data from measuring instruments in real time and issues warnings when thresholds are exceeded, and is managed and operated by the administrator (the expressway administrator for disasters on expressway project land).
Since the system is managed and operated by ID and PASSWORD, the stakeholders such us the local residents and users of the public infrastructures (the general nation) cannot access information such as various measurement data.
However, There are many cases where the functions of the early warning system have been reinforced, such as when local residents, rather than management engineers, are able to discover in detail and at an early stage the mechanism of landslide occurrence and peculiar deformation that cannot be grasped by monitoring. By opening the measurement data, active involvement from local residents can be expected, and it is also guaranteed that a better the landslide early warning system can be operated.
In recent years, an increasing number of local governments have been using disaster information from social networking services (SNS) sent out by local residents as a tool for understanding the detailed situation. Rather than keeping disaster information only in the hands of public sector, proactive disclosure and sharing of various information with local residents will lead to a more effective landslide early warning system.

Keywords: information disclosure, sharing and collaboration with local residents

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Regional Approaches in Forecasting Rainfall-Induced Landslides

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Hydrogeological hazards now exacerbated by the ongoing climate change pose serious challenges for the safety of the population worldwide. Among the others, the landslide risk can be mitigated by setting up efficient and reliable early warning systems. To date, rainfall thresholds are one of the most used tools to forecast the possible occurrence of rainfall-induced failures in large regions. In Italy a dense rain gauge network with hourly or sub-hourly temporal resolution is available. However, in some developing countries, where ground measurements are still absent or are available at coarser (daily) temporal resolution, satellite-based rainfall estimates could be a vital alternative. For this purpose, the reliability of rainfall thresholds defined using both satellite (SB) and ground-based (GB) data and with hourly or daily temporal resolution is assessed in a study area comprising the Abruzzo, Marche and Umbria regions (AMU), central Italy. The comparison between the performance of the different products allows to test their capability in eventually can GB rainfall measurements are gathered at hourly time steps (OBS-H) from a national network and aggregated on a daily scale (OBS-D); SB rainfall estimates are retrieved from the Climate Prediction Center Morphing Technique (CMORPH, hourly resolution), and from the SM2RASC product, based on the application of SM2RAIN algorithm to ASCAT (Advanced SCATterometer) soil moisture product (daily resolution). Results show that thresholds defined with GB rainfall data perform better than those obtained using SB estimates regardless of the temporal resolution. CMORPH and SM2RASC thresholds are still able to predict landslide occurrence although with a high number of false predictions.

Keywords: Landslides, Rainfall thresholds, Rain gauges, Satellites

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Seven Years of Landslide Forecasting in Norway—Strengths and Limitations

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The experiences acquired by the Norwegian Landslide Forecasting and Warning Service during the first 7 years of operation are herein presented. We summarize the warnings sent in the period 2013–2019 and we present the evaluation of the warning performance and discuss some of the main strengths and limitations of the service. In our opinion, of imperative importance to the success is: A national political will, the assignation of the landslide service to an existing well consolidated flood warning service and a strong collaboration across public agencies and a multidisciplinary approach. The existence of a national landslide database and of an operational distributed hydrological model, was essential for the rapid establishment of relationships between landslides events and hydro-meteorological conditions. A strong development of IT-tools and expansion of the meteorological and hydrological network was also crucial. Yet there are still several challenges and limitations, such as an insufficient process-understanding of rainfall- and snowmelt-induced landslides. The verification of landslide occurrence is also a difficult and tedious task. Finally, another challenging task is the prediction of landslides triggered by local intense rainshowers during summer, and rapid snowmelt events during winter, due to the limitations that exist in the models and thresholds currently in use.

Keywords: Rainfall- and snowmelt-induced landslides, Forecasting and warning services, Early warning systems, Debris avalanches, Debris flows

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Probabilistic modelling of uncertainties in physically based landslide susceptibility assessment

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Physically based model has been widely used because of their higher predictive capability and its capacity to reproduce the physical process governing landslide occurrence. However, physically based model requires sufficient and accurate information of input parameters to calculate an accurate landslide susceptibility. Therefore, the quality and quantity of information for the input parameters have been the main concerns in physically based model, especially for regional area. This is because such data have imperfections or variable quality. In addition, the input parameters used in the physically based approach should be obtained from wide study area, likely with limited sampling. Consequently, uncertainties are inevitably involved in the physically based model analysis. Uncertainty in model parameter evaluation has been recognized as an important cause of mismatch between simulated and observed distributions of landslide occurrence. Therefore, when performing susceptibility analysis with physically based models, uncertainties in ground conditions must be taken into account. In this study, two different analyses (Monte Carlo simulation and fuzzy point estimate method) were used to deal properly with uncertainties involved in physically based model analysis. The analysis methods were used to evaluate susceptibility to rainfall induced shallow landslide for a regional study area, which has experienced a large amount of landslide occurrence. Then the analysis results were compared with landslide inventory to evaluate the performance of the approaches.

Keywords: physically based model, uncertainty, Monte Carlo simulation, fuzzy point estimate method, landslide susceptibility

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Characterization of Hillslope Deposits for Physically-Based Landslide Forecasting Models

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Physically-based models employed for landslide forecasting are extremely sensitive to the use of geological information and a standard, universally accepted method to input maps containing information of geological interest into the models still has never been established. In this study, we used the information contained in a geo-database aimed to characterize the geotechnical and hydrological parameters of the hillslopes deposits in Tuscany, to find out how to organize and group the measurements to spatially create classes that mirror the distribution of the various types of bedrock lithology. Despite the deposits analysed are mainly consisting of well sorted silty sands, statistical analyses carried out on geotechnical and hydrological parameters highlighted that it is not possible to define a typical range of values with relation to the main mapped lithologies, because soil characteristics are not simply dependent on the bedrock typology from which the deposits originated. Instead, the analysis of the relationship of soil parameters with morphometric parameters (slope angle, profile curvature, planar curvature) shows that the highest correlation between the soil grain size class type (USCS classification) and morphometric attributes is with slope curvature, both profile and planar.

Keywords: Soil geotechnics, Physically based modelling, Landslides, Tuscany

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Landslide precipitation thresholds in Rwanda

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Regional empirical-statistical thresholds indicating the precipitation conditions initiating landslides are of crucial importance for landslide early warning system development. The objectives of this research were to use landslide and precipitation data in an empirical-statistical approach to (1) identify precipitation-related variables with the highest explanatory power for landslide occurrence and (2) define both trigger and trigger-cause based thresholds for landslides in Rwanda, Central-East Africa. Receiver operating characteristics (ROC) and area under the curve (AUC) metrics were used to test the suitability of a suite of precipitation-related explanatory variables. A Bayesian probabilistic approach, maximum true skill statistics and the minimum radial distance were used to determine the most informative threshold levels above which landslide are high likely to occur. The results indicated that the event precipitation volumes E, cumulative 1-day rainfall (RD1) that coincide with the day of landslide occurrence and 10-day antecedent precipitation are variables with the highest discriminatory power to distinguish landslide from no landslide conditions. The highest landslide prediction capability in terms of true positive alarms was obtained from single rainfall variables based on trigger-based thresholds. However, that predictive capability was constrained by the high rate of false positive alarms and thus the elevated probability to neglect the contribution of additional causal factors that lead to the occurrence of landslides and which can partly be accounted for by the antecedent precipitation indices. Further combination of different variables into trigger-cause pairs and the use of suitable thresholds in bilinear format improved the prediction capacity of the real trigger-based thresholds.

Keywords: Landslide, Precipitation thresholds, Trigger-based thresholds, Trigger-cause-based thresholds

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Methodology for developing a preliminary hydrological threshold for rainfall□induced landslides in Kuala Lumpur city, Malaysia

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Regional empirical-statistical thresholds indicating the precipitation conditions initiating landslides are of crucial importance for landslide early warning system development. The objectives of this research were to use landslide and precipitation data in an empirical-statistical approach to (1) identify precipitation-related variables with the highest explanatory power for landslide occurrence and (2) define both trigger and trigger-cause based thresholds for landslides in Rwanda, Central-East Africa. Receiver operating characteristics (ROC) and area under the curve (AUC) metrics were used to test the suitability of a suite of precipitation-related explanatory variables. A Bayesian probabilistic approach, maximum true skill statistics and the minimum radial distance were used to determine the most informative threshold levels above which landslide are high likely to occur. The results indicated that the event precipitation volumes E, cumulative 1-day rainfall (RD1) that coincide with the day of landslide occurrence and 10-day antecedent precipitation are variables with the highest discriminatory power to distinguish landslide from no landslide conditions. The highest landslide prediction capability in terms of true positive alarms was obtained from single rainfall variables based on trigger-based thresholds. However, that predictive capability was constrained by the high rate of false positive alarms and thus the elevated probability to neglect the contribution of additional causal factors that lead to the occurrence of landslides and which can partly be accounted for by the antecedent precipitation indices. Further combination of different variables into trigger-cause pairs and the use of suitable thresholds in bilinear format improved the prediction capacity of the real trigger-based thresholds.

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Development of a Rainfall-Induced Landslide Forecast Tool for New Zealand

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Landslides kill 2–3 people per annum in New Zealand and cost the country on average NZ$200–300 million dollars per annum. The majority of landslides (90%) in New Zealand are triggered by rainfall and often involve thousands to tens of thousands of landslides being triggered by a single event that can extend over areas up to 20,000 km2. Steep hillslopes (>26°) occupy over 60% of the New Zealand landmass, and much of this (5%) is classified as highly erodible land at risk of severe mass-movement erosion. To reduce the risk associated with landslides it is important to be able to predict where and when they might occur. To this end we are developing a landslide forecast tool for the National GeoHazards Monitoring Centre that will be used to forecast and warn the public of possible damaging rainfall-induced landslide events. We used logistic regression to investigate the influence of landslide triggering variables on landslide occurrence on a dataset of 20 recent and historic landslide-triggering rainfall events. From this we developed relationships to predict the probable spatial distribution of landslides triggered from a given forecast rainfall event.

Keywords: Rainfall induced landslide, Forecast tool, New Zealand, Threshold, Landslide modelling

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Influence of Intervals Measuring Surface Displacement on Time Prediction of Slope Failure Using Fukuzono Method

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Time-prediction methods based on monitoring the displacement of a slope are effective for the prevention of sediment-related disasters. Several models have been proposed to predict the failure time of a slope based on the creep theory of soil, which describes the accelerating surface displacements that precede slope failure. Fukuzono's method has been widely adopted in practice. This method can only be applied to the period when the surface displacement accelerates. However, the observed surface displacement appears to increase monotonically, slightly repeating the increase and decrease. These results decrease the accuracy of the predicted failure time. Thinning out the observed data is effective for minimising the influence of fluctuations. In this study, we predicted the failure time of a sandy model slope under artificial rainfall using four methods based on Fukuzono's model, compared the prediction accuracy of each method and examined the influence of measurement intervals on the predicted failure time using extracted data at different measurement intervals. The results showed that the variation of the extracted data group decreases and the prediction accuracy of the failure time improves if the measurement interval increases. Moreover, when the failure time of a slope is predicted using statistical methods, the accuracy of the prediction is further improved.

Keywords: Monitoring, Slope failure, Surface displacement, Time prediction, Fukuzono's model, Measurement interval, Prediction accuracy

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Velocity and Acceleration of Surface Displacement in Sandy Model Slope with Various Slope Conditions

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Measurement of surface displacement was implemented in three model slope test cases under constant intensity of artificial rainfall with different initial water content or slope inclination. The aim was to examine the relationship between velocity and acceleration of the increase in the surface displacement, which is the basis for predicting the failure time of a slope (Fukuzono T (1985) A New Method for Predicting the Failure Time of a Slope. In Proceedings of the IVth International Conference and Field Workshop on Landslides, Tokyo, Japan, pp 145–150.). The velocity and acceleration were derived from actual measured surface displacements. The relationship between the velocity and acceleration of the increase in the surface displacement was unique at different locations on the slope and with different pore pressure loading mechanisms (under unsaturated conditions or increased groundwater levels). The relationship was also unique under different slope inclination. This suggests the possibility of deriving the relationship by indoor shear tests with the same soil of actual slopes before monitoring of displacement on the slope, for predicting the failure time of the slope.

Keywords: Monitoring, Surface displacement, Model slope, Slope angle, Water content

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Comparison of Moving-Average, Lazy, and Information Gain Methods for Predicting Weekly Slope-Movements: A Case-Study in Chamoli, India

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Landslide incidence is common in hilly areas. In particular, Tangni in Uttrakhand state between Pipalkoti and Joshimath has experienced a number of landslide incidents in the recent past. Thus, it is important to forecast slope-movements and associated landslide events in advance of their occurrence to avoid the associated risk. A recent approach to predicting slope-movements is by using machine-learning techniques. In machine-learning literature, moving-average methods (Seasonal Autoregressive Integrated Moving Average (SARIMA) model and Autoregressive (AR) model), Lazy methods (Instance-based-k (IBk) and Locally Weighted Learning (LWL)) and information-gain methods (REPTree and M5P) have been proposed. However, a comparison of these methods for real-world slope-movements has not been explored. The primary objective of this paper is to compare SARIMA, AR, LWL, IBk, REPTree and M5P methods in their ability to predict soil-movements recorded at the Tangni landslide in Chamoli, India. Time-series data about slope-movements from five-sensors placed on the Tangni landslide hill were collected daily over a 78-week period from July 2012 to July 2014. Different model parameters were calibrated to the training data (first 62-weeks) and then made to forecast the test data (the last 16-weeks). Results revealed that the moving-average models (SARIMA and AR) performed better compared to the lazy and information-gain methods during both training and test. Specifically, the SARIMA model possessed the smallest error compared to other models in test data. We discuss the implications of using moving-average methods in predicting slope-movements at real-world landslide

locations.

Keywords: SARIMA, Instance-based, Locally weighted learning, M5P, REPTree, Tangni landslide

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New Insights into the Spatiotemporal Precursory Failure Dynamics of the 2017 Xinmo Landslide and Its Surrounds

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Sentinel-1 data on the kinematics of the 2017 Xinmo landslide and its surrounds are studied to understand the precursory failure dynamics of a large region with a historical predisposition to landslides. We perform a systematic spatiotemporal analysis over a period of two years to identify high-risk regions and discriminate between their precursory failure dynamics. We found the 2017 Xinmo landslide source to exhibit a unique kinematic signature which can be distinguished, almost a year in advance, from those of other sites of instabilities. Findings pave the way for the development of a new framework that exploits these differences in the dynamics of motions to accurately predict the location and size of a catastrophic landslide, and distinguish it from false alarms and/or smaller land slips early in the pre-failure regime.

Keywords: Sentinel-1, Kinematics, Clustering, Precursory failure dynamics, Spatiotemporal

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A comparative study of random forests and multiple linear regression in the prediction of landslide velocity

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The monitoring of landslides has a practical application for the prevention of hazards, especially in the case of large deep-seated landslides. Monitoring data are necessary to understand the relationships between movement and triggers, to predict movement, and to establish an early warning system. This paper compares two phenomenological models for the prediction of the movement of the Kostanjek landslide, the largest landslide in the Republic of Croatia. The prediction models are based on a 4-year monitoring data series of landslide movement, groundwater level, and precipitation. The presented models for landslide movement prediction are divided into the model for the prediction of groundwater level from precipitation data and the model for the prediction of landslide velocity from groundwater level data. The statistical techniques used for prediction are multiple linear regression and random forests. For the prediction of groundwater level, 75 variables calculated from precipitation and evapotranspiration data were used, while for the prediction of landslide movement, 10 variables calculated from groundwater level data were used. The prediction results were mutually compared by k-fold cross-validation. The root mean square error analyses of k-fold cross-validation showed that the results obtained from random forests are just slightly better than those from multiple linear regression, in both, the groundwater level and the landslide velocity models, proofing that multiple linear regression has a potential for prediction of landslide movement.

Keywords: Landslide monitoring, Groundwater level prediction, Landslide movement prediction, Random Forests, Multiple linear regression

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Machine Learning: Potential for Deep‐Seated Landslide Nowcasting

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Nowcasting and early warning systems for landslide hazards have been implemented mostly at the slope or catchment scale. These systems are often difficult to implement at regional scale or in remote areas. Machine Learning and satellite remote sensing products offer new opportunities for both local and regional monitoring and nowcasting of deep‐seated landslide deformation and associated processes. Here, we list the key variables of the landslide process and link them to satellite remote sensing products, as well as the available machine learning algorithms. Furthermore, we discuss both the challenges for the integration in an early warning system, and the risks and opportunities arising from the limited physical constraints in machine learning. This shows that data products and algorithms are available, and that machine learning technology is ready to be tested for regional landslide nowcasting applications.

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Prediction of Failure Time based on Velocity and Acceleration of Surface Displacement in Sandy Model

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Measurement of surface displacement (SD) plays a major role for predicting failure time of landslides triggered by rainfall and it was the basis, which can be used to predict the failure time of a slope (Fukuzono, 1985). To study this concept, small scaled-indoor slope models of sandy materials were tested under simulated rainfall with constant discharge to observe the behavior of SD. Five cases of experiment were conducted by changing the conditions of the model, such as rainfall intensity, slope inclination, and void ratio. Then, the relationship between velocity and acceleration of SD were examined for each case. Accordingly, failure time was predicted using two different methods considering the behavior of the slope just before the failure. First method is the original method of Fukuzon's inverse-velocity (INV method), which used the inverse number of velocity and the increment of ones at two different times. Second one is a new method based on velocity and acceleration (VAA method), carried out using the logarithmic acceleration and logarithmic velocity values for linear regression analysis.

The relationship between velocity and acceleration of SD shows unique behavior under different stresses and stress loading conditions of the same soil. This fact shows that the early warning system for rainfall induced landslides can be well established by using the relationship of velocity and acceleration of SD.

The analysis results reveal that, by VAA method it can acquire more accurate failure time than the INV method because of the results obtained from INV method were greatly affected by the individual velocity values, while the variation of the velocity gave less influence on the relationship between the velocity and acceleration method.

Keywords: Surface displacement, prediction of failure time of rainfall induced landslide, Fukuzono's inverse-velocity method, velocity and acceleration based least square method

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Theme 4 Testing, Modeling and Risk Assessment

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Application of Magnetic Tracking System in Laboratory-Scale Rock Avalanche Model Tests

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Many researchers have been investigating the mechanism of rock avalanches in the laboratory using flume tests, where dry rigid blocks are released on an inclined chute and the motion of the blocks are monitored using video cameras supplemented by image-based processing technique. In this paper, a recently developed sensing technique, which consists of permanent magnets as trackers and magne-tometers as receivers, is used to examine the behaviour of the blocks as they propagate downslope. For this purpose, a permanent magnet, whose density, shape and surface characteristics are adjusted to be similar to the other blocks, is incorporated into the pile of blocks at specific locations. Since a permanent magnet generates static magnetic field, its flux density is detected by the magnetometers positioned appropriately adjacent to the flume. From the readings obtained, the magnet's location and orientation at any given time is determined using an optimisation algorithm. For various combinations of pile height, block volume and surface inclination, the displacements and orientations of the permanent magnet, representing one of the blocks undergoing movement, are monitored from which kinematic quantities are captured to highlight the behaviour of the blocks as they flow down the chute. For comparison purposes, the movement of the blocks were also monitored by video camera. The results obtained using the magnetic tracking system coincide very well with those monitored using image analysis from video camera. These highlight the capability of the proposed magnetic tracking system in capturing key kinematic quantities during the downslope motion of the blocks, including translations and rotations.

Keywords: Rock avalanche, laboratory experiment, magnetic tracking system

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A Simple Physically-Based Distributed Translational Landslide Model

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Detailed landslide susceptibility mapping (LSM) requires a skillful landslide model. Considering that translational landslide is the most type of landslides occurred in the world, a well-behaved translational model is sought. This study presents a simple physically-based distributed translational landslide model. In this model, the incident of landslide is detected from the value of factor of safety (FoS) which computed based on Mohr-Coulomb failure criterion. In here, FoS is calculated as the ratio of shear strength and shear stress. The lower the FoS, the higher the possibility of a landslide to occur. The model input data consists of soil cohesion c (kg/cm2), soil specific weight γ (g/cm3), depth of surface of rupture (m), slope of surface of rupture β (degree) and friction angle φ (degree). Application of the model was performed in Sirampog and Kandang Serang, two subdistricts in Western Central Java that underwent the most frequent landslides in the region. Model validation was conducted by comparing the values of FoS of unsaturated and saturated soils and identifying FoS in the sites where landslide events recorded. Several goodness of fit indices to measure the model performance are accuracy (ACC), success index (SI), average index (AI) and distance to perfect classification (D2PC). Under unsaturated condition, the result shows that the number of grids having FoS less than 1 are 0% and 0.6% for Sirampog and Kandang Serang respectively, indicating no landslide occurrence. When the soil gets saturated, 17.6% and 36% of area have FoS less than 1 for Sirampog and Kandang Serang respectively. This shows that the landslide occurred in this region is rainfall-induced landslide. Overall, the model shows a good performance with ACC, SI, AI, D2PC values are 0.82, 0.58, 0.54, 0 and 0.64, 0.49, 0.49, 0 for Sirampog and Kandang Serang respectively.

Keywords: translation landslide, physical model, factor of safety, landslide susceptibility map

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Centrifuge Modelling of Slope Failure Due to Groundwater during Excavation

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In order to prevent occupational accidents during slope excavation work, it is important to include slope stability in all aspects of construction design. In slope excavation work, the two major factors are the excavation height and the gradient, both of which are prescribed by some guidelines and laws. However, accidents often occur during slope excavation work, even with the required safety gradient, because existing guidelines fail to consider the effects of water. In this study, the stability of a slope with rising groundwater was examined for different excavation slopes. The results show that the slope was stable in the absence of water, but it collapsed when the groundwater rose. We also propose a method for predicting landslides using slope movement measurements. The method uses the standard deviation from past measured values to detect data abnormalities on current measurements. Predictions obtained by this method were classified under advisory, warning, or emergency warning based on the deviation rate between the moving average and standard deviation of past data. It was observed that slope failure can be reliably predicted using this method.

Keywords: Slope failure, Groundwater, Centrifuge modelling, Excavation work, Prediction of collapse

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Experimental Studies on the Effect of Vegetation Density to Change Underground Seepage Rate and Stability of Slopes

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Vegetation plays in an important role in the amount of surface runoff or infiltration after a rainfall event, specifically on slopes. High infiltration or seepage reduce shearing resistance of soil through the reduction in matric suction of partially saturated slopes, ultimately causing slope instability. On the other hand, low infiltration increases surface runoff and velocity of surface flow, which ultimately causes soil erosion. In this study, three different slopes were prepared using fine sand, specifically at the same dry density and geometry, but with three different vegetation cover densities. The slopes were instrumented with tensiometers at different depths. The slopes were subjected to a rainfall event with an intensity of 30 mm/h and advancement of the wetting front of the seepage water and soil matric suction were recorded with time duration after the rainfall. The experimental result shows that up to certain threshold vegetation cover density, amount of surface flow increases causing soil erosion. For the vegetation density above that threshold, vegetation covers intercept the rainwater and the intercepted water is gradually passed to ground. Moreover, vegetation cover will ease the flow of surface runoff water. These actions, on the other hand, increase the seepage velocity. As such, less dense vegetation cover triggers more rainfall induced soil erosion and denser vegetation cover increases the instability associated with rotational or translational slides.

Keywords: Rainfall induced landslides, vegetation cover, soil erosion, suction, translational slides

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Laboratory Simulations of Submarine Landslide Failure Mechanisms

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Submarine slopes are subject to a variety of failure styles, ranging from large, long runout landslides to both shallow and deep-seated landslides with limited down-slope displacements. The upper continental slope off the east coast of the North Island of New Zealand, hosts numerous landslides which vary in size, volume and runout characteristics. The region is located on an active subduction zone experiencing regular earthquakes and is close to the base of gas hydrate stability. Consequently, both seismic loading during earthquakes and over-pressure in the slope from the migration of free gas may be plausible movement mechanisms for both shallow and deep landslides but their potential behaviour during earthquakes and in response to elevated pore fluid pressures remains poorly constrained. We conducted a series of experiments in a Dynamic Back Pressure Shearbox on sediments recovered from the Hikurangi subduction margin to simulate the complex stress conditions in submarine landslides and explore their potential movement mechanisms in response to elevated pore fluid pressures and seismic loading. Our experiments successfully simulated a range of landslide behaviour that advances our understanding of the variety of landslide types observed on active continental margins. The movement behaviours observed provide credible mechanisms to explain how some submarine landslides may be subject to episodic movement without undergoing catastrophic failure as a result of over pressuring by free gas and seismic loading during earthquakes.

Keywords: Submarine landslides, Movement mechanisms, Advanced shear testing

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Basal Stresses of Debris Flow in Instrumented Flume

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The solid-liquid coupling makes the debris flow distinct from other geophysical fluids such as debris avalanche and debris flood. Due to the complexity of the solid-liquid interaction of debris flow, current research of debris-flow mobility mainly focuses on dense debris flows (volumetric solid concentration ~ 0.6). However, few study has focuses on the physical processes in the transition from dense to dilute debris flows (solid concentration ~ 0.4). The objectives of this study are to explore the effects of change in solid concentration on basal stresses and debris-flow mobility. Taking the debris-flow solid concentration and fluid viscosity as variables, a series of well-instrumented flume experiments are carried out. Experimental results show that the high mobility of debris flow is closely related to the state of liquefaction. Based on the calculated and measured shear stresses, it is apparent that the shear resistance of dense debris flow is dominated by the friction between particles, while the shear resistance of dilute debris flow partly comes from viscous drag. The rheological model that characterizes the shear resistance of dense debris flows is insufficient to describe the rheological behavior of dilute flows. Models considering the interaction between particles (friction and collision) and the viscosity of fluid phase are warranted.

Keywords: debris flow, basal stress, mobility, pore fluid pressure, Coulomb friction

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Landslide Growth: Collisions and Contractile Skins

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The growth of the momentum of a landslide and its destructive potential depends on the rate of entrainment of the soil bed along the flow path. The bed fails when the applied external stresses exceed the strength of the bed material. The bulk of existing literature assumes that the external stresses is predominantly frictional in nature and that the bed strength can be comprehensively characterized by assuming saturated soil mechanics. However, field observations hint at the important role of collisional stresses in driving the process of soil bed entrainment. Furthermore, soil beds are rarely saturated when landslides occur. This means that the soil strength is strongly influenced by capillary stresses or matric suction in the soil. To consider both the effects of collisions generated in the flow and unsaturated bed strength, a new scaling parameter $N_{\text{collision}}$ is proposed. Physical experiments were conducted using a flume that is 2 m in length to model the entrainment of unsaturated soil beds by collision-dominated gravel flows. The experimental results were used to evaluate the proposed scaling parameter $N_{\text{collision}}$ and reveal a positive and linear correlation between the entrainment rate and the $N_{\text{collision}}$. Experimental results show that without considering collisions, entrainment volumes would be underestimated. More importantly, without considering unsaturated soil mechanics, entrainment volumes would be underestimated at low bed volumetric water contents (~ 10%). Taken together, findings hint at the significance of the effects of soil-atmospheric interaction on landslide growth and the need for novel analytical and numerical methods that can simulate the effects of collisions generated at the flow-bed interface.

Keywords: landslide, entrainment, collisional stresses, capillary stresses, physical modelling

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Innovative Use of Thermo-Active Pile Row in Unsaturated Soil Slopes

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Installing a row of discretely-spaced piles at the mid-height of slope has been a common method for slope stabilisation. An innovative approach is proposed to modify the reinforced concrete (RC) piles to be the thermo-active piles for solar energy storage and geothermal energy extraction. Solar heat can be collected in heat absorbing fluids circulated in pipes underneath the pavement, and the collected heat can be pumped to the piles for storage. Shallow geothermal energy may be extracted by the energy piles for road surface de-icing. This innovation has brought up some new and challenging research questions. Pile heating and cooling induce phase change between water liquid and vapour and liquid-vapour-heat transport in unsaturated soils, both of which affect the thermohydromechanical soil properties and soil-pile interaction. This presentation will illustrate new technological and equipment development and their uses to study non-isothermal unsaturated soil behaviour and soil-pile interaction, including (1) *Temperature-controllable soil column apparatus*, to measure temperature-dependent soil water retention curve and permeability function; (2) *Small-scale model RC for centrifuge testing*, which is a thermally-enhanced plaster-based material that can realistically reproduce the thermomechanical properties of RC at prototype; (3) *New and robust centrifuge-mounted heating-cooling system*, for circulating water of different temperature from/into multiple model RC energy piles during centrifuge flight; and (4) *New large-scale direct shear box*, for measuring the shearing behaviour of reinforced soils in centrifuge. Realistic stress and suction regimes can be recreated inflight, which is highly suitable for revealing underlying mechanisms of soil-structure interaction and stress transfer upon translational soil slip under realistic stress conditions that would not otherwise be possible in lab condition. The presentation will provide new data and understandings of how pile heating/cooling would affect the soil moisture transport mechanism and its effects on heat transfer efficiency in terms of energy storage/extraction and the thermomechanical soil-energy pile interaction upon soil translational movement.

Keywords: Thermo-active pile row, Slope stabilisation, Unsaturated Soils, Centrifuge modelling

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Numerical Modelling for Slope Stabilizations in Modern Geotechnical Practice

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Until recently geomechanical numerical modelling of slopes and landslides was mostly performed for academic research purposes and for the engineering design of high earth embankments. In recent years, the use of Finite Element and Finite Difference modelling packages has become commonplace, and allowed complex analyses to be performed by practicing engineers in firms of all sizes. Although these software packages have widespread use in geotechnical engineering, there are two applications that are particularly well-suited for slope stability and landslide modelling. The first one, is the analysis of slope repairs and landslide stabilizations that combine multiple structural elements (e.g., several rows of piles with tiebacks). The second is the seismic performance of slopes, e.g., designs where dynamic amplification and permanent seismic displacements are a major concern. This paper presents recent advancements for the practical design of slopes, the advantages for designers of performing geomechanical modelling, and provides guidelines for their use in modern slope engineering and landslide stabilization practice.

Keywords: Landslide, Slope Stability, Geomechanical Modelling, Finite Element Method, Finite Difference Method, Stabilizing Piles, Tieback, Landslide Stabilization, Seismic Slope Movement

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A Coupled Discrete Element and Depth-Averaged Model for Flow-Like Landslide Simulations

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Flow-like landslides commonly happen in mountainous areas and may cause economic and human life losses in the impacted areas. Computer modelling has become an effective tool for landslide risk assessment and reduction. Models based on discrete element method (DEM) have been widely used for landslide prediction; however, this method is computationally too demanding for large-scale applications. Depth-averaged models (DAMs) have been widely reported for simulating run-out and deposition flow-like landslides over large spatial domains due to its relatively higher computational efficiency. To combine the advantages of both types of modelling approaches, this work introduces a novel landslide model developed by coupling a DEM model with DAM for simulation of flow-like landslides, in which the DEM is employed in the landslide initiation area to better simulate the failure mechanism of slope, and the DAM is adopted in the landslide runout and deposition phase, where the landslide has developed into flow-like landslide with fluid-like behaviour. Finally, the new coupled model is validated against an experimental test case. Satisfactory results have been obtained, demonstrating that the coupled model is able to accurately capture the detailed dynamics of flow-like landslides.

Keywords: coupled model, discrete element method, depth-averaged model, flow-like landslide, granular collapse

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Advanced Methods for Simulating Complex Landslides

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Anticipation of complex cascading landslides, important to inform risk management, requires the use of advanced modelling approaches. Such approaches have become increasingly available during the last decade, and have been successfully applied for the back-calculation of well-documented test cases. These back-calculations have helped to identify the needs for further research in terms of making reliable predictive simulations possible. This paper summarizes the key challenges in doing so as well as the resulting ongoing and planned model enhancements. Thereby, the focus is put on the propagation and interaction of flow processes. The main challenges are related to the understanding of the physical processes, the numerical implementation, and model parameterization. Some important needs for enhancement are the better representation of (1) landslide-reservoir interactions and (2) entrainment, deposition, and stopping; (3) an improved numerical scheme; (4) consideration of “slow motion”; (5) interfaces to fall models; (6) guiding parameter sets; and (7) the dynamic adaptation of key parameters to flow dynamics. Further important issues, which are not the focus of this work, are landslide triggering and release as well as the communication of uncertain model results.

Keywords: Cascading landslide processes, Multi-phase mass flows, Numerical simulation, R.avaflow

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Preliminary results from the SMART-SED basin scale sediment yield model

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In this work we describe a first version of the simulation tool developed within the SMART-SED project. The two main components of the SMART-SED model consist in a data preprocessing tool and in a robust numerical solver, which does not require a priori identification of river beds and other surface run-off areas, thus being especially useful to provide accurate input data to more localized landslide and debris-flow models. Furthermore, a geostatistical tool is available to downscale SoilGrids particle size fractions (psf) data to a given resolution. The psf data is employed also within the SCS-CN method, used to model the infiltration process. The results of a complete numerical simulation are reported and possible future developments of the model are discussed.

Keywords: Sediment yield modelling, geostatistical kriging, semi-implicit finite volume method, 2D shallow water equations

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Hazard assessment of a rainfall-induced deep-seated landslide in Hakha city, Myanmar

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One of the most disastrous landslide events happened in Myanmar was Chin state landslides due to abnormal heavy rainfall in July 2015. The landslides destroyed and damaged nearly 3,000 buildings and killed 5 people. In particular, a deep-seated landslide occurred at Mt. Rung, Hakha city on 27 July 2015 was a serious event in the history of the Chin state with about 500 m wide and 1,000 m long. On the day of the landslide occurrence, an intense rainfall of 180 mm fell within a short time span in the Hakha area. This research aims to assess the potential rainfall-induced landslides of the remained body on the slope of July 2015 landside based on assumed pore pressure ratio (r_u), soil parameters from the ring-shear tests and computer simulation. In the simulation, pore pressure ratio r_u was gradually increased from 0 (no groundwater) to 0.5 (groundwater table at ground surface) to simulate two potential cases of rainfall-induced landslides with the depths of 30 m and 60 m. The landslides started when pore pressure ratio reached 0.35 and 0.39 which are corresponding to the groundwater level height equal to 71 % and 80 % of the total thickness of the sliding layers. The volumes and velocities as well as the affected areas of the landslides were also calculated. The method would provide an assessment of landslide hazard triggered by rainfall and the result would be of great help for the authorities in the management of slope disasters.

Keywords: 2015 Hakha Landslides, Rainfall-induced landslide, Ring-shear apparatus, LS-RAPID, landslide risk assessment

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Landslide Hazard Zoning Based on the Integrated Simulation Model (LS-Rapid)

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Urbanization has been related to natural disasters such as landslides and debris flows that can cause fatality, destruction of infrastructure and environmental impacts. From 19 to 20 August, 2014, heavy rainfall occurred in Hiroshima city causing many landslides and debris flows. This disaster killed 74 people, 255 houses damaged and a total of 4,576 houses were affected reported by the Ministry of Land, Infrastructure, Transport, and Tourism of Japan (MLIT). The cumulative rainfall from 8:30 PM of August 19 until 04:30 AM of August 20 reached 248 mm at Miiri rain gauge station in Hiroshima. This is the main reason caused the Hiroshima disasters. Although intense rainfall in the short time was the trigger, urbanization into the foot of steep mountain slope lead to increase the loss of life. This paper presents the adverse effects of urbanization on basis of site investigation and multi-temporal satellite images and estimate hazard zoning causing by a potential landslide using the ring shear tests and integrated simulation model.

Keywords: Hiroshima disaster, Urbanization, Ring shear test, Integrated simulation mode, Land-use change

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Numerical Simulation of a Creeping Landslide Case in Japan

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Creeping landslides are one of the major natural disasters in mountainous regions. Therefore, study of the creeping behavior of a landslide and associated Geotechnical issues are important. This study has addressed and evaluated the creeping behaviour of the Tomuro landslide Gunma, Japan induced by snow melt water using the 2D-FEM based elasto-viscoplastic constitutive model as a case study. Two new control constitutive parameters were incorporated in the numerical model for the first time to better understand the creeping behaviour of a landslide. Such control constitutive parameters were estimated based on the relation between the total factor of safety, calculated by the various Limit Equilibrium Methods such as Ordinary Method of Slice (Fellenius 1936) (case I), Bishop's Method (1955) (case II), Janbu's Simplified Method (1973) (case III), and Finite Element Method (case IV), and the field monitoring displacement rate of the Tomuro landslide. In addition, the snowfall precipitation was also considered during the calculation of total factor of safety using both limit equilibrium methods and finite element method. Others required material parameters for landslide simulation were calculated based on the field investigation and laboratory tests of the collected blocked samples. First, the predicted and measured time histories of horizontal displacement of the Tomuro landslide was compared for the validity of the proposed numerical model and found in good agreements with each other. Then, the simulation results of deformation pattern and shear strain pattern were presented and discussed. Finally, the possible failure mechanism along the slip surface of a landslide induced by snow melt water was discussed.

Keywords: Numerical simulation, snow melt water, creeping behaviour, Tomuro landslide

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Numerical Simulation of Debris Flows after Ash Fall at Mt. Fuji

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Mt. Fuji is the largest polygenetic volcano in the Japanese archipelago. Its last eruption was Hoei in 1707. Since it has been dormant for over 300 years, not only people live near Mt. Fuji, but the area supports many economic activities in Japan. Because volcanic eruptions are accompanied by sediment movements, debris flow occurs due to heavy rainfall after ash fall, snow-melting volcanic mud flow, etc. Debris flow occurs frequently and intensively when ash has accumulated. Herein we simulate debris flows caused by rainfall after an eruption with ash fall using a method that combines Cellular Automaton (CA) and Multi Agent (MA) Systems. The CA/MA method can realize high-speed calculations because large-scale simultaneous equations do not need to be solved and the results can be easily imaged. Although local rules must be set experimentally and calibrated, the CA/MA method can easily reflect knowledge and experiences of experts such as geologists, geomorphologists, and geotechnical engineers.

Keywords: Mt. Fuji, Debris flow, Numerical simulation, Cellular automaton, Multi agent system

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On the Progression of Slope Failures Using Inverse Velocity of Surface Movements in an Undercut Slope Model

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The undercutting method applied together with the cut-and-fill technique has been realized through open-pit coal mining. To predict the time of slope failure, a method of forecasting slope failure time by the inverse velocity of slope surface proposed by Fukuzono (1985 in A new method for predicting the failure time of a slope. Japan Landslide Society, Japan, pp. 145–150) is employed in practice. However, the characteristics of slope movements in undercut slopes are different from those of typical slopes due to arch action across the pit; therefore, more investigations are required to examine whether this method can be effectively used to predict the failure time for an undercut slope. In this study, the undercut slope failure prediction technique following this approach was examined via geotechnical centrifuge modelling. The movement distributions of the slope surface were recorded by a high-speed VDO camera and analysed by the image processing software. This study confirms that the inverse of the average surface velocity is qualitatively valid for a centrifuge model of undercut slope.

Keywords: Physical model, Monitoring, Undercut slope

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Rainfall Boundary Condition in a Multiphase Material Point Method

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The Material Point Method (MPM) is an emerging computational tool to simulate the complex dynamic process of rainfall-induced landslide. In this field, hydraulic boundary conditions play an important role. In recent researches, the average relative velocity of pore water with respect to the solid skeleton is considered as Darcy's velocity usually. Hence, rainfall intensity (mm/h) can be assigned to the node of the mesh as a velocity boundary directly. However, the evolution of true velocities of liquid and solid phases has missed so far in the investigation of the landslide process. In order to keep the information of true velocities in the simulation, this paper provided a new solution to estimate the true velocity of the liquid phase at the node of the boundary layer and has been implemented a coupled hydro-mechanical model using MPM. The validation of such implementation was achieved by simulating a 1D infiltration problem and comparing with the MPM results with those obtained through the commercial software PLAXIS. With the help of this newly implemented boundary condition, rainfall-induced landslides can be better investigated using MPM.

Keywords: Material point method, Boundary condition, Rainfall, Landslide

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Reproduction of Sedimentation State During Rock Slope Failure Using the Simplified DEM Model

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Safety estimations of nuclear facilities must assess the risk of earthquakes stronger than that assumed in the original design. We propose a simple model using the discrete element method to evaluate the traveling distance of a collapsed rock mass when slope collapse occurs. We introduce a new parameter, rotational friction, to evaluate the reach distance and the accumulation state of collapsed soil. We also present the range value of rotational friction and its evaluation method.

Keywords: Rotational friction, Repose angle, Numerical simulation, Validation

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An extreme May 2018 debris flood case study in northern Slovenia: analysis, modelling, and mitigation

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Debris floods can cause large economic damage and endanger human lives. This paper presents an extreme May 2018 debris flood that occurred in northern Slovenia near the Krvavec ski resort and caused large economic damage. The debris flood was initiated by an extreme rainfall event with a return period of over 50 years. There were large differences in the measured rainfall amounts using different equipment. The estimated volume of the debris material during the event was 4000 m^3/km^2 for the Brezovški graben. In order to mitigate the risk due to future debris flood and debris flow events, a check is planned to be constructed. The part of the design process is presented in this paper. Additionally, RAMMS model was used to validate the empirical equations that were used in the process of the check dam stability design. The model was calibrated using information about the deposition area. Two adjacent torrents were modelled, and we were not able to find a common RAMMS parameter set that would yield adequate simulation performance in both cases.

Keywords: Debris floods, Hyperconcentrated flows, Slovenia, RAMMS, Numerical modelling, Mitigation measures

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Numerical modeling of dynamic process and risk prediction of recent catastrophe landslides

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The prediction the runout of landslides is a huge challenge. Comprehensive analysis of the previous occurred landslides is helpful for revealing the related mechanism. Here we will analyse the recent catastrophe landslides and simulate the dynamic process by numerical modeling software Massflow. Massflow is developed and based on the depth-integrated continuum and solved by second-order MacCormack-TVD finite difference method. Shared code and friendly GUI are provided for researchers and engineers. Based the framework, we have done several insightful simulations of real landslides and debris flows. We will introduce the basic of the software, the mechanism and how to simulate the real landslides, such as the 2015 Guangming village landslide in Shenzhen, the 2017 Su village landslide in Lishui, the 2017 Xinmo Landslide in Maoxian, the 2018 Baige Landslide along the Jinsha River, etc..

Keywords: Landslide; Abandoned soil; Mobility; MacCormack-TVD; Discrete element method; Numerical modeling

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Sensitivity Analysis of DEM Parameters in Granular Flow Simulations

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This study presents a sensitivity analysis of granular flow simulations using the Discrete Element Method (DEM). A series of granular flow simulation are performed under the different combination of the input parameters, such as the spring coefficient, the damping coefficient, the restitution coefficient, and the friction coefficient. When we consider multiple parameters in sensitivity analysis, required number of calculation cases become large. To overcome this problem, the Latin Hypercube Sampling (LHS) is employed to adequately fulfill the parameter space. After the results of granular flow simulations are obtained, indexes related to the traveling distance are defined and surrogate models of the indexes are constructed based on the simulated results. Because the surrogate models are represented as simple mathematical functions, those computational cost is quite smaller than that of DEM simulation. It is therefore possible to perform effective sensitivity analysis using surrogate models. The Monte Carlo Simulation (MCS) is then carried out with quantified density distributions of input parameters. Finally, based on the results obtained in MCS, the contribution rate of each input parameter is quantified by checking the standard deviation of outputted distributions. According to the obtained results, the basal friction angle is the most important parameter for traveling distance of main sedimented part. Furthermore, the results indicate both the basal friction and the restitution coefficient has high contribution rate for the traveling distance of the front part.

Keywords: granular flow, DEM, sensitivity analysis

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Recent Developments in the Evaluation and Application of Residual and Fully Softened Shear Strengths for the Stability Analyses of Landslides

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Shear strength is an essential component of slope stability analyses and necessary for the design of landslide repair and prevention works. This paper provides an in-depth review of the shear strength of soil pertinent to landslide analysis—fully softened shear strength and the residual shear strength of soils. Methods currently used in practice to measures the fully softened and residual shear strengths are summarized along with their advantages and disadvantages. Specifically, this paper will present details regarding the methods used to measure these shearing resistances, such as direct shear, ring shear, triaxial compression and direct simple shear tests to measure the fully softened shear strength and the use of direct shear, ring shear and triaxial compression tests to obtain the residual shear strengths. Pertinent information and discussions are provided regarding the interpretation of the shear envelopes developed from these testing methods focusing on the use of linear and non-linear (or curved) failure envelopes along with the interpretation of the strengths in terms of the secant friction angles. The various forms of curved linear envelopes presented in the literature are discussed. The paper also includes details of several commonly used correlations to estimate both the fully softened and residual shear strengths. Recommendations by the authors on the use, measurement and interpretation of both the fully softened and residual shear strengths are also included.

Keywords: Residual shear strength, Fully softened shear strength, Direct shear, Simple shear ring shear, Triaxial shear, Mineralogy, Pore fluid chemistry, Shearing rate

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Shearing Rate Effect on Residual Strength of Typical Clay Soils in Ring Shear Test

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This paper presents the effect of shear rates on residual strength of four typical clay soils having high to low plasticity in its soil natures. The shear rates were fixed in a range of 0.073–0.586 mm/min. A series of tests were performed by means of ring shear apparatus. The effect of shear rates on residual strength of the high plasticity soils, medium plasticity soils and low plasticity soils were compared. The results showed that hardly increases in the strength from the residual-state of shear after the shear rate of 0.233 mm/min.

Keywords: Residual strength, Rate effect, Clay soils, Ring shear test

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Simple Shear Tests for Unsaturated Soils

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Rainfall-induced landslides in Southern Italy often affect the pyroclastic soils produced by the past explosive activity of Vesuvius volcano. Along hilly zones these soils are mostly unsaturated and characterized by a metastable structure, which can experience static liquefaction upon shearing. Several authors studied the mechanical behaviour and the wetting-induced collapse through triaxial tests and direct shear tests. Here, a new series of tests is performed - on remolded specimens - through the Suction Controlled Simple Shear apparatus, which is particularly suitable to reproduce the in-situ stress-strain hillslope conditions and the strain/stress paths induced by rainfall during the failure and post-failure mechanisms. The results are discussed in terms of shear strain, axial strain and saturation degree.

Keywords: Suction, Failure, Deformation, Wetting, Mechanisms

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Simplest Methods of Determining Dynamic Soil Properties for Use in Co-seismic Hazard Analysis

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The loss of shear strength in a soil subjected to cyclic loading resulting from a reduction in the effective stress is known as cyclic mobility. Although the occurrence of cyclic mobility can have disastrous consequences including the loss of lives due to landslides and structural failure as well as substantial damages, quantitative evaluation of strength loss as a result of cyclic loading is not well described in the literature. In this study, eighteen laboratory prepared mineral mixtures composed of powdered montmorillonite and kaolinite clay minerals mixed with ground quartz are used to perform static and cyclic simple shear tests to establish the degradation in undrained shear strength that results from cyclic loading. The results are used to establish a relationship between the normalized undrained strength ratio and the post-cyclic effective stress ratio. This relationship is then used to examine the expected reduction in undrained shear strength and corresponding factor of safety against landslide at a post-earthquake landslide site in the Lokanthali region of Nepal after the 2015 Gorkha earthquake. The estimates from the proposed relationship are within 10% of the measured values.

Keywords: Seismic slope stability analysis, Dynamic soil properties, Earthquake induced landslides

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New Understanding of the Initiation of Daguangbao Landslide Triggered by the 2008 Wenchuan Earthquake (Ms=8.0)

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Daguangbao (DGB) landslide involving a volume of about 1.2×10^9 m^3 was the largest landslide triggered by the 2008 Wenchuan earthquake. An exposed slip surface was observed with a length of 1.8 km along the main sliding direction and an area of 0.3 km^2. The rock mass under the sliding surface suffered not only historical tectonic fragmentation but also earthquake-induced fragmentation. Our work confirmed that the shear failure of the DGB landslide was triggered in a bedding fault with a maximum thickness of 5 m and a depth of 400 m in the slope. Besides, the bedding fault was the groundwater channel in the slope with saturated rock mass. Then, a series of shaking table tests were conducted to simulate the slope model of the DGB landslide. The results revealed that the deformation between the weak layer (to represented the bedding fault) and its upper hard layer (to represented the carbonate strata mainly composing the landslide body) was discordant during vibration. This discordant deformation response (DDR) can result in significant stress amplification in the weak layer. With this study, we proposed that a large pre-existing discontinuity within a slope may be the basis for initiating a large landslide during the earthquake. The Wenchuan earthquake-induced rock fragmentation within the large pre-existing discontinuity of the DGB landslide might be ascribed to the DDR of the bedding fault. Furthermore, the response characteristics of the model have been simulated by a fluid-solid coupling algorithm in the $FLAC^{3D}$ program. The excess pore water pressure featured with instant amplification and cumulative growth in the saturated water weak layer was observed. We proposed that the DDR-induced rock dynamic damage and rapid drop of effective inside stress caused by excess pore water pressure in the bedding during the strong earthquake gave rise to the sudden failure of the DGB landslide.

Keywords: Wenchuan earthquake, Daguangbao landslide, bedding fault, rock damage, $FLAC^{3D}$

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Residual-state Ring Shear Creep Tests on Clayey Materials and Development of Creep Failure Model

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Keywords: landslide creep, ring shear machine, residual-state shear creep, critical displacement

This piece of research work is primarily related with creeping type landslide displacement. Use of ring shear machines in measuring landslide material frictional resistance and studying landslide displacement behavior has been in practice for several decades, but creep tests in shear using a ring shear machine to study landslide creep behavior is still in preliminary stage (Bhat et al. 2013, Bhandary et al. 2014). Creeping landslides often exhibit large displacements before they completely fail or collapse, which means the sliding surface material of most such landslides may be in residual state of shear, which is ideally a state at which the shear strength of material is generated by truly frictional resistance between the platy clay particles.

A series of ring shear tests followed by residual-state shear creep tests is conducted on artificially prepared clayey materials using a modified Bishop-type ring shear machine. Then, based on the test results obtained from the experimental study, a numerical model for failure prediction in residual-state shear creep is developed considering a combination of Kelvin's (Voigt's) creep model and Maxwell's relaxation model together with a slider element. The test results reveal that the residual-state creep failure takes place only under a creep loading ratio of unity or greater, and that every soil material exhibits a certain amount of displacement (i.e., critical displacement, δ_c) beyond which the failure accelerates leading to complete collapse regardless of the loading ratio as indicated in Fig. 1 (upper). R_{rcs} in Fig. 1 represents residual-state creep stress ratio, which is a ratio of applied shear creep stress to residual strength of the clay material. The critical displacement is found to be dependent of the shear characteristics of the soil material.

Fig. 1 also compares the experimental and model results. There is certain level of similarity and an acceptable level of agreement in the experimental and predicted data, but the model still needs improvement. In this creep failure model, the state controlling parameters, such as shear modulus and coefficient of viscosity, were determined based on the experimental results. Additionally, the creep failure model discussed here is only a preliminary model, so it needs a generalization in the days ahead. Finally, it is also expected that this model helps predict landslide failure under an ideal condition (i.e., residual state of shear and no effective stress changes) of landslide creep.

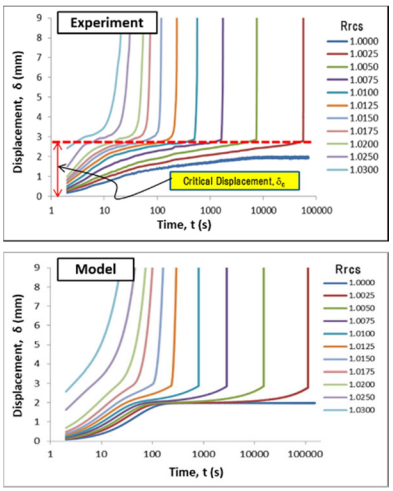

Fig. 1: Experimental and model-predicted data of residual-state shear creep tests on sand powder (75%) and bentonite (25%) mixed samples

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Challenges in Evaluating Shear-Rate Effects in Soils

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Some landslides move imperceptibly for years, while others rush downslope within seconds, destroying everything they encounter. The frictional resistance at the base of the sliding mass can control these behaviors. Generally, this resistance decreases to a minimum value as the material breaks down and is sheared. However, this value also depends on the shear velocity. Shear rate-dependent frictional resistance has indeed been recorded in many soils. We verify some expected trends from the literature using kaolin- and bentonite-sand mixtures, which we test in a classic fashion using a ring-shear apparatus under confining stresses representative of landslide shear zones. We evaluate the residual shear strength carefully, accounting for – and trying to minimize – experimental uncertainties. We observe velocity strengthening in clay-rich mixtures, and both strengthening and weakening in soils with smaller proportions of clays, with the largest weakening in mixtures containing ~30% of clay minerals. However, upon statistical analysis, we conclude that many of these trends are insignificant or inconsistent, especially under low confining stress. We suggest that shear-rate-dependent formulations in landslide runout models should be used cautiously, and only if supported by strong evidence, accounting for inherent uncertainties in soil testing and soil heterogeneity.

Keywords: residual shear strength, shear-rate effect, velocity weakening, statistical analysis, landslide

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Monotonic and Cyclic Behaviour of Tephra Layer Landslide at Takanodai from the 2016 Kumamoto Earthquake

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The 2016 Kumamoto earthquakes, Japan, caused a large numbers of slope failures, especially a large—scale flow—type landslide was induced in the area near the Aso Volcanological Laboratory of Kyoto University in Takanodai, Minamiaso Village Kumamoto, Japan. From the field observation, sliding surface was the tephra layer of Kusasenrigahama fallen pumice (Kpfa) which was deposited by the volcanic activity (around 30,000 years ago, Miyabuchi et al. in VSJ 48(2):195–214, 2003). This tephra layer (Kpfa) was a key soil to understand the mechanism of this large-scale flow-type landslide, then some soils from this tephra layer were retrieved from the sliding surface in the field. This study is focused on the physical properties, monotonic and cyclic direct shear behaviour for the tephra layer (Kpfa) to understand the mechanism of this landslide during earthquake. Constant vertical stress and constant volume cyclic direct shear tests were performed to study the cyclic behaviour of the tephra layer (Kpfa). From the constant vertical stress test, strain hardening behaviour was observed. From the constant vertical stress test, shear displacement increased largely during cyclic loading, despite the tephra layer being in an unsaturated state, which were similar to the behaviour of saturated sand during liquefaction. In the future, this research will be developed considering the study of particle breakage on Kpfa.

Keywords: Monotonic and cyclic shear behavior, Tephra layer landslide, Kumamoto earthquake, Shear strength

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Slope Stability Assessment of Weak and Weathered Rocks with BQ System

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Rock slopes can be affected by weathering and human activities. Depending on the type of the rock, the impact of weathering and excavation can change. This leads some strength reductions and consequently some stability problems. Limit equilibrium analyses are widely used to assess slope stability but empirical methods are also very useful and quick. Basic quality (BQ) system is very popular method which is developed in China to assess slope stability of the rock slopes. Generally it leans on strength and rock soundness/GSI to determine slope stability. In this study, rock slope stabilities were assessed with limit equilibrium method and BQ system. 55 cut slopes located in Western Black Sea Region of Turkey were used to evaluate the stability conditions. 39 of the cut slopes are located in flysch deposits consisting mudstones and sandstone/limestone alternations. Other rock types are granite, basalt, andesite, granodiorite, serpentinite and tuff. According to the field observations, degree of weathering of most of the cut slopes are moderate (38), and the rest are slightly (10) and highly (7). Uniaxial compressive strength, point load strength index and Schmidt hammer tests were applied to find strength values. According to the tests, most of the rocks are in the category of weak and medium strong (5–50 MPa) throughout the study area. The field observations revealed that all cut slopes are stable except surficial failures due to weathering and excavation. According to limit equilibrium analyses, all cut slopes are stable, but only surficial failures were observed due to degradation which is completely coherent with the field observations. However, BQ System revealed that most of the results are not coherent with the field observations and limit equilibrium results. It is concluded that rocks stronger than 50 MPa can be assessed properly by BQ System in the study area.

Keywords: BQ system, Excavation, Flysch, Rock strength, Slope stability, Weathering

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Soil Databases to Assist Slope Stability Assessments in the Eastern Caribbean

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Rainfall-triggered landslides are an 'everyday risk' to Small Island States, such as Saint Lucia in the Caribbean, and have the potential to destroy or damage buildings and disrupt lifelines such as roads and pipelines. To better evaluate these landslide hazards, efforts have been made to develop decision-support tools linking rainfall scenarios to stability for different types of road cut slope. Many thousands of stochastic simulations can be performed using a combined hydrology and slope stability model (CHASM) which requires inputs of slope cross-sectional geometry, soil and hydrological parameters which allows representative rainfall-triggered landslide scenarios to be produced. To use CHASM for this purpose the statistical variation of the relevant geotechnical properties such as friction angle needs to be assessed. This paper presents the analysis of an updated database for Saint Lucian soils that has been compiled using data supplied by the Government of Saint Lucia Ministry of Infrastructure, Port Services and Transport. The Coefficient of Variation values of the key soil mechanics parameters are reported and previously developed transformation models for estimating effective friction angle are updated. The Weibull statistical distribution is shown to be the best fit to the friction angle data.

Keywords: Coefficient of variation, Soil database, Soil variability, Transformation models, Statistical distributions, Tropical soils

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Failure mechanism of a flow-like landslide triggered by the 2018 Western Shimane Earthquake

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The flow-like Kataragai landslide triggered by the 2018 Western Shimane Earthquake occurred in a gentle slope out of the area which suffered from the most intense ground motion. The geotechnical and hydrological conditions are considered as the primary factors for the landslide occurrence. It is confirmed through the field survey that the Kataragai landslide occurred in a refilled slope composed of medium sand with gravel, and several small ponds scattered on the refilled slope with perennial water. The existence of downslope seepage flow was validated by self-potential tests and the seepage flows at the center of the crown near the pond are more noticeable. A weak layer with low dry density and fine-particle content was confirmed through hardness tests and penetration tests. The triaxial tests indicate that the anti-liquefaction strengths of the soils in the Kataragai landslide are relatively low on the whole, while the weak layer is the lowest. The erosion of fine content in soil due to seepage flow is responsible for the formation of the weak layer. Based on the soil property and hydrologic condition, the initiation and motion mechanisms of the Kataragai landslide were discussed as well.

Keywords: 2018 Western Shimane Earthquake, Flow-like slide, Seepage, Liquefaction

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The Mt Gamalama Instability Level in Generating Landslide-Induced Tsunami in Ternate Island, Indonesia

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Mt Gamalama is a volcanic island which has a history of tsunamigenic volcanic eruptions with known events in 1608, 1840, and 1871, where tsunami generation is suspected due to landslides or sector collapse of the steep flanks entering the Molucca Sea threatening the coastal population and infrastructure. The potential landslides were investigated by applying a limit equilibrium method and the generalized Hoek–Brown failure criteria. This resulted in a so-called factor of safety (FoS) which describes the Mt Gamalama slope stability level. The critical FoS values ranging from 1.945 to 3.361 have been obtained for the four sections of the Mt Gamalama edifice the north, south, west, and east sides and are considered in a relatively stable condition. These values hold for a static condition only under gravity and in the absence of any volcanic activity. The application of so-called seismic loads kh of 0.103, and 0.155, 0.457, and 0.685, and magma pressures of 2–17 MPa due to vertical and tilted dyke intrusion decreases FoS values (FoS < 1.000) in all sections. We show that these additional factors destabilize the Mt Gamalama slopes and even lead to failure.

Keywords: Mt gamalama, Instability, Landslides, Tsunami

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Seepage and deformation of unsaturated slope during post-earthquake rainfall

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This study sets out with the aims of evaluating the effect of earthquake on the seepage and deformation of slopes to the rainfall after earthquake and examining the impact of different factors such earthquake intensity and rainfall intensity on the response of slopes subject to rainfall. It was found from the experiments that, shaking-induced cracks on the slope were near its shoulder and the existence of cracks greatly affected slope behavior during the following rainfall, and the rainfall-induced landslide was affected by both rainfall intensity and previous-shaking intensity. The effect of preferential flow due to the presence of cracks was more evident when the slope was under rainfall with a greater intensity and the landslide features and deformation patterns could be largely different due to different rainfall intensities. Heavy rainfall greatly accelerated the failure of the slope with shaking-induced cracks, resulting in a rapid and massive landslide, whereas light rainfall might cause a different landslide pattern but the landslide kinematics would be similar to the slope under rainfall without shaking. In addition, experiments on slopes subjected to shaking with different intensities but the same rainfall revealed that, for the slopes containing shaking-induced cracks, even though being subjected to the same rainfall, their deformation could vary significantly in magnitude, thus the previous-shaking event was important in evaluating the slope behavior during rainfall. The velocity of rainfall-caused landslide could be greatly influenced by the prior shaking event alone. Despite a low intensity, the rainfall could still lead to an instant landslide once the slope has encountered more intense antecedent shaking.

Keywords: keyword1, keyword2, keyword3, keyword4, keyword5

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3D analysis of settlement and stability of the open-cast coal mine landfill: Bílina mine case

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Bílina open-cast coal mine lies in North Bohemia region in the Czech Republic and its approximate dimensions are 6x4 km with the depth of over 200 m. The overburden is transported into an internal landfill of up to 200 m in height. The deposited material consists of a lumpy heavily overconsolidated clay. The soil is loosely dispersed on the surface of the landfill without compaction, forming an inhomogeneous double-porosity material with a porosity up to 70% and lump size of the order of magnitude 0.1 to 1 m. Due to its own weight and weather conditions, the lumps slowly disintegrate, filling the intergranular space with slurry soil. Eventually, the slurry soil between the original lumps controls the overall mechanical response and the material behaves analogous to the reconstituted soil, although lumpy structure remains clear even in old landfill. In this talk, we present 2D and 3D settlement and stability analysis of the Bílina landfill. For the numerical analysis hypoplastic constitutive model for clays is adopted allowing to predict such features as soil non-linearity, stiffness dependency on the OCR and loading direction and critical state. Hypoplastic model is calibrated on the reconstituted soil samples as well as on the model material prepared from the reduced granulometry curve to account for lumpy structure. The validation of the constitutive model calibration is done in 2D via landfill settlement analysis – the predicted settlement is evaluated against in situ measured settlements of 5 pre-installed 5x5m steel plates. Then, 3D numerical analysis is performed to assess evolution of landfill settlement during its construction, simulating individual phases of soil deposition. Eventually, recently developed strength reduction method for hypoplasticity is employed together with stabilizing surface layer method in the 3D stability analysis to quantify factor of safety for basal landfill slope failure.

Keywords: landfill, slope stability, settlement, hypoplasticity, three-dimensional

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Engineering Risk Mitigation for Landslide Hazard Chains: The Baige Landslides on the Jinsha River in 2018

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On 10 October and 3 November 2018, two large landslides occurred at Baige on the Qinghai-Tibet Plateau, and completely blocked the Jinsha River. Accordingly two landslide dams formed and breached sequentially, with the breaching of the 3 Nov. dam generating a flood larger than the 10,000-year return period flood over a river reach of approximately 400 km, endangering the serial cascade dams and towns along the river. These were two typical large-scale hazard chains originated by landslides. This paper presents a five-phase protocol to manage the risks of landslide hazard chains, which includes definitions, multi-hazard assessment, exposure assessment, multi-vulnerability assessment, and multi-risk assessment. The protocol is illustrated in the case of the Jinsha River landslide hazard chains. How the hazard chains developed in space and time are introduced. The major engineering measures for mitigating short-term and longer-term risks are described, including the use of a 15 m deep diversion channel to reduce the dam failure flow rate and flow quantity, removal of two cofferdams along the river to avoid flood amplification effects, flood regulation using six reservoirs over 630 km downstream, load relief at the crest of the instable slope to increase its stability, and removal of part of the residual landslide barrier to minimize future landslide dam risks. Finally, several scientific topics are suggested for further study.

Keywords: Hazard chain, Landslide, Landslide dam, Dam breaching, Multi-hazard risk management, Jinsha River

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Engineering Geological Investigation and Slope Stability Analysis for Landslide Hazard Assessment in Indian Himalayas

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The Indian Himalaya is very prone to landslides due to its complex geology and tectonic set-up along with high intensity rainfall and aggravated slope conditions as a result of anthropogenic activities. Landslide hazard assessment is very essential before any hill development construction activity begins. Engineering geological investigation forms the primary basis for any slope stability assessment leading to plan for any construction so that landslide occurrences are minimized. Engineering geological data for rock slope stability assessment can be very easily collected from the field. These data can be used for rock mass characterization and classification such as Geological Strength Index (GSI), Rock Mass Rating (RMR) and Slope Mass Rating (SMR). The paper describes these rock mass classification techniques and presents some field examples. The paper also presents application of these techniques to derive some relevant geotechnical parameters for numerical analysis to determine the stability of slopes in terms of factor of safety.

Keywords: Engineering geology, Landslide, Slope stability, Rock mass classification

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First Consideration about Post 2017 Wildfire Erosion Response and Debris Flow in Susa Valley (NW Italy)

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This paper contains the first results of an ongoing research dealing with post-fire mass movements in Italy. Although the attention of the scientific community is increasing worldwide, very few geo-hydrological processes occurring in burned areas are reported for Italy. As the probability of occurrence and magnitude of wildfires is expected to increase in the future because of climate change, more efforts should be made to deepen knowledge on interacting disturbances. Here, we present a case study regarding the erosional response after fire recurrence in a watershed located in NW Italy, where multiple flow processes occurred after six months since the last wildfire, as a consequence of different rainstorms. It contains a description of the geological and geomorphological background, the burn severity assessment together with the analysis of the triggering rainfalls and the outline of the main geomorphic effects that affected people and lifelines.

Keywords: Wildfire, Debris flow, Erosion, Fire severity, Susa, Valley - N-W Italy

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Identification of Sliding Surface and Crack Pattern in the Soil Creep, Case Study: Unika Soegijapranata Campus, Semarang, Central Java, Indonesia

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The development of a sports hall in the Unika Soegijapranata Campus in Central Java is constrained by geological conditions. At the time of land preparation, a crack appears on the fence of the sports hall foundation that was predicted as a sign that they have a soil creep. This condition has threatened the implementation of such development. Therefore, it is necessary to know the subsurface conditions, especially the sliding surface location and pattern of the existing cracks in the ground. This information is beneficial to avoid soil creep risk. In order to support the information, both the geological survey and seismic refraction were conducted in this location. According to the survey, it is found that the sliding surface was identified as volcanic breccia with the depth from 5 m up to 20 m. There are many faults found based on the seismic data, and many cracks appear on the surface, which suspected as the creep crown. Some areas of the sports hall are located in the soil creep crown. According to the drilling data and geo-electrical survey, the sliding surface location of the soil creep was identified within volcanic breccia layers. It is recommended to shift the planned location of the sports hall in order to avoid or minimize the soil creep risk.

Keywords: Seismic refraction, Geological survey, Crack structure and pattern, Soil creep

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Preliminary Result of Real-Time Landslide Monitoring in the Case of the Hinterland of Koroška Bela, NW Slovenia

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Landslides are a common and widespread phenomenon in Slovenia, as they are in most European countries. Because we cannot avoid the risk of landslides and must live with it, it is important to understand and predict landslide dynamics. Research on landslide dynamics forms the basis of landslide hazard prevention and serves as a basic requirement for the development of prediction models and for defining prevention and mitigation measures. The principal aim of this study is to form a basis to predict real-time dynamics of landslides that have been posing a direct threat to settlement Koroška Bela (with approximately 2200 inhabitants) for centuries. Prediction modelling is based on monitoring and recognition of displacement triggering mechanisms and their interactions. The study area is located above the settlement of Koroška Bela (NW Slovenia, Karavanke) which exhibits a number of deep-seated landslides (the Urbas and Čikla landslides) in weathered siltstone and claystone.

Keywords: Real-time monitoring, Landslide, Koroška Bela, Slovenia

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Quantitative Risk Analysis of Earthquake-Induced Landslides

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Quantitative risk analysis is valuable tool in risk management, yet the calculation of risk is often hampered by a lack of quality spatial input data, particularly landslide event inventories. These event inventories provide information to determine the number, size and spatial location of landslides triggered by discrete events such rainfall or earthquakes. This paper presents an approach whereby we use historical New Zealand earthquake-induced landslide inventories to estimate the landslide hazard for the Franz Josef and Fox glacier valleys, West Coast, South Island, New Zealand, as no pre-existing complete earthquake-induced landslide inventories exist for this area of New Zealand. We outline a methodology for the calculation of earthquake-induced landslide magnitude-frequency relationships from the 2016 Mw 7.8 Kaikōura earthquake, the 1968 Mw 7.1 Inangahua earthquake, and the 1929 Mw 7.8 Murchison earthquake to determine the probability of a given volume of landslide occurring for different levels of ground shaking.

Keywords: Earthquake-induced landslides, Magnitude-frequency analysis, Quantitative risk analysis

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Role of Remote Sensing Technology in Landslide Risk Management of Hong Kong

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Natural terrain covers over 60% of the land area of Hong Kong. With the close proximity of developments to hillsides and high annual rainfall, Hong Kong is under a constant threat from natural terrain landslides. Over the past years, the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department of the Hong Kong Special Administrative Region Government has applied state-of-the-art remote sensing techniques, for example, laser scanning, photogrammetry and interferometric synthetic aperture radar, in landslide risk management. These include landslide hazard identification and monitoring, post-landslide responses and residual risk management, design of landslide prevention and mitigation measures etc. This paper discusses the advantages of remote sensing technology and their applications to enhance the slope safety of Hong Kong. Pilot studies applying machine learning on identification of geological features from aerial imageries and further studies being/to be conducted are also covered.

Keywords: Remote sensing, Natural terrain, Slope safety management, Machine learning

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Risk assessment of submerged rock mass in reservoir area

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A new analysis method was proposed to study the damage evolution process of the dangerous rock masses on the reservoir bank. This method involves the generalization of a mechanical model, the derivation of the constitutive damage model based on laboratory results, iterative damage calculations, and the refinement of the factor of safety methodology based on the reservoir water level. Through this new method, we can continuously track the mechanical state of a dangerous rock mass and quantify the relationship between the changing water level and the potential failure of the rock mass. By using this method to analyze Jianchuandong Dangerous Rock Mass (JDRM), it can be found that the theoretical pressure data and the observed pressure data were consistent with one another, and both exhibited nonlinear progressive deformation; this agreement shows that our new modeling technique is both valid and robust. As of December 2018, our calculations indicate that the JDRM will be in a critical state of instability after two dry‐wet cycles. According to the parameters obtained by the prediction model, the dynamic collapse analysis of JDRM is carried out. The collapse of JDRM is similar to that of the Zhenziyan collapse, which not only proves the effectiveness of parameter selection but also expands this analysis method's capabilities.

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Prediction the Global Factor of Safety in Soil-Nailed Slope by A Simplified Method

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Reinforcement of slopes using soil nailing can effectively improve slope stability, and it has been widely used for cutting slopes. At the present time, there is no derived formula having an adequate accuracy for a tentative design without complex and detailed numerical analysis on the stability of soil nail structure. Based on the finite element analysis, a new simplified method has been established which can consider the effect of nail spacing, nail inclination, nail head size and slope angle. With the aid of master curve approach, the contour curve charts of global factor of safety were drawn to facilitate engineering application and to acquire optimal design parameters of soil nailing. Parametric study for various soil-nailed slopes has been conducted based on finite element simulations. Statistical analysis between the rigorous numerical analysis and developed formula for the global factor of safety showed that 0.7282 of the coefficient of determination was achieved. Therefore, the new simplified method can be an appropriate tool to estimate the global factor of safety of soil-nailed slope. However, the further analysis in various types of soils is also needed to improve this derived formula in the future.

Keywords: Finite element analysis, Master curve, Simplified method, Parametric study, Global factor of safety.

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On the Scale Effect of the Catchment Landslide Susceptibility with Consideration of Climate Change

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Due to the impact of climate change, the increasing frequency of extreme rainfall events, with concentrated and intensive rainfalls, commonly cause landslide hazard in the mountain areas of Taiwan. Although the extraordinary rainfall behavior is critical for the geohazard, it is significantly affected by the topography, the route of typhoon, etc. Therefore, the predicted rainfall could be quite different in different catchment, which also suggests the scale effect on the predicted rainfall. This study employs rainfall frequency analysis together with the atmospheric general circulation model (AGCM) downscaling estimation to understand the temporal rainfall trends, distributions, and intensities in the adopted study area in Central Taiwan. To investigate the scale effect, three catchments in Central Taiwan, i.e. Ta-Chia River, Wu River, and Chuoshui River were adopted as the study area. For a better prediction of rainfall, the rainfall behavior was analyzed in different scales. To assess the hazard of the landslides, logistic regression methods and supporting vector machines method were applied, in which the control factors were analyzed and discussed. The results of predictive analysis can be applied for risk prevention and management in the study area.

Keywords: scale effect, landslide susceptibility, climate change, catchment scale, rainfall induced landslide

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Fragmental rockfalls and the analysis of risk

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Fragmentation is a phenomenon frequently observed in rockfalls although it is rarely considered in risk analysis. Ignoring it can result in both over- and under-estimation of risk due to its contrasting effects, which we briefly summarize in what follows. The quantitative evaluation of risk requires determining the probability (or frequency) of rockfall occurrence, the probability of reach, and the exposure or temporal spatial probability of the element at risk (Hantz et al. 2021). Fragmentation reduces the size and increases the number of blocks that propagate down the slope. For this reason, the assessment of the probability of reach must be adapted to the fact that more blocks can reach a given location than those initially detached from the cliff. The new fragments generated follow independent trajectories, often diverging significantly from that of the unbroken blocks, which increase the impact probability on the exposed elements. Moreover, the width of the affected area varies with distance. When the moving fragments do not form a continuous front, it is necessary to adapt the exposure taking into account the space actually occupied by the blocks (Corominas et al. 2019). Observations from real-scale tests suggest that, contrary to what is commonly assumed, blocks that fragment bounce faster and show higher coefficients of restitution. Nevertheless, on long slopes, the roughness of the ground affects mainly the small fragments, which reduces the distances traveled and the impact energies. This facilitates the capture of the blocks by the protection structures but, on the other hand, the occurrence of multiple impacts introduces uncertainty in their performance. Finally, when impacts generating fragmentation occur near the protective structures, the bullet effect and the greater rebound angles of the fragments must be taken into account.

Hantz, D., Corominas, J., Crosta, G.B., Jaboyedoff, M. 2021. Definitions and Concepts for Quantitative Rockfall Hazard and Risk Analysis. Geosciences 2021, 11(4), 158; doi:10.3390/geosciences11040158

Corominas, J.; Matas, G.; Ruiz-Carulla, R. 2019. Quantitative analysis of risk from fragmental rockfalls. Landslides, 16: 5–21. https://doi.org/10.1007/s10346-018-1087-9

Keywords: rockfall, fragmentation, exposure, hazard, risk

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Satellite Soil Moisture for Estimating Landslide Hazard

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Continuous monitoring of soil water content profile is necessary to assess the likelihood of landslide. Remote sensing offers observation of soil water content that are difficult by in-situ inspections in spatially and temporally varying condition. This study aims to construct a landslide prediction system that combines satellite observation, soil testing and modeling. Simulations were carried out using hydrological models and soil stability index to evaluate the association between soil water content, rainfall, and landslides. Soil Moisture and Ocean Salinity (SMOS) from European Space Agency's Earth Explorer satellite images are downscaled to a local scale using soil humidity derived from hydrological model as independent variable. The factor of safety in the slope stability analysis is modeled to estimate the landslide hazard. By comparing the soil moisture estimation with in-situ measurement, the reliability of the system was proven. For estimating the landslide events, the evaluation is also conducted by applying the model to five landslide location in upper Brantas river basin. This early warning system for the landslide can give a more accurate prediction for the soil movement induced by rainfall.

Keywords: landslide, soil water content, hydrological model, downscaling, safety factor

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Shaking table tests of small scaled slope models

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Simulations of geotechnical problems with cyclic or dynamic loads such as those caused by earthquakes are still the subject of research worldwide. There is often a lack of reliable measurement data for validating the simulations. Model tests can provide important insights and measurement data for the derivation and validation of theoretical approaches and simulations. As part of a smaller research project at the National Polytechnic University (EPN) in Quito Ecuador in collaboration with the researchers of the Leipzig University of Applied Sciences, small-scale model tests with a one-dimensional shaking table are being developed. The project aims to contribute to the stability assessment of slope systems under the effects of earthquakes. The main aim of the tests was to record the behavior of a regional soil and later the interaction with buildings on models and to obtain reliable measurement data for later validation of calculations and simulations. The method of digital image correlation (DIC) was used to record ground movements and deformations. In the contribution, the main development steps for setting up the experiments and for using the DIC method are explained. In addition, the first results for the evaluation of ground movements and deformations on a model slope are presented.

Keywords: slope stability assessment, benchmark test, digital image correlation, earthquake loading

Theme 5 Catastrophic Landslides and Frontiers of Landslide Science

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Study on the Phenomena of Liquefaction Induced Massive Landslides in 28 September 2018 Palu-Donggala Earthquake

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Liquefaction Induced Mass Landslide in Palu Donggala Earthquake on 28 September 2018 was one of the rare and biggest event on these types of landslides in the world. The phenomena was the most complete occurrence since all mechanism of liquefaction and liquefaction induced landslides were represented. On these particular event, the author has conducted study on the liquefaction mechanism based on field observation including running drone in several areas, conducting soil investigations, work on analysis and collect as much as data from local people. This paper discusses Liquefaction Mechanism in these unique and spectacular sites (mainly in four areas: Balaroa, Petobo, Jono Oge and Sibalaya) because the earthquake seems to trigger liquefaction by multidirectional vibration and of particular interest is because the earthquake are near faults with shallow earthquake focus of about 10 km below the city. The extraordinary distance of liquefaction flow and lateral spreading is one of unique phenomena which is believed to be caused by the existence of initial artesian pressure and significant vertical acceleration causing the soil loosing contact stress. Layers of sands and clays or silts might have caused significant force to the liquefied sands and flow laterally. Instead of surface phenomena, the main objectives of this paper is also to discuss the results of CPTu tests conducted for analysis and fact findings on liquefaction phenomena. Each data of CPTu yields liquefaction potential index which is used to characterize the severity of ground damage and discuss mitigation and risk reduction in the future.

Keywords: Liquefaction, Lateral spreading, Liquefaction induced landslides, Liquefaction potential index

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The Krasnogorsk Landslide (Northern Caucasus): Its Evolution and Modern Activity

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This article describes large landslide on the left-bank slope of the Kuban River Valley, Northern Caucasus, Russia. Its evolution along with the conditions of its triggering and activation are described. Landslide that took place in 2016 was just is a partial reactivation of a much larger ancient landslide. While modern landslide was triggered by the climatic factors, slope stability assessment allows assumption that formation of the ancient landslide could be induced by seismic activity.

Keywords: Slope stability, Landslide hazard assessment, Seismically induced landslides, Northern Caucasus

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Slope Deformation caused Jure Landslide 2014 Along Sun Koshi in Lesser Nepal Himalaya and Effect of Gorkha Earthquake 2015

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Although there is no commonly accepted methodology for evaluation of deep-seated landslide susceptibility, the progress on remote sensing technology such as aerial photos, satellite images, precise DEM and InSAR data have made it easier to detect ground movement at time interval and cost-effective. Combining these techniques and ground truth, the authors attempt to understand the nature of Jure landslide in Nepal that occurred due to heavy rain in August 2014. They have also studied the effect of Nepal Gorkha earthquake on the Jure landslide. Gravitational deformation, so-called “rock creep” has proceeded for long time forming thick weathering layer at the Jure landslide site. Small and shallow deformations have occurred in and around the site since a decade or before. However, significant enlargement of the landslide due to the earthquake in 2015 was not detected by InSAR because the quake occurred at the end of dry season.

Keywords: Gravitational creep, Deep weathering, Optical satellite image, Nepal gorkha earthquake 2015, InSAR

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Pressure Head Dynamics on a Natural Slope in Eastern Iburi Struck by the 2018 Hokkaido Earthquake

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The 2018 Hokkaido Eastern Iburi Earthquake triggered numerous shallow landslides on slopes covered with thick pyroclastic fall deposits. These shallow landslides tended to occur on concave rather than convex slopes and their slip surfaces were very wet, indicating that water played an important role in landslide initiation. As a first step toward clarifying the role of water in these landslides, we used tensiometers to monitor pressure head dynamics on a natural hillside covered with thick pyroclastic deposits that remained in place throughout the earthquake. We found that on concave slopes, the lower part of the pyroclastic fall deposits throughout the weathered basement complex (sedimentary rock) were always wet. Notably, the interface between the pyroclastic fall deposits and weathered basement complex, which forms a potential slip surface for earthquake-induced landslides, was always at or near saturation. On convex slopes, the weathered basement complex was never saturated and showed greater pressure head fluctuation. We infer that the pyroclastic fall deposits over the basement complex tend to weather more easily and are more susceptible to intense ground motion on concave than on convex slopes and the landslide slip surface was saturated at the timing of the earthquake on concave slopes. We conclude that these factors contributed to the larger number of shallow landslides initiated on concave slopes.

Keywords: 2018 hokkaido eastern iburi earthquake, Pyroclastic fall deposits, Pressure head, Shallow landslides

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New insights on recent and active large rock slides in the Andean paraglacial environments of central Chile

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Large volume rock slides are common geomorphological features in glacial valleys of the central Andes. At the latitude of the Chilean capital city of Santiago (33°S), several deposits are found in the tributaries of the Maipo river basin. The origin of these landslides is not clear, but the present-day activity of some slope failures at high altitudes plus the lack of large landslide evidences from the 2010 megathrust earthquake suggest an important role of stress state changing conditions and progressive failure, possibly combined with rapid snowmelt or local seismic triggers. In 1987 a large rock slide in the Parraguirre creek derived into a catastrophic rock avalanche and debris flow, with dozens of fatalities. In 2018 a new developing landslide was detected in the nearby Yerba Loca valley, posing a new threat to the communities. We present advances in the monitoring of the active Yerba Loca landslide using satellite image analyses and InSAR techniques and numerical modelling of the Parraguirre landslide. The analysis of Yerba Loca shows that the movement gradually started several years prior to the 2018 failure, and that after the main event deformation continues in some areas around the landslide, which is corroborated with field observations of propagating tension cracks. Preliminary results of the models of Parraguirre landslide show that the influence of the previous glacier on the slope stress-state would have led to rock damage in the final failure zone, while failure could have been favoured by rapid snowmelt as trigger. The studies show that previously glaciated valleys may still be subject to paraglacial conditions that may lead to the development of new rock slides, which can evolve into large rock avalanches, debris flows or river dams, with high potential risks to communities and infrastructure downstream the valleys. FONDECYT project 1201360.

Keywords: rock slope failure, paraglacial conditions, Andes, Chile

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Earthquake-Triggered Landslides and Slope-Seismic Waves Interaction Inferring Induced Displacements

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Earthquake-induced landslide mass mobility is a topic of particular relevance for the analysis of earthquake induced ground effects scenarios. The landslide masses already existing on the slopes interact with the seismic waves that propagate from the bedrock, giving rise to effects of amplification of the seismic motion at specific frequencies connected to their geometry and their dynamic properties. The quantification of the earthquake-induced displacements expected in landslide masses through numerical models under dynamic conditions highlights how, especially for medium-low energy levels of the seismic input, the displacements thus obtained are generally higher than those computed by conventional approaches (e.g. Newmark method applied to the hypothesis of rigid or deformable block and related semiempirical relations). A series of case studies has also proved that the geometry of significantly dislodged landslide masses (i.e. segmented into kinematically distinct portions, namely "blocks") due to their geomorphological evolution over time, significantly controls the seismic-induced displacements obtained by numerical models. In particular, the results highlight that the maximum displacements computed through the numerical models do not correspond to seismic inputs whose characteristic periods coincide to those of the resonance or of the length of the landslide mass but are more directly connected to the smaller dimensions of the individual blocks in which the landslide mass is segmented.

Keywords: Earthquake-induced landslides, Earthquake-induced displacements, Numerical modeling

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Rockfall/Rockslide Hazard, Lake Expansion and Dead-Ice Melting Assessment: Lake Imja, Nepal

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The current global climate change is accelerating many natural processes that can lead to the rupture of dams of glacial lakes. One of these lakes is Lake Imja in the Khumbu area of Nepal. Three factors that influence the stability of the moraine dam were selected for analysis in this work—rockfalls/rockslides, growth of the lake area and melting of dead ice in the frontal moraine. The results of this study show that there is currently no risk of rockslide into the lake, which, however, may change due to the accelerating growth of the lake in the near future. The development of temperatures is also observed, where the increase in the last two decades is particularly striking. Crucial for the stability of the moraine dam is now the melting of dead ice at its core, as new thermokarst lakes are forming on the moraine surface, and a leak through the moraine in its southwestern part has also been discovered.

Keywords: GLOF, Rockfall, Glacial lake, Imja, Sagarmatha, Nepal

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Formation of the 2018 Bureya Landslide, Far East of Russia

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The Bureya landslide was formed on December 11, 2018 in the Bureya River valley in the Far East of Russia. It affected metamorphic rocks of the Upper Proterozoic age. The peculiarity of this rock slope failure was that it occurred in winter when air temperature dropped from ca. −3 °C to −37 °C. Landslide had complex structure and was formed in several stages with variable displacement mechanism. The first stage of main displacement can be classified as wedge failure transformed into rock avalanche more than 700 m long (measured from the slope foot) that moved with velocity up to 25–26 m/s. Landslide collapsed into reservoir and formed the splash wave up to 60 m high that washed out the taiga forest on the opposite slope of the valley. During the second stage that followed the first one in few seconds, large block of rock (260 × 280 m) slid down from the eastern part of the headscarp and formed rock avalanche up to 860 m long. The mean velocity of its motion was ~23–25 m/s, while the maximal one in its front could reach ~60 m/s. During the last stage several smaller secondary slides occurred on the slopes of the main landslide body and within the main headscarp. The total volume of the affected rocks can be estimated as 25 million m3, up to 12 million m3 of which were displaced during the first stage, up to 11.8 million m3—during the second stage and up to 1.2 million m3—during the secondary landslides formation. The Bureya landslide formed the natural dam more than 70 m high and up to 550 m wide that split the reservoir into two parts, so that special measures had to be undertaken to restore normal water flow.

Keywords: Large-scale slope deformations, Rock avalanche, Multistage development, Landslide dam

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Landslide Dam Hazards: Assessing Their Formation, Failure Modes, Longevity and Downstream Impacts

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In the last few decades, >200 new natural (mainly landslide) dams have formed in New Zealand. Several of these dams, such as the: 1996/97 Mount Ruapehu tephra dam (formed by volcanic eruption); 2007 Young River landslide dam; largest ten landslide dams associated with the 2016 Kaikōura Earthquake; and 2019 Kaiwhata landslide dam, have been studied in detail to better understand their: (a) formation mechanisms; (b) material properties; (c) failure modes; and (d) downstream impacts. This paper outlines a method to assess the longevity and downstream impacts of landslide dams, post-formation, by adopting a combination of field techniques, forecast models and expert judgement based on the performance of past landslide dams, immediately post-event. To do this we use the following steps: (1) carry out initial breach and inundation modelling using existing information—done prior to visiting the site; (2) detailed, high-resolution topographic surveys of the dam and downstream area; (3) site-specific investigations to measure key parameters such as the volume and geometry of the dam and lake, and the particle size distribution of the dam materials; (4) dam breach modelling using empirical methods to identify dam failure scenarios; (5) numerical flood/debris inundation modelling to determine area of impact; and (6) overlaying dam failure and debris inundation scenario models on asset maps to identify people, buildings and other infrastructure that are potentially at risk. This study summarises the method for assessing the likelihood of dam failure and the potential downstream consequences, using the Hapuku River and Kaiwhata dams as case studies.

Keywords: Landslide dam, Dam outburst flood, Kaikōura earthquake, Kaiwhata landslide, Rapid response

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The Sedimentology and Internal Structure of Landslide Dams—Implications for Internal Erosion and Piping Failure: A Review

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Detailed information on the internal structure and sedimentological characteristics of landslide dams is important for natural dam hazard assessment studies. The materials composing landslide dams play a significant role in determining their overall longevity and stability. This, on the other hand, is linked to their source stratigraphy and the degree of fragmentation and pulverization undergone by the materials during their transport and emplacement history. Overall, the time of failure of landslide dams and the magnitude of the outburst flood depend on the internal characteristics of the impoundment, such as the grain size distribution, grain shape, degree of consolidation, presence of subsurface discontinuities, erodibility, and clay percentage. The evolution of internal erosion and piping in landslide dams has been ascribed to the relationship between the internal structure of the dam and the discharge rate through the impoundment. This paper presents a systematic review of the influence of the internal structure and sedimentological characteristics of landslide dams on the piping failure of natural river blockages. The paper highlights the processes of emplacement of landslide dams, the internal modification of the sediment during transport, the different facies assemblages and their role in the evolution of internal erosion and piping. Results obtained from the microtremor (MTM) chain array survey gave a better understanding of the evolutionary history of landslide dams. Furthermore, preliminary results obtained from laboratory experiments gave credence to the notion that the longevity and stability of landslide dams formed by translational mass movements are higher than those formed by rock avalanche processes.

Keywords: Landslide dam, Sedimentology, Internal structure, Seepage, Piping, Internal erosion

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Investigation, characterization and monitoring of deep-seated landslides in the surroundings of large dam reservoirs

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In mountainous regions, deep-seated landslides, comprising volumes of millions of cubic metres, are often encountered. If active or reactivated over longer periods of time, slowly moving landslides can adversely affect infrastructure such as high- and railway lines, reservoir dams, pressure pipes, pipelines, and settlements due to differential and localised displacements of the ground surface and subsurface. A high danger potential is given when deep-seated landslides fail in a rapid manner characterised by very high sliding velocities, and/or when they develop into long run-out rock avalanches.

This contribution presents an overview of the experience gained from the application of different in-situ investigation, characterisation and monitoring methods on deep-seated landslides in the surroundings of large dam reservoirs. The aim is to increase process understanding, improve engineering geological models and provide new fundamentals for slope stability analyses and hazard assessments. Various surface and sub-surface in-situ investigation methods comprising i) detailed geological mapping, ii) drilling supplemented by core and geophysical logging, as well as hydraulic testing, iii) excavation of investigation drifts, and iv) geophysical exploration were applied at different case studies. The utility of these data in terms of hazard assessment was evaluated. Point- and line wise as well as area-based deformation monitoring methods are discussed using selected case studies. Special emphasis is placed on major improvements from remote sensing methods for investigation and monitoring such as airborne and terrestrial laser scanning, photogrammetry and radar interferometry to measure slope displacements, analyse terrain geomorphology and geological structures, and use the results for geological mapping and geometrical model design. Concluding, the challenge and need for a comprehensive process-based synthesis of the different types of investigation and monitoring data to obtain the greatest insight and benefit for hazard assessment is discussed.

Keywords: deep-seated landslides, in-situ investigation, monitoring, dam reservoirs

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March 2019 flood impact on the stability of Ambal salt ridge in the Gotvand dam reservoir, Southern Iran

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Ambal salt ridge is a unique exposure of salt piercement in the reservoir of Gotvand dam in the southwest of Iran. It is composed of Gachsaran Formation of Oilgo-Miocene Age with dominant salt, gypsum and marly layers. This structurally controlled piercement is a accompanied by subsidence and sliding of highly soluble layers into the dam reservoir. The region is affected by neotectonic activity in such a way that the Ambal ridge is aligned with an N-S basement lineament. Based on a four years field observation and monitoring, a gradual and continuous sliding is occurring that is intensified by ground water circulation through evaporite karstic sinkholes and fracture systems. The subsidence and sliding of the Gachsaran evaporitic layers were significantly increased after a severe flash flooding in March 2019. Flooding increased the reservoir water level to exceed the maximum normal operation elevation (234 masl) up to an elevation of about 236 masl. The water level rising caused filling and saturation of the existing sinkholes in the salt ridge that facilitated and prompted development of land sliding. The situation was expected to be more critical if a moderate to high earthquake would happen as the dam region laid in an active tectonic zone that is the Zagros Active Fold Belt. Land subsidence and sliding was facilitated by high fracturing due to proximity to two known and important active faults namely, Lahbari and Pir-Ahmad thrust faults. Finally, based on the Newmark method, slide potential of the largest landslide body on the western flank of the Ambal ridge was calculated considering geotechnical parameters obtained from core drilling and regarding to partial saturation of the salt body during March, 2019 flooding of Karun River.

Keywords: Gotvand dam, Landslide, Ambal salt, Slope stability

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Rock Avalanches: Basic Characteristics and Classification Criteria

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Rock avalanches represent the specific type of flow-like landslides—dry granular flows—that pose major threat to population in mountainous regions and in the adjacent plains. Being extremely mobile, they can affect areas up to dozens of square kilometers, extending sometimes for more than 10 km from the feet of the collapsing slopes. The internal structure of their deposits is characterized by intensive fragmentation of inner parts overlain by much coarser carapace. Such internal structure is typical of the vast majority of large-scale rock slope failures, both long runout and forming compact blockages in narrow river valleys. Therefore, all of them should be classified as rock avalanches, rather than as rock slides. Three additional classification criteria closely related to rock avalanche mobility and allowing more strict definition of a particular rock avalanche are discussed, i.e. the confinement conditions, debris distribution along the rock avalanche path, and directivity of debris motion. Besides providing information on debris motion mechanism(s), these characteristics predetermine the assessment of the exposure of elements at risk that might be affected by rock avalanche. It is demonstrated that transformation from the block slide to granular flow depends somehow on the morphology of the transition-deposition zone and on the mechanical properties of the basal surface, but is independent from the type and mechanical properties of the host rocks.

Keywords: Rock avalanche, Rock slide, Classification, Fragmentation, Internal structure

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An Interdisciplinary Assessment of a Coal-Mining-Induced Catastrophic Landslide (Czech Republic)

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The results are summarised of the correlation between long-term geotechnical monitoring, geological and geophysical surveys, finite element method modelling and their geomorphological interpretation in the area of North Bohemia affected by coal mining for more than 100 years. An underground mining-induced catastrophic landslide occurred in 1952 and had direct impacts on the local municipality, this still active and complex landslide has been well described since a detailed monitoring network was installed in the 1980s. Unique deep rock-mass monitoring is based on precise geodetical measurement in an exploration gallery from 1980. Several different types of deep-seated and near-surface landslide processes with different dynamics were identified during four decades of interdisciplinary monitoring, FEM modelling, ERT profiling and numerous other surveys. Landslide processes are influenced by anthropogenic activities in varying degrees, but climate factors have played the main triggering role in the recent past.

Keywords: Complex landslide, Mining-induced landslide, Monitoring, ERT, FEM, Czech republic

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Could Glacial Retreat-Related Landslides Trigger Volcanic Eruptions? Insights from Mount Meager, British Columbia

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Mount Meager, a glacier-clad volcanic complex in British Columbia, Canada, is known for its large landslides, as well as a major eruption about 2360 years ago. In 2010, after decades of glacier retreat, the south flank of Mount Meager collapsed, generating a huge (53 Mm^3) landslide. In 2016, fumaroles formed ice caves in one of the glaciers on the complex. This glacier is bordered by a large unstable slope presently moving about 3.5 cm per month. If this slope were to fail, a long-runout debris avalanche would reach the floor of the Lillooet River valley, with possible destructive effects on downstream infrastructure. The unloading of the volcanic edifice from an abrupt failure would also have unknown effects on the magmatic plumbing system. From geochemical, geophysical, and petrological data, we infer the presence of a magmatic chamber at 3–16 km depth. Based on numerical model simulations carried out to constrain the stress change, the failure would affect the stress field to depths of up to ~6 km, with changes in effective stress of up to ~4 MPa. The change in effective stress following such a landslide might destabilize the magmatic chamber and trigger an eruption. This result also suggests that a previously documented major flank collapse may have had a role in the 2360 cal yr BP eruption.

Keywords: Volcanic landslide, Stress changes, Eruption trigger, FEM, InSAR

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Structural and Dynamic Numerical Models of Rockslides in the Carpathians and the Alps

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The stability of rock slopes is often guided by the structural geology of the rocks composing the slope. In this work, we analyse the influence of structural characteristics, and of their seismic response, on large and deep-seated rock slope failure development. The study is focused on the Tamins and Fernpass rockslides in the Alps and on the Balta and Eagles Lake rockslides in the southeastern Carpathians. These case studies are compared with catastrophic rock slope failures with ascertained or very likely seismic origin in the Tien Shan Mountains. The main goal is to identify features allowing to identify seismically induced deformation modes based on the source zone rock structures. We will present examples of classical anti-dip slope and along-strike rock structures that hint at a possible/partial seismic origin, but we will also consider a series of mixed structural types, which are more difficult to be interpreted. This morpho-structural study is supported by distinct element numerical modelling results showing that seismic shaking typically induces deeper seated deformation in initially 'stable' rock slopes. In addition, for failures partially triggered by dynamic shaking, these studies can help identify the contribution of the seismic factor to slope movements. The identification of the partial seismic origin on the basis of the dynamic response of rock structures can be particularly interesting for case histories in less seismically active mountain regions (in comparison with the Andes, Tien Shan, Pamirs), such as in the Alps and the Carpathian Mountains.

Keywords: Deep-seated failure, Bedding and joint orientation, Seismic deformation, Structural analysis, Discrete element modelling

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Quantitative Investigation of a Mass Rock Creep Deforming Slope Through A-Din SAR and Geomorphometry

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A Deep-Seated Gravitational Slope Deformation (DSGSD) affects the SE slope of the Siah-kuh anticline in its SE periclinal tip in the Ilam region (Zagros Mts., Iran), almost 30 km south of the Seymareh Landslide, which represents the largest landslide on Earth surface. The DSGDS is driven by a Mass Rock Creep (MRC) process and involves an area of about 8 km2. The evolution of such a gravity-induced process is strictly related to the evolution of the of Dowairij River drainage system. River incision originated a stress release at the bottom of the slope which likely caused the initiation of the deformational process. The present study is part of a broader International Programme on Landslide project (Project IPL-237) focused on the role of time-dependent rock mass deformations and landscape evolution rates as predisposing factors for massive rock slope failures. In this regard, the preliminary results of an ongoing research are here presented focusing on the assessment of the present-day landscaping processes. Specifically, a geomorphological survey was carried out in this area firstly through the analysis and interpretation of remote data (Google Earth satellite optical images), which led to the first detection of possible gravity-induced landforms, such as evidence of bulging and lateral release within the deforming slope of the Siah-kuh fold-related ridge. To confirm and quantify the existence of ground displacement due to a MRC process, InSAR techniques were performed for the Siah-kuh slope and surrounding areas by processing 279 satellite Sentinel-1 (A and B) radar images of the ascending and descending orbit spanning from 06 October 2014 to 31 March 2019. Moreover, a quantitative morphometric evaluation was also performed through a morphometric index suitable for predicting the catchment-scale suspended sediment yield on the deformation area produced by the Dowairij River system. We derived the erosion rate of the drainage network responsible for the valley engraving which allows to estimate a starting time for MRC in the order of 101 ka. The comparison between the valley erosion rate and the slope strain rate reveals a difference of almost one order of magnitude allowing to assume that the gravity induced process, identified from remote and field geomorphological survey, evolves faster and originates landforms which can be preserved by the drainage system of the Dowairij River.

Keywords: Mass Rock Creep, SAR interferometry, Tu index, Zagros Mts

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Deformational Features of Deep-Seated Gravitational Slope Deformation of Slate Slopes in the Central Range, Taiwan

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Catastrophic landslides are reported to be related to large amounts of unstable rocks preceded by deep-seated gravitational slope deformation (DGSD), where the slopes are underlain by Eocene to Miocene slate in the Central Range of Taiwan. To understand basic geological causes of the slope processes, the study was conducted in the Cifeng, Lixing, and Maliguan areas along the Lixing Industrial Road where many DGSDs threat important infrastructures and villages directly. Geological survey suggests that the beds beneath the slopes are mainly slate interlayered with thin metamorphosed sandstone. The slate along the river beds displays a distinct slaty cleavage which strikes NE–SW and dips 60–80° to the SE, but was observed to have gravitationally deformed to form buckling and toppling folds. DGSDs on overdip cataclinal and anaclinal slopes are subjected to buckling and toppling, respectively. Some of DGSDs of both types have led to deep-seated rockslides. Besides, sites with potential of future catastrophic landslides may be geomorphically identified at undercut slopes that have small head scarps upslope.

Keywords: Deep-seated gravitational slope deformation, Catastrophic landslide, Slaty cleavage, Toppling, Buckling

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Bathymetric Analyses of Submarine Landslides on the Jan Mayen Ridge, Norwegian–Greenland Sea

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This paper considers the formation of submarine landslides on the Jan Mayen Ridge. A large submarine landslide, about 50 km wide, 40 km long and 500 m deep, has developed into an amphitheatre-shaped depression with subsequent retrogressive sliding along bedding planes to form secondary and tertiary landslide scars. This retrogressive process proceeded via small slope failures that generated erosive, confined turbidity currents. Consequently, long channels developed downslope of the secondary and tertiary landslide scars. Other small landslides are located on the deep-sea terraces at the foot of the southeast ridge. Internal normal faults on the terrace have generated an irregular bathymetry with many superimposed landslides. These small landslides formed on areas of relatively steep seafloor and are triggered by normal faulting.

Keywords: Retrogressive slide, Sliding from normal faulting, Channels, Turbidity currents, Norwegian sea

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Forkastningsfjellet Rock Slide, Spitsbergen: State of Activity in a Changing Climate

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The coastal ridge of Forkastningsfjellet comprises a ~100 million m^3 rock rotational slide, which occurred in the hangingwall of a listric, northwest-dipping slide surface, probably in postglacial times. Active mass wasting and seacliff erosion, mainly controlled by the inherent discontinuities of the fractured and tilted rock masses, currently take place along the steep slopes of the coastal tilt blocks. A catastrophic reactivation of such slide blocks as very rapid rock slide could have severe consequences for the surrounding coastal regions and for Longyearbyen, the capital of Spitsbergen, which is situated nearby. This paper introduces the present knowledge about the rock slide and describes the current multidisciplinary investigation program that is conducted to better understand the nature and state of activity of the rock slide. The investigation is necessary to improve the hazard assessment of Forkastningsfjellet rock slide, which also serves as a showcase for the impact of climate change on landslide activity in the Longyearbyen region.

Keywords: Forkastningsfjellet rock slide, Spitsbergen, Natural hazard, Climate change

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Catastrophic Landslides in Indian Sector of Himalaya

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The Himalayan geo-environment has been experiencing slope instability hazards of catastrophic dimensions in historical past. Large rocks and debris avalanche have been recognized largely in higher domains in easternmost extremity covering Sikkim and Arunachal and Northwest Himalaya encompassing Kumaun, Garhwal, Himachal, Jammu and Kashmir and Ladakh Himalayas. These domains have witnessed societal and morphological impacts due to such extreme events. The catastrophic landslides are mainly triggered by earthquakes and climate change related intense rainfall, cloudbursts, Glacial Lake outburst Floods (GLOF) etc. in different sectors of Himalaya. These cataclysmic events are caused by various proportions of geological, geomorphologic and geotechnical characteristics of slopes, relief and tectonic conditions including anthropogenic activities. Each of the recorded landslides differs greatly in their causes, triggering agents, run-out distances and impacts. A case study of recent catastrophic landslide in Garhwal Himalaya has been presented. The paper highlights importance of the historical records of catastrophic landslides and attendant changes in terrain morphology to plan for strategy for sustainable regional development.

Keywords: Catastrophic landslides, Himalaya, Cataclysmic events

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Landslides that caused fatalities in Canada from 1771 - 2019

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A revised compilation of historical fatal landslide events revealed that at least 785 people perished in Canada from 1771 - 2019. No event was reported in 2019. British Columbia (BC) experienced the highest number of fatalities at 355 (45%) and Québec (QC), the 2nd highest, at 239 (30%). These fatalities mainly reflect development within the landslide prone mountainous terrain in BC, and sensitive glaciomarine clay areas in QC. The mountains of Alberta have witnessed one event (73 fatalities; 9%). In Newfoundland and Labrador (NL), rockfall from rugged terrain are the main reason for 103 fatalities (13%). Fatalities only occurred in two other provinces and one territory: Ontario, 13 fatalities (2%), and 1 fatality (0.1%) in New Brunswick and the Northwest Territories. The lack of fatalities elsewhere is likely related to fewer landslide events and low density of population and development. The greatest number of landslides and fatalities occurred during the 1880s to 1920s, when major infrastructure corridors were developed, but landslide hazards were poorly understood. The most common months for fatal landslide events were September to January. In coastal BC, this reflects the occurrence of debris flows triggered along steep channels by high intensity rainfall events during the fall and winter months. In the St. Lawrence Lowlands, spring and fall months are the most common for fatal landslides in sensitive clays. The worst Canadian landslide disaster occurred in the mountains in 1903 at Frank, Alberta, where 73 people perished from a rock avalanche that buried a mining town. In QC, 35 historical landslides caused 239 fatalities; 24 of these fatal events occurred from landslides in sensitive clays. Since 2003, the Québec Ministry of Transportation developed regional landslide susceptibility maps to help mitigate landslides. Moreover, since the 1770s, understanding of landslides and their potential triggers has led to several mitigation measures and thus, fewer fatalities per decade and per event.

Keywords:

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Basal Liquefaction from Rapid Landsliding: The 2014 Deadly Oso Landslide (USA)

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Rapid landslides that travel long distances can devastate large areas, greatly increasing hazard and risk. In debris flows and flow slides, pervasive liquefaction can dramatically boost mobility, but liquefaction's effects on more coherent landsliding can be difficult to assess. On 22 March 2014, the Oso landslide in Washington, USA failed rapidly and swept more than 1 km across a flat alluvial valley, killing 43 people as it travelled. Our extensive field investigations revealed clear and abundant evidence for liquefaction of the alluvium beneath the landslide. We mapped more than 350 sand boils that emanated from alluvium underlying the debris-avalanche hummock field; the hummocks themselves were not liquefied and contained intact layered glacial sediments and upright vegetation rafted across the valley floor. Based on extensive laboratory testing of field samples and numerical modeling, we found that several mechanisms likely contributed to liquefaction of the underlying alluvium, including rapid undrained loading, shearing of loose contractive sediment, and cyclical loading from ground shaking. Here, we further explore the potential for a rapidly moving landslide mass to liquefy underlying sediments. We use a fully coupled poro‐elastic numerical model with parameters determined from laboratory tests of the alluvium beneath the Oso landslide. Given a landslide speed of 10 m/s estimated from seismic records, our modeling demonstrates that rapid loading induces transiently elevated pore‐fluid pressures nearly equal to the vertical load from the overriding landslide. These transient pore pressures are capable of liquefying the in situ alluvium, reducing its shear strength, and enhancing mobility. Sensitivity analyses indicate that the potential for liquefaction is strongly modulated by landslide speed and the hydraulic conductivity of the underlying alluvium. With slower speeds and/or greater alluvial hydraulic conductivity, pore pressures from loading dissipate before reaching liquefaction levels. Specific combinations of both landslide speed and hydraulic conductivity promote basal liquefaction.

Keywords:

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The evaluation of Deep-seated catastrophic landslides (DCLs) on Kii Peninsula 2011 by means of the historical deformation)

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The heavy rain induced by Typhoon Talas in 2011 caused deep‐seated catastrophic landslides on Kii Peninsula in the central part of Japan. Several areas experienced higher rainfall amounts and precipitation of 1,322 mm or more occurred in mm of rain was recorded at this site over the storm's duration. Geologically, the Kii Peninsula consists mainly of an accretionary complex in the Shimanto Belt, which generally has a north‐east‐south‐west strike and a north‐westward. The accretionary complex consists of foliated mudstone, sandstone, acid tuff, chert, and greenstone, and contains a small amount of Miocene granite and sedimentary rocks [Chigira et al ., 2013]1). Nara Pre. Published DCLs map2) in 2015. The total volume of DCLs 2011 was 100million cubic‐m, the height of DCLs was 92.2m – 609.5m, the angle of DCLs is 24.2 degree – 45.1 degree. As shown slide4, specific Occurrence site of almost DCLs does not exist on paleosurface4). Recent deep‐seated catastrophic landslides have occurred on slopes with the slope breaks or newly incised slopes below the breaks (L2)5). Recently, InSAR technology can be applied monitoring in mm6), 7). SqueeSAR™ has been carried out on the distribution area of DCLs in Kii peninsula (Slide5, 828 square km). ALOS (L‐band, 6m*6m) were analyzed before TALAS and SENTINEL8)(C‐band, 5m*20m) were analyzed after TALAS. Vertical and E‐W deformation were decomposed by using Ascending and Descending images. Time series of deformation of LOS direction on the surroundings of Kawabri thrust (by Chigira3)) before TALAS is shown Slide8. The crown of Akatani DCL was subsiding about 10mm – 20mm before TALAS as CODE No. B815KOK, B87FRTJ and ATOP6S0 in Slide 8. The crown of Kwarabi DCL was subsiding about 15mm as CODE No. ASLEKKW before TALAS. The foot of Nagatonotani DCL is up‐thrust about 10mm as CODE No. BEQLZTD before TALAS. The middle head and foot of Nigoridani DCL was up‐thrust about 20mm as CODE No. BIX8NP5 and BJFP3FQ. And The top of Shimizu (Ui) was subsiding about 50 mm before TALAS as CODE No. BCPDP35 and BD49J76. Time series of deformation LOS direction on the surroundings of Kwarabi thrust after TALAS is shown Slide 10. The tip of Kawarabi and Nigoridani is being up thrust about 10mm – 20mm after TALAS as CODE No. PTBRMS3, Q6KNU88 and Q5XFXN7. The foot of Akatani, Kawarabi, Nagatonotani and Nigoridani is subsiding about 20mm – 50mm after TALAS as the deformation of Descending direction. The deformation of LOS direction on DCLs after TALAS using SENTINEL is constant not effected precipitation. The vertical and E‐W deformation contour before TALAS was shown Slide 11 and 12. Mountain peak is subsiding along N‐S parallel line. DCLs distributed along up‐thrust area N‐S parallel line on the surroundings of Kawarabi thrust. Almost DCLs on the surroundings of Kawarabi thrust was deforming to West direction cause of slope inclination. It is important that W‐E deformation have been effected by tectonic motion of Kii peninsula.

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Catastrophic landslide and subsequent tsunamis in North-Patagonian District, Chile

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Landslides occur frequently in Norpatagonian Andes due to susceptible geomorphology and geological features and recurrent trigger events of heavy rainfall and earthquakes. Some of these landslides are tsunamigenic when hit lakes or fiords, which in turn, have caused disasters by impacting communities. This work present three events, contrast them and discusses the conditioning and triggering factors and impacts. The first case, May 1960 earthquake (Valdivia, Chile, Mw 9.5) induced countless disasters in populated areas, among them Rupanco Lake area. Here the soils and volcanic sediments layers were saturated by 2 days of heavy rainfall, later, during the earthquake hundreds of debris avalanches were triggered, traveled 1,000 m through slopes over 40 degrees at a speed about 30 km/h, impacted the NW Rupanco Lake corner and a at least 12 m wave high raise. This caused the complete destruction of Las Gaviotas settlement. The second case, in February 1965, in Yate volcano, after 15 days rainfall, a mass of rock and ice of ~6.1-10><10^6 m^3 detached from 2,000 m s.n.m. and transformed in a debris flow, moving 40 m s^{-1} velocity in the upper part, travelled 7,500 m and descended 1,490 m in the SW flank, and the wavemarker of estimated volume 9±3 >10^6 m^3 impacts Cabrera Lake causing a tsunami with an estimated amplitude of 25 m and a run-up of ~60 m at the west end of the lake. This event caused 27 fatalities. The third event, in April 2007, a crustal earthquake (Mw. 6.2), related to Liquine-Ofqui Fault Zone activity triggered several landslides, in granitic rocks, that travelled about 1,000 m with velocity 15-50 ms^{-1}, and impacted Aysen fjord, caused a tsunami with wave 5-10 m high and runout about 300 m. This caused destruction of salmon farms and 10 fatalities.
There are other events without historical record, characterizable through the sedimentary record, for example in the Puelo area. We are looking for other places where tsunamigenic events of such magnitude could occur through landslide inventory, fieldwork, and image analyze and mapping.

Keywords: landslide and tsunami, norpatagonian landslide

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The massive February 17, 2006, Leyte, Philippines, rockslide

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The results of a field reconnaissance and computer modeling study of the February 17, 2006 rockslide which occurred in Guinsaugon, Southern Leyte, Philippines are presented. The rockslide created a large scarp on the 800-m high Mt. Canabag and involved a large amount of debris consisting of mud and boulders. The debris flow resulted from the slide had a volume of about 25 million m3 and completely inundated the village of Guinsaugon located at the foot of Mt. Canabag. The rockslide occurred between 10:30 and 10:45 AM on February 17, 2006. It involved the movement of an extremely large piece of rock, and the scarp created by the slide is about 600 m high, 200 m at its deepest part and possibly about 600 m wide at its base. Prior to the slide, there was an overhanging rock formation at the location of scarp, as identified in pre-slide topographic maps and old photographs of the area. The debris completely inundated the village of Guinsaugon located at the foot of Mt. Canabag. In the aftermath of the slide, at least 1,328 persons were reported to have been killed. Numerous houses and buildings, including an elementary school with about 300 students and teachers in attendance, were completely buried. The field reconnaissance used LIDAR to establish the geometry of the scarp created by the slide, and to obtain data on fracturing at the side. Three-dimensional distinct element modeling (DEM) was used to determine the cause of the triggering of the slide and the subsequent long-running flow of the debris materials. Different loading mechanisms were tested in the simulations, and the results were compared with accounts made by slide survivors and observations made during post-slide reconnaissance surveys of the rockslide site.

Keywords: rockslide, debris flow, LIDAR, reconnaissance, distinct element modeling, triggering mechanisms

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Giant landslides in the foreland of Patagonian Andes: effects of deglaciation and drawdown of glacial lakes

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Giant catastrophic landslides (>108 m^3) dot the formerly glaciated mountain forelands of the eastern Patagonian Andes. From geomorphic mapping, sedimentological logs and radiocarbon dating, we infer the emplacement kinematics and approximate timing of giant landslides in moraines and other glacial deposits in the Lago Pueyrredón valley (LPV), Argentina. For the first time, we report in detail examples of giant low‐gradient landslides with hummocky lobes derived from unconsolidated glacial deposits and weak bedrock. We find that at least 4.5 km^3 of debris and weak bedrock were mobilized by slope failures in an area of ~500 km^2 since the Last Glacial Maximum (LGM; ~25–18 ka). Nearly 90% of this landslide volume originated along the shores of, or as subaqueous failures in, a postglacial moraine‐dammed meltwater lake. The larger landslides (>1 km^3) detached from moraines fringing the lake, whereas other landslides displaced glacial and lake deposits in a river gorge that was cut upon drainage of the glacial lake. Sequences of till, glaciofluvial and glaciolacustrine deposits overlying weak Early Miocene marlstone are mostly conducive to major landslides in the LPV. Cross‐cutting relationships indicate that largest landslides in the area originated during rapid glacial lake‐level drops. It suggests that giant catastrophic landslides in the glacier forelands of Patagonia can result from layered weak rocks, changes in meltwater‐lake levels, and possibly as a consequence of strong earthquakes linked to rapid post‐glacial rebound following the retreat of the Patagonian Ice Sheet (PIS).

Keywords:

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Enhancing Preparedness Against Impact of Climate Change on Slope Safety in Hong Kong

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Over the past 40 years, a comprehensive slope safety system has been developed and implemented by the Geotechnical Engineering Office (GEO) to manage the landslide risk in Hong Kong to a reasonably low level. However, extreme rainfall events due to the effect of climate change could bring about widespread and large-scale landslides. Therefore, the GEO has made concerted efforts to enhance our preparedness for extreme landslide events. This paper highlights the holistic, multi-pronged approach adopted to manage the landslide risk associated with climate change.

Keywords: Landslide, Slope safety system, Extreme rainfall event, Rain-induced landslide, Emergency preparedness and response, Risk management

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Climate Change and Surface Deformation Characteristics in Degradation Area of Permafrost in Lesser Khingan Mountain, China

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Over the past 100 years, the process of global climate change has accelerated, and the air temperature has also appeared an increasing trend in the high latitude permafrost area of northeast of China, the permafrost degradation which dramatically changed the environmental geological conditions,resulting in the change of landform and the increase of geological disasters.However, there are few research results about this area. In this paper, we take the road area of Bei'an-Heihe highway crossing the Lesser Khingan Mountain as the study area. Using a total of 18 ALOS/PALSARSAR images, through the SBAS-InSAR technique to draw the surface deformation map of the study area from July 2007 to December 2010, combined with the local meteorological data and the permafrost distribution map in the study area obtained by our research group, the relationship between distribution characteristics of permafrost, permafrost degradation, and surface deformation were analyzed. The results show that the annual average deformation rate of surface in the study area is ± 70 mm/year, the surface deformation is closely related to the permafrost distribution, and the distribution law is consistent.Climate warming is the main factor leading to the permafrost degradation. In the context of continued warming and accelerating degradation of permafrost, we will face landslides, ground surface subsidence or more ecological and engineering problems, threaten the safety of local engineering structures. The results reveal the law of the permafrost degradation process under the background of climate warming, and provide a reference for future research.

Keywords: climate change, Permafrost degradation, Permafrost distribution, Surface deformation, SBAS-InSAR

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Climate Change Impact Evaluation on the Water Balance of the Koroška Bela Area, NW Slovenia

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Climate change is expected to affect the elements of the hydrological cycle, which are also related to the landslides and debris flows triggering mechanics. In the scope of this contribution, we evaluated climate change impact on the water balance components in the hinterland of the Koroška Bela (NW Slovenia), which is one of the endangered settlements in Slovenia. For this purpose, we focused on the representative concentration pathway (RCP) RCP4.5 scenario, which can be described as a midway scenario. Lumped conceptual hydrological model was used in order to model the relationship between the hydrological cycle elements. Moreover, climate change impact on the intensity-duration-frequency (IDF) curves was also estimated. The results indicate that total rainfall as well as effective rainfall could increase in the future. Mainly due to air temperature increase, we could see an evapotranspiration increase in the future. Moreover, hydrological model results indicate a possible surface runoff increase from the Bela stream catchment. However, these changes are mostly in the range of the 5% with the exception of the air temperature data where difference between future and past is larger. Furthermore, subsurface water storage included in the model indicates that only slight changes in the wetness of the catchment might be expected. Additionally, climate change could also affect the extreme rainfall characteristics, which can be seen as a change in the IDF curves. However, these changes are relatively small.

Keywords: Climate change, Water balance, Rainfall, Runoff, Koroška bela, Landslides

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Characteristics and Causes of the Debris Flow in Shelong Gully, China

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A rainfall-induced debris flow disaster occurred in Shelong Gully on the 22th June, 2019. More than 26,300 m^2 of farmland and 14 houses were buried and transportation and power supply broke down in the worst catastrophe in the history of Shelong area. To investigate this disaster, a detailed interpretation was carried out using (Unmanned Aerial Vehicle) UAV-based images. Analysis of disaster characteristics based on images and field survey revealed that the disaster could be identified as a consequence of compound mountain hazards including mass movements and mountain torrent in Shelong Gully. Moreover, the dynamic process of debris flow was analysed by using the finite difference method. Its dynamic characteristics indicated that the structure of debris materials changed during the movement process of debris flow. The results reveal that the loose materials, steep terrain condition and abundant rainfall are the main causal factors of this disaster event. This research on the analysis of hazard formation conditions and dynamic process for debris flows is of guiding significance to the formulation of disaster risk assessment and disaster mitigation plans.

Keywords: Debris flow, Dynamic process, Hazard formation, Disaster risk reduction, Rainfall

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Extreme Rainfall Induced Landslide Susceptibility Assessment Using Autoencoder Combined with Random Forest

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The purpose of this study is to evaluate Autoencoder-based landslide susceptibility areas triggered by extreme rainfall in Shimane Prefecture, Japan. Deep learning methods can take advantage of the high-level representation and reconstruction of information from landslide-affecting factors. In this paper, a novel deep learning-based algorithm that combine classifiers of both deep learning and machine learning is proposed for landslide susceptibility assessment. A stacked autoencoder (StAE) and a sparse autoencoder (SpAE) both consist of an input layer for raw data, hidden layer for feature extraction, and output layer for classification and prediction. As a study case, Oda City and Gotsu City in Shimane Prefecture, southwestern Japan, were used for susceptibility assessment and prediction of landslides triggered by extreme rainfall. The prediction performance was compared by analyzing real landslide and non-landslide data. The prediction performance of random forest (RF) was evaluated as better than that of a support vector machine (SVM) in traditional machine learning, so RF was combined with both StAE and SpAE. The results show that the prediction ratio of the combined classifiers was 93.2% for StAE combined with RF model and 92.5% for SpAE combined with RF model, which were higher than those of the SVM (87.4%), RF (89.7%), StAE (84.2%), and SpAE (88.2%). This study provides an example of combined classifiers giving a better predictive ratio than a single classifier. The asymmetric and unsupervised autoencoder combined with RF can exploit optimal non-linear features from landslide-affecting factors successfully, outperforms some conventional machine learning methods, and is promising for landslide susceptibility assessment.

Keywords: Autoencoder, Support vector machine, Random forest, Landslide susceptibility, Deep learning

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Rainfall-induced landslides and debris flows in Mengdong town, Yunnan province, China

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On 2 September 2018, an intense rainstorm swept Mengdong town in Yunnan province of China, inducing a serious landslide and debris flow disaster with 10 deaths and 11 missing. Image interpretation, field survey, and slope stability analysis were used to examine the characteristics and initiation mechanism of this hazard. A total of 1774 landslide scars were identified, the area of which occupied 8.26% of the study region. Due to the spatial inhomogeneity of precipitation, these scars mainly concentrated along valleys in the lower part of the study area. Besides, well-forested hillslopes were more prone to landslides, indicating the limited role of trees in stabilizing slopes in extreme rainfall evens. The initiation of landslides is mainly attributed to the weak cohesion of the saturated clayey sand beneath the root zone, where the tensile resistance of roots was absent. Additionally, 288 landslide scars were situated adjacent to roads, demonstrating that the road construction activity had intensified the landslide disaster. Owing to the relatively low mobility of landslides, a considerable portion of landslide debris deposited on the valley floor in smaller watersheds (< 6.03 hm2), while the remaining portion entered high-order channels. In these channels, where stream power was relatively large, the woody debris and soil carried by landslides were entrained by streamflow, and debris flows were formed. Moreover, the magnitude of debris flow was amplified by the vertical and lateral erosion of the stream channel.

Keywords: shallow landslide, debris flow, initiation mechanism, spatial distribution, forested slope, stream power

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Landslide triggered by rainfall and Land use change: A case study of Laptap Landslide, Arunachal Pradesh, India

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Landslides occur every year in Arunachal Pradesh, however, human and financial losses generated by a landslide event vary considerably with the location of the landslide and its intensity. The state receives 64% of annual rainfall during southwest monsoon (June-September;IMD Records1989-2018). In the tectonically active eastern Himalayas, landslide triggering is closely linked to the stability of the hill slopes. The Laptap settlement falls in the high landslide hazard zone (Landslide Hazard Zonation map of Arunachal Pradesh, 2008 and Global Landslide Susceptibility Map, 2019). The Laptap landslide occurred on 11th July 2017 at around 2.30 pm killing 14 people from a particular clan. Eight of them were adult female and others are children(aged 2-18 years). It was a high intensity debris flow consisting of boulders and huge lump of wet soil material that ran over the highway and buried five houses, fish pond and a portion of the agricultural field located within the run-out path of the landslide. The area has undergone significant Land use/Landcover changes mainly due to conversion of the open mixed forest to orange plantation (1962-2017) and widening of road for the construction of highway. The affected slope facet is steep, facing S-SE. The rdNDVI (loss) range is around -15.25% to -34.91% in the six months pre-and post landslide event window (HazMapper). In March 2017 pre-event worldview imagery the earth cutting is visible at the toe of the affected slope facet. From 30 June to 11 July 2021, 245 mm rainfall was recorded and highest rainfall of 61.4 mm was on 10th July, a day before the fatal event. The antecedent rainfall made favorable hydrological condition of soil saturation, reduction in cohesive strength and degradation of slope stability due to a weak exposed base of the facet. The incident established the importance of hazard resilient planning, slope stability analysis and inter-departmental cooperation for land use development. The Laptap case also suggests that the capacity development to prepare, respond and recover from hazard risk should be inclusive. Awareness about the high landslide susceptible hotspot areas before arrival of monsoon is imperative to improve disaster resilience.

Keywords: Laptap Landslide, landuse change, rainfall

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Relationships between antecedent rainfall and volume of earthquake-induced landslides in historical era of Japan

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Dellow and Hancox (2006)[1)] indicated strong influence of rainfall on earthquake-induced landslides. The author also confirmed closely relationships between antecedent rainfall, snow piles and the volume of the earthquake-induced landslides in Japanese historical examples.

The author examined 17 inland (intra-plate) shallow large (M≧6.8) earthquakes since latest 19th century. Precipitation in 10 to 30 days prior to the earthquake at the nearest meteorological observation station were gathered from the homepage of Japan Meteorological Agency (www.data.jma.go.jp/obd/stat/etrn/index). Historical earthquakes' documents (e.g. Earthquake Research Institute, 1981[2)]), volumes of landslide debris of the largest ones in each event were after the Japan Landslide Society (2012)[3)]

There is a close relationship on antecedent rainfall and the volume of the earthquake-induced landslides, and somewhat semi-log correlation is also recognizable. This means groundwater is a major factor in earthquake-induced landslides formation. And this suggests the necessity of meteorological data for early seizing of earthquake disaster. This study is a preliminary one, much more examples are needed, especially from different climatic regions. It may contribute to mitigate earthquake disaster that draining prior to earthquake in mountain region, however, we need more research on the influence on ecosystem by draining and behavior of groundwater during the earthquake-induced landslides.

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Keywords: earthquake-induced landslide, historical disaster, antecedent rainfall, landslide mass, Japanese islands

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Looking for a Temperature Control on Slope Stability

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Climate change is influencing our society in many ways. Frequent and intense storms, prolonged draughts, heatwaves, wildfires, and changes in land use play a major role in defining the frequency and patterns of landslides, and hence the risk they pose to people, infrastructures, and ecosystems. The short-term behavior of slopes under climatic forcing is typically studied via hydrological-hydraulic-mechanical approaches. Susceptibility and hazard models usually focus on established triggers and controls, such as rainfall, seismic shaking, morphology, and lithology. Yet, they neglect the possible role of thermal variables in directly controlling the slope mechanics. By doing so, they disregard thermo-hydro-mechanical processes, which are instead, well recognized in other engineering geological contexts. Temperature exerts a control on the strength of rock exposures, particularly in seasonally cold climates, whereas evidence of its role in defining soil strength is scarcer. Coupled thermo-hydro-mechanical processes in soils and rocks are highly complex and, at times, counterintuitive. They are well studied in high-pressure and high-temperature conditions, such as in seismic faults and slip zones of large and fast landslides. They are also considered in the design of specific engineering infrastructures, such as underground radioactive waste repositories and heat exchangers. However, laboratory experiments show that most hydro-mechanical properties of geomaterials depend on temperature significantly, also in ranges that are typical in shallow soils in temperate climates. In our research, we hypothesize that temperature fluctuations and trends, propagating from the surface to the subsurface, may exert a direct effect on the stability of soil slopes and the kinematics of landslides. Here, we review temperature-dependent processes potentially relevant to slope stability, and discuss their complexity. We show results of laboratory experiments and catchment-scale studies, and discuss a research path to fill knowledge gaps across the scales, arguing for the beneficial effect of accounting for temperature-related variables into hazard assessments under climate scenarios.

Keywords: landslide, slope stability, climate change, temperature, THM coupling

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Bellwether sites for evaluating changes in landslide frequency and magnitude in cryospheric mountainous terrain: a call for systematic, long-term observations to decipher the impact of climate change

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Permafrost and glaciers are being degraded by the warming effects of climate change. The impact that this degradation has on slope stability in mountainous terrain is the subject of ongoing research efforts. The relatively new availability of high-resolution (≤ 10 m) imagery with worldwide coverage and short (≤ 30 days) repeat acquisition times, as well as the emerging field of environmental seismology, presents opportunities for making remote, systematic observations of landslides in cryospheric mountainous terrain. I reviewed the literature and evaluated landslide activity in existing imagery to select five ~ 5000-km^2 sites where long-term, systematic observations could take place. The five proposed sites are the northern and eastern flanks of the Northern Patagonia Ice Field, the Western European Alps, the eastern Karakoram Range in the Himalayan Mountains, the Southern Alps of New Zealand, and the Fairweather Range in Southeast Alaska. Systematic observations of landslide occurrence, triggers, size, and travel distance at these sites, especially if coupled with observations from in situ instrumental monitoring, could lead to a better understanding of changes in slope stability induced by climate change. The suggested sites are not meant to be absolute and unalterable. Rather, they are intended as a starting point and discussion starter for new work in this expanding landslide research frontier.

Keywords: Climate change, Landslide, Rock avalanche, Rock fall, Debris flow, Frequency, Magnitude, Mobility, Hazard, Permafrost, Glacial retreat, Air temperature, Satellite imagery, Landsat, Sentinel, NISAR, Seismology, Monitoring

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MPM Modelling of Buildings Impacted by Landslides

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The paper discusses the topic of dynamic impact of fast-moving flow-like landslides against structures such as masonry walls and buildings. A set of numerical simulations is developed through the Material Point Method (MPM) to investigate the landslide-structure interaction. First, some experimental results available in the literature for masonry walls made of clay bricks and mortar joints are simulated in 2D and 3D conditions appropriately reproducing the overall stiffness, resistance and displacement of the wall in out-of-plane loading, until plastic hinges are formed and complete collapse occurs. In these cases, a known external pressure is applied to the wall. Then, realistic flow-like landslide scenarios are considered for analysing the impact on reinforced concrete buildings with unreinforced masonry infilled walls. Particularly, the impacting mass is modelled as a frictional material composed of a solid skeleton saturated with water. MPM simulations are developed in 2D conditions, focusing the attention on the failure of non-structural elements and damage to the different floors. MPM simulations are varied again over a range of properties to assess the role of key parameters, among impact velocity, volume, and soil properties such as unit weight and internal friction angle. The potential of a unitary approach for simulating the fast propagation of a saturated soil and the stress-strain response of a structural element is discussed.

Keywords: MPM, Displacement, Interaction, Failure, Building, Out-of-plane

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Accelerating Landslide Hazard at Kandersteg, Swiss Alps; Combining 28 Years of Satellite InSAR and Single Campaign Terrestrial Radar Data

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In summer 2018, in an area above lake Oeschinen in Kandersteg (Bernese Alps, Switzerland), significant terrain changes with indication of fast ground movements were observed. The NW dipping rock and debris slope named “Bim Spitze Stei” had been known to be under constant movement before. However, the rapid acceleration from a maximum volume prone to failure of about 20 mm^3 prompted the authorities to undertake a thorough analysis of the situation and analyse primary (rock avalanche) and secondary (floods and debris-flows out of the rock avalanche debris) hazard processes and the risk they pose to the nearby Village of Kandersteg. A first assessment of the most recent Sentinel-1 satellite InSAR data confirmed rapid ground movement in the order of several mm/d up to cm/d and a rapid acceleration of the west-flank of “Bim Spitze Stei” landslide from initially 7 mm/d to few cm/d within 2 weeks in July 2018. In addition, different sectors with different kinematics could be identified by interpretation of single interferograms. In a second step, an archive analysis of historical InSAR data reaching back to 1991 clearly showed that an acceleration trend from initially sub-stable conditions up to several m/a. Finally, based on the findings from the satellite InSAR analysis, a survey campaign with a terrestrial radar interferometer was performed in order to define the current state and location of the potentially outcropping glide plane in the west-flank. The successful campaign led to the observation of the presence of two active glide planes with the lowermost encompassing the maximum estimated volume of the mass in movement thus helping for the definition of potential failure scenarios thus helping in the selection of enhanced monitoring systems and increasing the preparedness for the runout-areas.

Keywords: Landslide hazard assessment, Landslide acceleration, Satellite InSAR, Terrestrial radar interferometry, Glide plane detection

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Identification Old Landslides in Permafrost Degradation Area in Northeast China by Difference Distribution of Surface Trees

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With the development of global warming, the permafrost in Northeast China, which is located in the south margin of permafrost area in Eurasia, has gradually degenerated, resulting in an increased incidence of landslides. At present, research on the occurrence mechanism, movement process characteristics and evolution trend of landslides in permafrost area, is limited and lacking in detail. It is difficult to identify landslides that have cured within the last hundred years as movements have been relatively small during this time period. In addition, the lack of written records, the unusual geological environment and landforms and the surface coverage, as well as the landslide mechanisms mean that accurate identification is difficult using existing technology. In this paper, Beian-Heihe expressway, which is located in the permafrost degradation area of Northeast China, is selected as the research area. Field investigation, 3D modeling of UAV image, high-density electrical survey, geological drilling and other methods are used to study the distribution of new and old landslides in the area. The study found that the distribution of tree populations at the boundary of the old landslide and some parts on the landslide body was significantly different from the distribution of tree populations outside the landslide body. In combination with tree core sampling, with the help of the relevant theories and methods of dendrochronology, Statistical analysis of tree species distribution and tree ring differences was used to estimate the occurrence time of old landslides. Combined with the previous research results, the relationship between the movement process of landslides and the degradation of permafrost in the study area is analyzed. This method can effectively realize the positioning and model reconstruction of old landslides in a short time scale, which will have important theoretical and practical significance for the early warning and treatment of landslides in permafrost degradation area.

Keywords: Eurasia permafrost, Climate change, Old landslides, Trees population, Tree ring

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A Landform Evolution Model for the Mannen Area in Romsdal Valley, Norway

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The Quaternary geology of western Norway's landscape is the result of glacial and post-glacial sedimentation and erosional processes, a significant sea-level drop and high rock-slope failure activity. All these processes are represented within a small valley section below the Mannen rock-slope instability in Romsdal valley, western Norway. Here, exposure ages, Quaternary geological mapping and geophysical investigations permit the development of a paraglacial landscape evolution model. The model contextualises at least six catastrophic rock-slope failure events within the overall sequence of fjord-valley infilling following deglaciation. A transition from a wide basin-like valley into a strongly confined valley section led to the build-up of more than 40 m thick stratified drift, which was at least partly deposited within a marine environment. The morphology of these sediments features two distinct erosional levels, which are interpreted to be connected to tidal currents during post-glacial sea-level drop. The landform evolution model illustrates the importance of catastrophic rock-slope failures and the impact of strong tidal currents on the typical sediment fill in narrow, high-relief fjord valleys.

Keywords: Fjord-valley fill, Catastrophic rock-slope failures, 10Be dating, Quaternary geology, Paraglacial landscape evolution

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Multimethodological Study of Non-linear Strain Effects Induced by Thermal Stresses on Jointed Rock Masses

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A multimethodological method based on environmental, stress–strain, microseismic, and ambient seismic noise monitoring is here presented, with a view to identifying non-linearity of thermally-induced deformation of jointed rock masses at different dimensional scales. Rock masses experience non-negligible deformation cycles due to the continuous fluctuations of their surficial temperatures. However, the interpretation of such strain effects, in terms of the ratio between elastic and inelastic percentages, is still debated. In particular, the relation between microseismic emissions, considered as primary indicators of crack-growth related energy release, and resonant frequencies fluctuations of rock structures, witnesses of the thermally-induced effect at the macro- or structure-scale, have not been yet studied within a coupled framework. The combination of different approaches able to investigate the behavior of rock masses from micro- to macro-scale, then from fracture-scale to joint-isolated rock blocks up to rock structures, could provide new insights and perspectives on the effects related to shallow thermal stresses fluctuations. This paper presents the preliminary outcomes from two case studies, the Acuto experimental test-site (Italy) and the Wied Il-Mielaħ sea arch (Malta), where multiparametric monitoring surveys were conducted and are still ongoing, aiming at the assessment of the cause-to-effect relation between near-surface thermal stresses and induced strains. Data analysis was carried out following different approaches, with a particular emphasis on the Acuto test-site dataset recorded so far, allowing to establish a well-constrained correlation among temperature fluctuations and rock mass deformation both at the daily and seasonal scale.

Keywords: Multiparametric monitoring, Thermal stress, Rock masses

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Economizing Soil Nailing Design by Drainage Improvement - Case History at Ginigathhena

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As a tropical country which faces two monsoons with heavy precipitation, rainfall is identified as the major triggering factor for landslides in Sri Lanka. Reactivation of ancient landslides is a major challenge faced by the engineers in infrastructure development in the hilly terrain of the country. An ancient landslide at Bridge No. 48/2 in Avissawella—Hatton—Nuwaraeliya road was reactivated by excavation at the toe for the proposed widening of the bridge. This propagated further by the extensive rainfall that occurred subsequently. The site is a sloping ground with undulating topography towards upper slope in the form of a valley formed by an ancient landslide. Mitigation of the landslide was done to accommodate the widening of the bridge and to minimize the risk of further activation by rainfall. Mitigation measures adopted were drainage improvement, slope modification and soil reinforcement. Soil nailing was used as the reinforcement technique. Surface and subsurface drainage improvement was used for economizing the nailing design. This study presents how the nailing design was optimized by using different drainage arrangements. GeoStudio SEEP/W and SLOPE/W software were used for seepage and slope stability analyses, respectively.

Keywords: Drainage, Landslide, Slope stability, Soil nailing, Rainfall

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Large and Small Scale Multi-Sensors Remote Sensing for Landslide Characterisation and Monitoring

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In the last years, the use of Unmanned Aerial Vehicles (UAVs) has developed rapidly across several field of earth sciences application, including landslides characterisation and monitoring, therefore providing a strong support for hazard and risk management activities especially with the introduction and advances in the miniaturization of traditional and new generation sensors. The flexibility, low cost, easy operability, and rapidness of intervention in emergency situation gives to these instruments, a strong potential in opening up a vast new area of opportunities in remote sensing for observation, measuring, mapping, monitoring, and management in various landslide environment. Unless initially only air photography was the main application for UAVs, recently new sensors, both passive and active, are being increasingly used. This paper, through some case studies on landslide investigations, aims at giving an overview on several sensors and techniques using UAVs platform addressed to landslide detection, characterization and monitoring.

Keywords: Remote sensing, Drone, Landslide

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Modeling Landslide Volumes: A Case Study in Whatcom County, Washington, USA

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In mountainous terrains, landslides and their deposits form a major natural hazard for human settlements and economic activities. The characterization and analysis of landslide volumes is important to understanding their behaviors and the effects of their potential propagation distances. The Washington Geological Survey (WGS) created a new protocol to map landslides with consistent data in Washington State using Light Detection and Ranging (LiDAR). The protocol uses the surface area and the average depth of landslides to estimate their initial volumes. The aim of this paper is to present the ongoing research project from the Institute of Geography at the National Autonomous University of Mexico (UNAM) and WGS to estimate sediment production and distribution by taking full advantage of LiDAR and standardized landslide volume calculation in a Geographic Information System (GIS). We develop two landslide volume models by using Python scripts. These models are a systematic methodology for modeling volume of shallow and deep-seated landslides. The methodology and its implementation in the GIS-based technology is presented and discussed.

Keywords: GIS, Landslide inventory map, Landslide volume, Washington state

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Geosynthetic Reinforced Soil Structures for Slope Stabilization and Landslide Rehabilitation in Asia

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The paper presents successful experiences using geosynthetic reinforced soil structures for slope stabilization and landslide rehabilitation in Myanmar, Indonesia, and Japan. In all the presented cases, reinforced soil structures, combining high strength uniaxial geogrids and metallic gabion units provided with integrated reinforcing tails, were built. The first project highlights the challenges faced in the design and construction of a reinforced soil structure built to rehabilitate the collapsed portion of a national road in Myanmar. The second case study focuses on the application of reinforced soil structures for the reconstruction of road slope failures in Indonesia. The last case study describes the technical solution selected to stabilize a 14 m high slope for the Harima Expressway embankment located in Hyogo prefecture, Japan.

Keywords: Reinforced soil structures, Slope failure, Landslide remediation

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Mobility characteristics in loess landslide over erodible bed: insights from sandbox experiments

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Due to the high susceptibility to hydraulic erosion and the wetting-induced collapse character of the loess, the Chinese Loess Plateau has been considered as a landslide-prone area in NW China. Given that the interactions of loess deposit and terrace sediment have been under-explored in the literature, this lack of research has caused difficulty in loess landslide prevention and mitigation. This study presented a total of 40 loess landslides in the South Jingyang Platform where 4 out of the loess landslides are subjected to a detailed investigation with a focus on the geomorphology character and the internal structure. Further, the sandbox experiments were responsible for distinguishing three domains representing varying degrees of interaction between the loess deposit and the terrace sediment, namely push forwards domain, shear up/out domain, and original terrace sediment domain. The push forwards domain can be characterised as an area containing thoroughly the loess deposit with most significant surface upheaval. The shear up/out domain can be recognised with remarkable evidence of interactions. The original terrace sediment can be considered as an area that is not completely disturbed by the interactions. Moreover, the field investigation and the sandbox experiment all witnessed the terrace sediment shearing upwards. More than that, the former also witnessed the occurrence of shear liquefaction which is the greatest contributor to the trigger of high speed, long runout loess flowslides in the study area. These phenomena were further interpreted from perspectives of the velocity of loess deposit movement and the apparent friction angle. The findings of this study reveal the interactive mechanism between the loess deposit and the terrace sediment and guide countermeasures against loess flowslides.

Keywords: South Jingyang Platform, loess, terrace sediment, flowslide, sandbox experiment

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Different dynamics of permafrost degradation-induced landslides revealed by molards

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This study explores the possibility to use the landform called “molards” to characterize different landslide processes in terrains affected by permafrost degradation. Molards are cones of loose debris that result from thawing of blocks of ice-rich sediments mobilised by a landslide in periglacial environments. Molards cannot form without ground ice, which cements the source material, allowing it to behave like solid during transport. Once the ground ice has thawed, its cementing action is lost, inducing collapse of the material into molards (Morino et al., 2019). In this study, we show that molards can be a landform directly revealing landslide processes in terrains under different permafrost conditions, from continuous to discontinuous. We apply quantitative terrain analysis using high-resolution DEMs to describe and quantify the morphometric characteristics of molard examples that reveal different types of gravitational mass movements, from free fall to rock avalanche, from debris flow to rotational slide. We also report on the morphometry of landslides characterised by molards that we have identified and analysed from remote sensing at several locations around the globe. This study highlights the need for a better understanding of molard formation, evolution, morphology, longevity, and their environmental settings, and we emphasise that they can be used as a geomorphological tool to understand climate change and landslide hazard in cold environments.

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Keywords: molards, landslide processes, permafrost, ground ice, morphometry

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Recent Development of the Mechanically Stabilized Earth Walls with Geosynthetic Strap Reinforcements

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Soil reinforcement has lately many applications for stabilization in a slope. Since the Mechanically Stabilized Earth (MSE) Walls utilizing geosynthetic strap reinforcement was also developed in the same way as application with a conventional steel strip reinforcement, it have been used successfully for 15 years by effectiveness of material characteristics in all over the world. The MSE Walls with a gosynthetic strap reinforcement was developed after the MSE Walls with a steel strip reinforcement, has many applications under the severe corrosion environmental condition for a material characteristics of gosynthetic reinforcement. Various projects have been working on the establishment of optimized design methodologies for a geosynthetic strap reinforcement. For design by the all public design code of the MSE Walls with a steel strip reinforcement with much experience of construction works in the past, the numerical analysis by lab testing, field measurement of walls and dynamic centrifugal model experiment for earthquake resistance were carried out to investigate the application properties. The studies provide the information about the influence of difference of the rigidity of strip reinforcement on a stability of the structure; that is, an established statistical analysis of accumulation data by the field measurement of walls, the laboratory testing and a numerical analysis by the model experiment for the design optimization in the current state.

Keywords: Mechanically Stabilized Earth Walls, Geosynthetic strap, Earthquake-Resistance

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Japanese case histories on use of geosynthetics in reconstructing failed slopes

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In Japan, severe damage to slopes and earth structures was induced by frequent heavy rains and large earthquakes. In their reconstruction works, geosynthetic-reinforcements were used to improve the performance against future similar events. If needed, such reinforcements were combined with other reinforcement/ improvement methods. As an example, a set of case histories on railway slopes in east Aso area, Kumamoto prefecture, Japan, is reported, where geosynthetic-reinforced slopes performed well against heavy rain and large earthquake events. Another set of case histories in Japan is also briefly reported on combined use of geosynthetic-reinforcement with other reinforcement/improvement methods.

Keywords: case history, geosynthetics, reinforced slope, heavy rain, large earthquake

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A spatiotemporal object-oriented data model for landslides (LOOM)

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LOOM (landslide object-oriented model) is here presented as a data structure for landslide inventories based on the object-oriented paradigm. It aims at the effective storage, in a single dataset, of the complex spatial and temporal relations between landslides recorded and mapped in an area and at their manipulation. Spatial relations are handled through a hierarchical classification based on topological rules and two levels of aggregation are defined: (i) landslide complexes, grouping spatially connected landslides of the same type, and (ii) landslide systems, merging landslides of any type sharing a spatial connection. For the aggregation procedure, a minimal functional interaction between landslide objects has been defined as a spatial overlap between objects. Temporal characterization of landslides is achieved by assigning to each object an exact date or a time range for its occurrence, integrating both the time frame and the event-based approaches. The sum of spatial integrity and temporal characterization ensures the storage of vertical relations between landslides, so that the superimposition of events can be easily retrieved querying the temporal dataset. The here proposed methodology for landslides inventorying has been tested on selected case studies in the Cilento UNESCO Global Geopark (Italy). We demonstrate that the proposed LOOM model avoids data fragmentation or redundancy and topological inconsistency between the digital data and the real-world features. This application revealed to be powerful for the reconstruction of the gravity-induced deformation history of hillslopes, thus for the prediction of their evolution.

Keywords: Object-oriented, Landslide system, Landslide complex, Landslide object

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Emergency mitigation measures of a dip slope slide with uplifted toe caused by heavy rain in Chichibu, East Japan

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Due to the extreme heavy rain caused by the 2019 East Japan Typhoon (2019/10/12; 511 mm/day), a large-scale landslide occurred in Chichibu City, Saitama Prefecture, East Japan. The maximum length and width of the landslide were 250 m and 350 m, respectively. It was a translational slide with a dip of 15 degrees arising in Miocene well-bedded mudstone layers. Upheaval of the landslide toe naturally dammed up a torrent with a width of 280 m and formed a pond with a length of 120 m, width of 15 m, and depth of 10 m. Because the overflow started due to rainfall, the risk of debris flow has become an urgent concern. As emergency measures, two countermeasures were taken. The first countermeasure was a monitoring system to observe landslide and damming, which consists of ground extensometer, water level gauge in the pond, surveillance camera, and debris flow wire sensors. The second countermeasure was an emergency drainage work, which bypasses the water flowing from the upstream river to the downstream of the landslide by pumps with a relative height of 60 m and an extension of 210 m. This drainage work eliminated the pond and reduced the risk of landslide dam burst. While it was in operation, a temporary drainage channel using a pipeline with a length of 500 m to prevent erosion of the landslide dam and a temporary concrete block Sabo dam with a height of 3.5 m that captures runoff sediment and driftwoods were constructed. These temporary measures ensured the safety until the remedial countermeasure works are completed. These two countermeasures reduced the risk of unstable large-scale landslide and damming temporarily, and provided time for the precise design and construction of safe and reliable remedial countermeasures. These measures will promote the landslide stabilization and make the lives of downstream residents safer.

Key words: Mitigation measure, dip slope slide, landslide dam, drainage channel, concrete block Sabo dam

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Influence of geology and geological structures in triggering landslides: Bangladesh perspective

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Bangladesh is mostly a flat country but eastern territory of the country, covering about 20% of the area, is hilly. The hilly areas are in Chattogram, Chattogram Hill Tracts (CHT) and eastern Sylhet areas of the country. These areas are frequently affected by landslides induced by rainfall and accelerated by human activities. In many cases, landslides are deadly and happen in densely populated areas. Study shows that landslides are also linked to nature of the geological materials and presence of different types of sedimentary structures (syndepositional and post depositional) and their orientations. Rocks/sediments types, age of rocks and degree of weathering are important characteristics of the geological materials related to landslides. Rocks are weathered under excess rainfall and temperature under tropical climates. Important syndepositional structures are bedding planes, laminations, fissures, cleavages, fissility, etc. Post depositional structures are fractures, joints, faults, fold, etc. weaken the rocks due to tectonic activities. Landslides have been investigated in the field to know their dimensions, geological materials involved and types of sedimentary structures. Along with the physical verification samples are taken in the laboratory for geotechnical analysis to validate possible findings. It has been found that rock are sandstone, siltstone, shale and their admixture mainly. Sandstone is more susceptible to landslides due to higher degree of weathering. Age of the rocks is related to compactness of the materials. Older rocks are more compacted than the younger rocks. Younger Dupi Tila and Tipam formations are less compact and more susceptible to landslides than older Bokabil and Bhuban formations. Degree of weathering also governs landslides, more weathering added landslides. Density of weak zones like joints, fractures, bedding planes, etc reduce the strength of rocks and its favorable orientations strongly influence landslides. Even the rocks are compacted and old but the presence of weak zones make it susceptible to landslides. Rocks of Bokabil and Bhuban formations are older and compacted less susceptible to landslides but fissile shale of these formations is very much prone to landslides. Considering susceptibility, Dupi Tila Formation is more susceptible to landslides due to its sandy nature, deep weathering and younger age. Attention should be taken adequately on these geological factors during construction of structures as well as in preventing/mitigating landslides to save lives and properties of the area.

Key words: Landslides; geology; tectonics; sedimentary structures; fissile shale.

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3D landslide models in VR

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The present paper describes the elaboration of 3D surface and geological models generated for a series of landslide sites, zones marked by large incipient slope failures, or those presenting structural characteristics of an ancient giant mass movement. For both, surface and geological models, high-resolution satellite or drone imagery was draped on the digital elevation model constructed from the same imagery or using Radar or LiDAR data. The geological models further include geophysical data, supported by differential GPS measurements, complemented by georeferenced geological and tectonic maps and related geological sections. The soft layer thickness information and borehole data are typically represented in terms of logs inside the model. For several sites also slope stability analyses were performed, either in 2D or in 3D. Inputs for those analyses were directly extracted from the 3D geomodels, outputs were again represented in the models.
Some of those models, such as the one produced for the right-bank slopes of the Rogun Dam construction site can be quite complex and we clearly could notice that an immersive analysis using VR technology helps understand their internal structure and perform a better slope stability analysis. Still these analyses have their limits, as a study in Virtual Reality is purely individual (at present time, the visiting researcher is separated from the rest of the World). Therefore, we suggest that a real advancement can only be achieved if the technological developments go along with a stronger collaboration between scientists from the various geo-domains, who could also be immersed in the same virtual model (~collaborative VR).

Keywords: Landslide dynamics, Geomodel, 3D analysis, Immersion, Collaboration

Theme 6 Specific Topics in Landslide Science and Applications

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Recent Earthquakes that Hit Areas Covered and/or Underlain by Pyroclastic Matters and Their Impacts on Lifelines

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Two major earthquakes highlighted in this review article are the 2016 Kumamoto Earthquakes and the 2018 Hokkaido Eastern-Iburi Earthquake. These two events that hit the southern and northern Japanese islands known as Kyushu and Hokkaido, respectively, have one thing in common from geological and geotechnical viewpoint; the quake-hit areas are covered and/or underlain by volcanic matters. These volcanic matters such as pumice and volcanic ash have crushable nature that can cause large ground deformations, thus resulting in significant service interruption of lifelines and hindering quick recovery of the quake-hit areas. The phenomena to be discussed in this article include a never-seen-before ground subsidence that occurred on a flood plain west of Mt. Aso in Kyushu, and multiple landslides in Hokkaido with the total area of the exposed bare earth reaching 13.4 km2; the largest area that we've ever recorded since the Meiji era. The observed geometric features of the multiple landslide masses have a striking resemblance to those in a past event; the fact thus inspires a feeling of hope that this resemblance will allow for quick estimation of runout distances of these landslide masses with a simple empirical equation.

Keywords: Earthquake-induced landslides, Volcanic matters, Lifelines, Ground subsidence

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Lessons Learned - Landslide Induced Lifelines Disasters from Past Earthquakess

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Lifelines sustain significant service interruption in medium to large magnitude earthquakes from landslides. There were many examples of long duration service interruptions and recovery to normalcy due to landslide disasters other than earthquake induced, for example heavy rainstorm. This paper intended to bring a focus on landslide impact to lifelines. The attempt is to reinforce the need to encourage more research in order to develop tools to protect lifelines from losses—direct and indirect losses. The cases discussed in this paper were significant earthquake events and rainstorms from 2007 to 2018. The lifelines to be discussed in this paper are telecommunication and transportation. The inherent spatial characteristics of these networks render many segments exposing to landslides, rock falls and mud flows. The paper will not discuss methods of prevention but will identify lesson learned from good geotech engineering.

Keywords: Lifelines, Telecommunication, Transportation, Research

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Risk Assessment of Structural Damage for Rock Collision due to Earthquake-Induced Landslide

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Either earth collapses or rock collapses due to recent earthquakes caused human damage, as well as the damage to social infrastructure facilities, such as the collapse of the Aso bridge caused by the 2016 Kumamoto earthquake. As for the rock protection facilities such as a rock shade, the design methods based on the past studies about the evaluation of the influence of the impact force on the facilities are described in the falling rock manual and the road earthwork guidelines. On the other hand, the Japan Society of Civil Engineers and Architecture Institute of Japan indicated the ideas to evaluate the influence of the impact action on social infrastructure facilities by the sand and the falling rock, but the ideas have not been systematized as the standard like Eurocode 2. Because the method by using dynamic response analysis can utilize without depending on the characteristics of the action, it is useful for the safety evaluation of the important social infrastructure facilities including nuclear power plants.

The objective of this paper is to establish the evaluation method of damage risk for the impact action against the important social infrastructure facilities caused by the rock falling and the rock collapse. As a result of the past experiments about rock rolling and free fall of rocks, the time history of the impact force of a rock mass, which is necessary for dynamic response analyses of a structural member, in other words, modeling of impact action is modeled. Moreover, the evaluation of the fragility characteristics is carried out.

Keywords: impact action, experiment, rock, momentum, fragility curve

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Seismic Performance of Buried Pipelines Against Large Ground Deformation of Strike-Slip Faults

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The response of a pipeline buried in soft soil and hard soil subjected to movement of strike-slip fault at a 90° crossing with and without axial soil–pipe interaction was evaluated. The results of a FEM-based model were compared with those of an existing analytical solution based on the “beam on elastic foundation” theory. The results show that the effect of axial soil–pipe interaction was negligible in soft soil but had a slight effect in hard soil. When the axial soil–pipe interaction is taken into account for the hard soil cases, the bending moment, shear forces and compression stresses of the buried pipeline decrease, and the axial force response of the pipeline increases. For a buried pipeline subjected to movement of a 90° strike-slip fault, the bending moment response was predominantly in the stress field, which indicates that if the 90° strike-slip fault moves, the pipeline is most susceptible to buckling damage.

Keywords: Buried pipeline, Strike-slip fault, FEM analysis, Soil-pipe interaction, Oil and gas pipelines

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Impact on Infrastructure by 2015 Gorkha Earthquake Induced Landslides

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The 7.8 (Mw) magnitude Gorkha Earthquake of 25 April, 2015 and the four subsequent aftershocks greater than magnitude of 6.0 induced numerous landslides and other instabilities. The Earthquake caused over 8,790 casualties and 22,300 injuries. It had affected 31 districts of the western, central and eastern regions of Nepal, among which seriously impacted 17 districts had been studied. The earthquake had impact to many sectors, i.e. social, productive, infrastructure and other cross‐cutting sectors. The destruction was widespread covering residential and government buildings, heritage sites, schools and health posts, rural roads, bridges, water supply systems, agricultural land, trekking routes and hydropower plants. The strong tremors and continuous aftershocks have resulted in other secondary impacts other than landslides as cracking of the land surface, drying of some water sources, shifting of the springs, changes in the groundwater hydrology and water quality. The assessment of damages to infrastructure is based on the GIS based spatial analysis of high resolution Remote Sensing data such as satellite imagery of pre and post‐earthquake scenario, Google Earth maps and other digital platforms. In addition, data provided by MoHA on the DRR portal have been incorporated in the inventory list. Field visits were made to some locations in the study districts for verification of the identified infrastructural damages. This paper briefly describes the damages to road, bridge, hydropower, buildings, and irrigation canal due to the Gorkha earthquake‐induced landslides. It tries to provide comprehensive damage assessment of the locations, dimensions of the infrastructures by the earthquake‐induced landslides and analyses the relationship between the landslides with slope gradient, geology, and land use pattern of the study area.

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Reconstruction Strategies for Mw 7.8 Earthquake-Induced Landslide-Affected Settlements in Nepal

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Nepal was rocked by Mw 7.8 earthquake on April 25, 2015 which damaged lives and physical infrastructures worth millions of dollars. The mainshock and its subsequent aftershocks also triggered thousands of landslides which, at several locations, killed people, damaged highways and public buildings, and destroyed hundreds of settlements severely. Consequently, the government decided to move the landslide-affected villages first to temporary shelters and then relocate to safer sites. As a means of implementing the decision, the National Reconstruction Authority (NRA) devised strategies which include, among others, conducting geological engineering investigation to confirm the state of geo-hazard in each of the reported earthquake-induced landslide affected settlements. Accordingly, 283 settlements were decided to move to safer sites, whereas another 320 settlements were recommended to start reconstruction only after applying control measures to landslides existed in and around the settlements. Several difficulties were also faced during the relocation of those 283 vulnerable settlements (4598 households). But these were resolved by revisiting the vulnerable sites and collecting science-based data by a team of experts and also holding several rounds of professional dialogues with the stakeholders. Finally, after 4 years of rigorous works, majorities of the landslide-affected families have already been well managed as each of them is now having an earthquake-resistant residence constructed in safer locations. Remaining 434 households are being managed with the aim of completing all the administrative processes by the end of June 2020.

Keywords: Gorkha, Earthquake, Landslide, Reconstruction, Strategy

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Relationship between Arias Intensity and the Earthquake-Induced Displacements of Slopes

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Earthquake-induced landslides have a direct impact on human society. In order to evaluate and mitigate the damage associated slope failure, a well understanding of displacements of slopes induced by earthquakes is pivotal. Acknowledging both the energy-based Arias Intensity as a reliable intensity measure to describe the severity of the earthquake and the finite element analysis as a practical and effective method to conduct seismic hazard analyses. This study is focused on the relationship between the Arias Intensity and the earthquake-induced displacements of slopes. Twenty near-field motions from the 1999 Chi-Chi earthquake and the 1979 Imperial earthquake were scaled to peak acceleration of 70, 100, and 200 gals and applied to the simple models with slope angles of 20°, 30°, and 45°. It was found that the range of the Arias Intensity has effects on the relationships between Arias Intensity and the normalized earthquake-induced slope displacements while the angles of the slopes for the three simple landslide models show a trivial influence on the relationships between Arias Intensity and the normalized earthquake-induced slope displacement, which may be due to the same material properties.

Keywords: Earthquake-induced landslide, Arias intensity, Finite element analysis, Seismic hazard, Empirical relationships

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Controls on Landslide Size: Insights from Field Survey Data

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Proper characterization of landslide size distribution is very important for estimating the landslide risk, quantifying the integrated effects of erosion and sediment yield, and determining the magnitude of landslide events. This paper quantitatively addresses the effects of topographic condition and landslide types on landslide size distributions. A detailed landslide inventory based on field work is developed. The landslide spatial distributions are then clustered. There exist some clustered centres in the study area. Statistical analysis showed that the large and very large landslides play an important role in determining the total landslides area in current study area. The double pareto and inverse gamma functions can well fit with the landslide probability distribution and can quantitatively reveal the maximum probability and rollover effect. The probability density of landslide size empirically agrees well with a simple power law relationship above a certain size threshold. Below this size, there exists a rollover effect. The local topographic conditions and landslide type play an important role in landslide size. About 33% of landslides occurred within a slope gradient between 30°–40°. The landslide size decreases with increasing slope gradient, and more frequent small landslides occur on larger slope gradients. About 80% of landslides occurred within a slope height less than 100 m. The landslide frequency decreased sharply with increasing slope height. The local slope height can limit the landslide size. The landslide size increases as slope height increases, and relationship of which can be well fitted by using a power law form. The peak of landslide probability density increases with increasing slope height. Moreover, the landslide size is also controlled by the landslide types and slope morphology. About 62% of the total landslides are retrogressive landslides. Most landslides concentrate on convex slopes. The lowest percentage of landslides occurred on a concave slope. This suggest that the convex slopes are preferentially susceptible to landslides. The probability densities of landslide size are influenced by the landslide types and slope morphology. Many thrust-type landslides were small landslides. More frequent small landslides occur on planar slope. The study here provides a reliable method for landslide hazard mapping.

Keywords: Landslides, Size distribution, Field survey, Topography

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Geologic and Hydrologic Investigations on Slope Failures Triggered by Extreme Rainfall on Izu Oshima Island, Japan

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A volcanic slope on Izu Oshima Island in Japan experienced a significant rainfall-induced landslide disaster in October, 2013. Because this slope had been stable for centuries, a special investigation was carried out on the cause. Because of its volcanic origin, the failed slope consisted of layers of ash, sand and lava. While the investigation concerned many disciplines, this paper addresses the post-disaster geotechnical studies. The emphasis was put on the reason why some parts of the slope “did not” fail because the post-disaster construction of infrastructures in the affected area relied on the future stability of the affected mountain slope. In line with this, another focus was on the geohydrological characteristics in the underlying lava layer. We concluded that the lava layer is pervious and allows drainage of infiltrated rain water and that, only during extremely heavy rain, slope failures are triggered in subsurface “valleys” that are carved in lava bedrock. For seven years after the disaster, the remaining parts of the slope have been stable.

Keywords: Rainfall-induced landslide, Volcanic slope, Lava, Seepage, Restoration

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Investigation of Internal Erosion of Wide Grading Loose Soil—A Micromechanics-Based Study

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The Wenchuan earthquake (Mw 8.0) on May 12, 2008 led to abundant loose landslide deposits in the southwestern mountainous areas of China. Field observations reveal that this loose soil is ideal source material for debris flows and landslides several years after the earthquake, particularly when mobilized by rainfall. An important slope failure mechanism is rainfall infiltration-induced fines migration within soil slopes. Previous studies of fine particle migration in soil mainly focused on seepage experiments, mid-scale flume tests with rainfall as a boundary condition, and other macro-scale methods. However, these methods have not been able to directly obtain parameters of pore structures, velocity of fine particles, and pore pressure inside soil samples which could be used to quantify the internal erosion process. In this study, the characteristics of wide-grading loose soils (WGLS) pore structure are analyzed quantitatively with serial tomography which uses scanning electron microscopy. The results of statistical analysis of pore size distribution are also presented. Compared with traditional silty soil with bimodal pore size distributions, WGLS corresponds to a second peak with much larger diameter particles. Numerical simulation using the Lattice Boltzmann method (LBM) coupled with the Discrete Element Method (DEM) is used to investigate the jamming probability of fine particle migration through three different samples during seepage. Simulation results indicate that jamming is most prevalent in samples with smaller pores that are dominated by bimodal pore size distributions, which agrees with previous analytical solutions.

Keywords: Shallow failure, Wide-grading loose soil, Micropore structure, LBM-DEM coupling, Fine particle migration

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Experimental Study on the Formation and Propagation of Debris Flows Triggered by Glacial Lake Outburst Floods

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In high mountainous areas, debris flows can be triggered by snowmelt, excessive rainfalls, glacier lake outburst floods (GLOFs) or multiple factors combined. Debris flows often pose significant threats to human life and property. In this study, experiments were conducted to investigate the surge waves triggered by glacier avalanches, failure process, GLOFs, debris flow formation and propagation. Additionally, by considering the effect of debris flow scale enlargement, the relationship between the scale enlargement parameter k and the flow density were deduced. The results indicated that the successive surge waves triggered by glacier avalanches have a great effect on the failure of moraine dams. The flow density increased in the flow direction. The maximum flow density in the experiment was approximately 1.49 g/cm^3. The discharge of debris flow at the outlet reached 0.095 m^3/s and the experimental discharge measured at the outlet was approximately 0.1 m^3/s. The error between the calculated peak discharge and the experimental one was approximately 5.26%. The results presented in this paper can provide information for another kind of debris flows triggered by GLOFs in high mountainous areas.

Keywords: Debris flows, GLOFs, Moraine dam, Discharge, Scale enlargement

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Quantitative Analysis of Landslide Processes Based on Seismic Signals - A New Method for Monitoring and Early Warning of Landslide Hazards

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Effective monitoring and early warning methods can greatly reduce the threat of sudden landslide damage to lives and property in mountainous areas. Seismic monitoring is a newly developing remote monitoring method that can make up for the shortage of on-site data obtained from traditional methods. This review article summarizes the authors' recent developments involving the combination of band-pass filter, empirical mode decomposition, and fast and short-time Fourier transform methods to deduce event sequences of actual landslides. Two case studies of landslides in Xinmo and Shuicheng, China are used to follow the methodology development. Through seismic signal processing, seismic signals caused by the two landslides are extracted and successfully denoised, and the time-frequency characteristics of the seismic signal in each stage are analyzed in detail. The results show good correspondence between each seismic signal stage caused by the landslide and the field investigations. This further demonstrates the feasibility of applying monitoring and early warning methods based on seismic signals.

Keywords: Seismic signal, Monitoring and early warning, Signal extraction and identification, Landslides process

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Water Exfiltration from Bedrock: A Drastic Landslide Triggering Mechanism

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Landslides triggered through hydraulic perturbations are initiated by a decrease in the effective stresses, and hence the mobilised shear strength of the soil, as a result of the increase in the pore water pressure. This may occur either due to rain infiltration or to exfiltration of water from the bedrock into the slope. Although numerous investigations have been conducted to study the first triggering mechanism (rain infiltration), less attention has been devoted to the latter (exfiltration of water from the bedrock). This paper presents the results of a full-scale landslide triggering experiment, which has been carried out on a natural slope in Northern Switzerland, with emphasis on the observations and measurements regarding exfiltration of water from the bedrock. A series of centrifuge tests was also performed to study the effect of the hydro-geological interactions of the bedrock with the overlying soil mantle on the stability of the slope. Moreover, the behaviour of the full-scale test slope prior to the failure induced by the artificial rainfall event, and/or water exfiltration from the bedrock, was investigated using coupled hydro-mechanical numerical methods. The results of both physical and numerical modelling confirm the importance of the exfiltration from bedrock in triggering of landslides.

Keywords: Water exfiltration from bedrock, Landslides, Geotechnical physical modelling, Hydro-mechanical coupled analysis

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High-Resolution Point-Cloud for Landslides in the 21st Century: From Data Acquisition to New Processing Concepts

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The economic downturn at the start of the 21st Century combined with the rise of new economies have helped propelling the need for cheaper, rapid and yet accurate data acquisition methods, including point-cloud producing technologies. As population is ageing in countries like Japan or Taiwan, and as climate change is bound to increase the frequency and number of landslides (at least until sediment stocks are depleted), the need of rapid and low-manpower data acquisition and processing has become increasingly essential. It is within this framework that the present contribution aims (1) to present research on present technologies for landslide monitoring, as well as emerging systems, and (2) to propose “new” ideas for point-cloud processing and data usage without having to grid or interpolate data. The authors thus use a variety of field locations around the pacific and in France using as a method ALS (Airborne Laser Scanning), TLS (Terrestrial Laser Scanning) and SfM-MVS (Structure from Motion—Multiple View Stereophotogrammetry). Then the authors present recent advances in landslide monitoring technology with the YellowScan UAV-ALS. As the resulting mounting amount of data presents constrains to the data processing steps, the authors also present ideas to progress processing: (1) developing a point-cloud signature to avoid gridding, and (2) a conceptual algorithm to process the point-clouds as vectors between a machine and a reflective object, recording the free space and the objects. In this way catastrophic landslides can be characterized from the signature of the data and the distribution of fill and voids without going through the traditional analysis on a Cartesian grid. The authors have worked on those techniques to provide fast and accurate data for landslides hazards and disaster risk.

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Automatized Dissemination of Landslide Monitoring Bulletins for Early Warning Applications

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Complex landslides are often monitored by multi-instrumental networks. These networks can be coupled with early warning systems that could reduce human, economic and environmental losses. The large amount of data provided by landslides monitoring networks can create issues related to the data management and processing. The use of different monitoring instruments can create problem in data interoperability and in the definition of multi-source landslide activity maps. In particular during emergencies, when monitoring data are a crucial element to support decision makers and to inform the population about the evolution of the slope instability, the communication of monitoring results should be managed using a dedicated communication strategy. In this paper, we present the developed communication strategy based on the use of a dedicated single page bulletin. This bulletin has been developed and tested during the Mont de La Saxe rockslide emergency and it has supported the landslide management team to inform the population about the evolution of the slope instability.

Keywords: Landslide monitoring, Early warning, Monitoring results dissemination, Risk management

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Detecting Change of Patterns in Landslide Displacements Using Machine Learning, an Example Application

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Machine learning and signal processing can support the definition of landslide alert/alarm systems based on monitoring data. The possibility to rely on a straightforward and automatic procedure to identify hazardous situations could be very useful for risk management and decision makers. In this work, we propose a hierarchical clustering algorithm to identify changes of pattern in the displacements of monitored landslides. Our test site is a large, active Deep-seated Gravitational Slope Deformation (DGSD) in which secondary movements provide sediment for debris flows that threaten downstream settlements. An Automated Total Station (ATS) has been installed in 2012 to measure the three-dimensional displacements of several benchmarks distributed on the source area and to trigger alarms if superficial movements potentially leading to collapses are detected. Results show that the procedure allows to group benchmarks with similar displacement patterns. The unsupervised definition of homogenous areas from a kinematic viewpoint supports an unbiased geomorphological characterization of the large landslide. Moreover, the method allows to trigger alert warnings if some monitored points change displacement pattern. The identification of possible hazardous situation is performed without imposing fixed and arbitrary thresholds and without calibration. The recognition of areas with new types of activity supports the definition of the sediment volumes available for transport for the next debris flow event and assists the definition of reliable risk scenarios.

Keywords: Machine learning, Hierarchical clustering, Automated total station, Landslide monitoring, Rotolon

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Predicting Rainfall Induced Slope Stability Using Random Forest Regression and Synthetic Data

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Water fluxes in slopes are affected by climatic conditions and vegetation cover, which influence the effective stress and stability. The vegetation cover is the intermediate layer between the atmosphere and the slope surface that alter water balance in the slope through evapotranspiration and leaf interception. This paper studies the data-driven approach for predicting the macro stability of an example grass-covered dike based on actual data and also synthetic data provided by numerical modelling. Two numerical models are integrated in this study. The water balance in the root zone is simulated through a crop model, whereas the hydro-mechanical and safety analysis of the example dike is done using a two-dimensional Finite Element model. The considered period for these analyses is 10 years (3650 daily instances) which will be used to generate a time-series dataset for a secondary dike in the Netherlands. The features included in the dataset are parameters that (i) have a meaningful relationship with the dike Factor of safety (FoS), and (ii) can be observed using satellite remote sensing. The output dataset is used to train a Random Forest regressor as a supervised Machine Learning (ML) algorithm. The results of this proof-of-concept study indicate a strong correlation between the numerically estimated FoS and the ML-predicted one. Therefore, it can be suggested that the utilized parameters can be used in a data-driven predictive tool to identify vulnerable zones along a dike without a need for running expensive numerical simulations.

Keywords: Slope stability, Vegetation, Machine learning

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Hybrid Analytics of Rainfall Infiltration with Physics-informed Neural Networks

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Predicting rainfall-induced landslides relies on the capacity to model the coupled hydro-mechanical processes that control the stability of slopes. Among these processes, modelling of water infiltration in response to storm or rapid snowmelt events is often challenging due to nonlinearities associated with water infiltration in partially saturated conditions. This paper investigates the application of hybrid analytics to the problem of water infiltration in partially saturated soil. Hybrid analytics is a computational approach where physics-based and data-driven (e.g., machine learning) models are being combined in one modelling framework. This study features the application of the Physics-Informed Neural Network (PINN) method to the water infiltration model, modeled with the Richards partial differential equation. The results of the study demonstrate that PINN can capture the nonlinearity of the Richards equations and providing reasonable results. Once the PINN is trained it can provide solutions under lower computational cost than conventional approaches, thus providing a basis for the implementation of computationally demanding problems such as parametric studies, inverse analyses, or solutions for real-time monitoring of rainfall-induced landslides.

Keywords: rainfall, landslide, hybrid, neural network, physics-informed

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Loess Stratigraphy and Loess Landslides in the Chinese Loess Plateau

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Chinese Loess is a dust deposit brought by wind from North-West desert. In the past four decades, the age and the strata of the loess stratigraphy were well defined by dating and correlating with deep sea core isotopic curves. A standard loess stratigraphic profile and the correlation among the different areas are introduced, and typical river terrace with loess deposit is also illustrated. Loess has a loose texture and is sensitive to water, which makes it susceptible to failure during rain or engineering activities. Landslides on the Chinese Loess Plateau are the most common and widespread geological hazard, which results in human deaths and severe injuries. Moreover, it damages infrastructures such as road, tunnels, bridges, railway tracks and engulfs agricultural land every year. Based on the failure modes and motion characters, the loess slope failure can be classified into two main types, shallow slide, and deep-seated landslide. The shallow failure can be further divided into two types of small collapse and shallow flow slide; while the deep-seated failure can be divided into the four types of rapid long run-out slide, rapid flow slide, slow creep slide and quick slump slide. The mechanism of the landslide movement is controlled by the moisture state on the failure surface and the moving path. Based on the Sassa's motion simulation model, the modified models for simulating the catastrophic long run-out loess landslides are proposed which consider the effects of curved moving path, frontal plowing, bed entrainment on the running distance and coverage area of the sliding materials.

Keywords: Loess Stratigraphy, The chinese loess plateau, Landslide, Run-out, Simulation, Failure mechanism

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Mapping, Hazard and Consequence Analyses for Unstable Rock Slopes in Norway

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Systematic mapping for unstable rock slopes that can cause catastrophic failures has been carried out in Norway for 15 years. In this time a systematic mapping approach was developed that includes a hazard and a consequence analysis. The first weighs morphological signs of rock slope deformation, structurally based stability considerations, the state of slope activity and past events to come up with a hazard score. The second includes the analysis of the volume, the potential run-out area and if applicable the assessment of related displacement waves in case that the failure hits a water body or the assessment of the landslide dam in case that the failure would dam a valley. The goal of the consequence assessment is to assess the potential loss of life for possible failure scenarios. The hazard and consequence analyses are used by the Norwegian Water and energy Directorate to define high risk sites and for hazard zoning in relation to the Norwegian building codes. So far, 523 unstable rock slopes have been found, of which 110 were hazard and risk classified. 48 of the slopes have hazard zones that restrict building activities and 7 sites have been defined as high risk sites that are today under continuous surveillance.

Keywords: Rock slope failure, Displacement wave, Landslide dam, Risk matrix, Mapping approach

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Landscape Formation and Large Rock Slope Instabilities in Manndalen, Northern Norway

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Manndalen valley in northern Norway has a high density of unstable rock slopes. Geomorphological characteristics, geological structures and slope activity have been mapped for all 10 rock slope instabilities. Foliation is sub-horizontal and joints almost vertical throughout the entire valley, leading to the conclusion that geological structures do not allow for an easy kinematic failure process. However Interferometric Synthetic Aperture Radar (InSAR) data from the TerraSAR-X satellite indicate that six of the sites are displacing with average rates in between 3 and 26 mm/yr. The most active unstable rock slope in Manndalen is Gamanjunni-3, showing displacements of locally up to 5 cm/yr and clearly developed limits of the displacing rock mass. Two rock avalanche deposits have been dated to 10.6 ± 0.6 ka and 4.1 ± 0.3 ka BP. This revealed a frequency of ~5000 years for rock avalanches in Manndalen in post glacial time, supporting earlier conclusions that the Gamanjunni-3 site is prone for a failure in close future.

Keywords: Terrestrial cosmogenic nuclides dating, InSAR, Landslide, Rock avalanche

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Landslides after Wildfire: Initiation, Magnitude, and Mobility

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In the semiarid Southwestern USA, wildfires are commonly followed by runoff-generated debris flows because wildfires remove vegetation and ground cover, which reduces soil infiltration capacity and increases soil erodibility. At a study site in Southern California, we initially observed runoff-generated debris flows in the first year following fire. However, at the same site three years after the fire, the mass-wasting response to a long-duration rainstorm with high rainfall intensity peaks was shallow landsliding rather than runoff-generated debris flows. Moreover, the same storm caused landslides on unburned hillslopes as well as on slopes burned 5 years prior to the storm and areas burned by successive wildfires, 10 years and 3 years before the rainstorm. The landslide density was the highest on the hillslopes that had burned 3 years beforehand, and the hillslopes burned 5 years prior to the storm had low landslide densities, similar to unburned areas. We also found that reburning (i.e., two wildfires within the past 10 years) had little influence on landslide density. Our results indicate that landscape susceptibility to shallow landslides might return to that of unburned conditions after as little as 5 years of vegetation recovery. Moreover, most of the landslide activity was on steep, equatorial-facing slopes that receive higher solar radiation and had slower rates of vegetation regrowth, which further implicates vegetation as a controlling factor on post-fire landslide susceptibility. Finally, the total volume of sediment mobilized by the year 3 landslides was much smaller than the year 1 runoff-generated debris flows, and the landslides were orders of magnitude less mobile than the runoff-generated debris flows.

Keywords: Landslide, Wildfire, Geomorphology

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Disaster Risk Assessment of the Silk Road

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Disasters Risks, generated by the interaction of complex human and natural systems, are more significant, more complicated, and more difficult to foresee. Silk Road spans Asia, Europe, and Africa, involving more than 140 countries and nearly 66% of the world population. Relevant studies show that the countries along the Silk Road area suffered from the most frequent natural hazards and the most severe losses in the world. In order to promote social and economic development in Silk Road areas, it is urgent to carry out comprehensive research on disaster risk and disaster reduction. This compels new conceptual and analytical approaches to improve understanding of disaster risk at different scales. This paper presents the Silk Road disaster risk assessment at four scales, which could serve a different purpose. It is a robust response to one of the prioritized areas of Sendai Framework on Disaster Risk Reduction for people to understand disaster risk better.

Keywords: Silk road, Disaster, Risk assessment, Sendai framework, Disaster risk reduction

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Rehabilitation of Gully-Dominant Hill Slopes by Using Low-Cost Measures - A Case Study in Nepal

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A study was carried out to find out the effectiveness of low-cost measures for the rehabilitation of gully-dominant hill slopes of the river terraces in the Central Nepal. The main process of gully development on these hill slopes involved crack formation in the laterite soil in dry season and subsequent soil block failure at gully heads followed by incising bed erosion. In order to stabilize these gullies and rehabilitate the hill slopes, low cost measures were adopted which mainly comprised gabion check dams and bamboo plantation. Some other measures such as catch drains and grass plantation were also implemented. As a collective result of these measures, gully erosion rates were minimized and also the gully-dominant slopes were rehabilitated as evident by increasing forest cover. Such low-cost measures were found effective for controlling gully erosion as well as for promoting land resource recovery.

Keywords: Gully erosion, laterite, Slope failure, Bamboo, Gabion check dam, Nepal

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Site Suitability Analysis for Nature-Based Landslide Risk Mitigation

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Nature-based landslide risk mitigation involves use of vegetation in mitigating slope instabilities and has become popular in Asian countries such as Philippines, Malaysia, Hong Kong, Nepal, India and Thailand. They are considered as cost effective, environmental friendly and sustainable solutions for landslide risk mitigation. However, not all unstable sites, with landslide risks can be mitigated with nature-based techniques. The failure mechanism and the level of risk must be studied in detail before implementing such solutions. Hence, there is a need for a site selection process in order to select the most appropriate sites for applying nature-based techniques. In this study, five factors were selected in determining the level of appropriateness of vegetation in slope stabilization. Relative importance (weightage) of each individual factor towards applicability of nature-based techniques were determined using the Analytic Hierarchy Process (AHP). Site characteristics can be evaluated against the five factors and can be given marks on a scale of 4 which is multiplied by corresponding weightage of factors. The results of the multiplication are added to arrive at the final score for a particular site. This score can then be used to conclude the level of appropriateness of nature-based techniques at site-specific level. The proposed site selection process can be applied as a tool to rank candidate sites and decide on suitable landslide risk mitigation solutions.

Keywords: Nature-based, Vegetation, Landslides, Site suitability

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Biogeomorphic feedbacks between plants and mass movement processes in periglacial environments

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Freeze‐thaw processes affect slow and rapid mass movements in periglacial environments, such as creep, solifluction, retrogressive thaw slumps and active layer detachments. Through specific growth forms, root and leaf properties, plants survive depite ground movement, cold and heat stress. Mass movement magnitude and frequency, as well as plant species composition and distribution, are changing with rising temperatures, thawing permafrost and changing precipitation and snow cover. Feedbacks between plants and mass movement processes are likely a key factor to understand current and future changes in periglacial landscapes and ecosystems. Based on research in alpine periglacial environments, this contribution will provide first answers to the following questions: (1) Under which conditions can feedbacks between plant and mass movement processes occur? (2) How do plants influence periglacial mass movement processes; and (3) Which role do plant-mass movement feedbacks play for periglacial landform, landscape and ecosystem development? Presented results show how feedbacks between ecosystem engineer plants and low magnitude mass movements influence periglacial landform, landscape and ecosystem development and demonstrate that more research on biogeomorphic feedbacks is needed to understand environmental change in cold regions.

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Classification of Cryogenic Landslides and Related Phenomena (by Example of the Territory of Russia)

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Large part of Russian territory (more than 60%) is located within permafrost zone. Cryogenic landslides and related phenomena in the permafrost zone are quite specific and include some types of slope processes that are absent in “warm” regions (e.g. block fields, very thin earth flows with diurnal cycle of activity, etc.). However, common types of landslides in the permafrost zone also have some specific peculiarities. The classification of cryogenic landslides and related phenomena is proposed. Compiling this classification, we considered both seven types of the frozen (permafrost) soil and six well-known landslide types. Role of the permafrost surface in the formation of the sliding surface was considered too, as well as the thermodynamic instability of the permafrost when temperature changes from positive to negative and vise-versa, which is a specific factor of slopes instability typical of the permafrost zone. Peculiarities of various types of the cryogenic landslides evolution and related phenomena at the territory of Russian Federation are described.

Keywords: Permafrost, Cryogenic landslides, Classification

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Relation Between Horizontal Direction of Crustal Deformation Surveyed on the Control Points and Area Ratio of the Slope Failures Triggered by the 2016 Kumamoto Earthquake (Mj 7.3)

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The 2016 Kumamoto earthquake (Mj 7.3) induced more than 3000 slope failures along the dextral strike-slip epicentral fault, as well as along steep slopes on the caldera wall and the central cones in the caldera. We investigated dominant slope aspect (orientation bias) of the slope failures triggered by the earthquake using horizontal direction and amount of the crustal deformation surveyed by Geospatial Information Authority of Japan. Consequently, we observed that the dominant slope aspect of the failure was correlated with the direction of the crustal deformation in terms of the common component of the direction; i.e., both the dominant slope aspect and deformation direction have an E component along the NW(N) and NW(S) sides and a W component along the SE side of the fault line. This correlation was confirmed at the distances of 2000 and 4000 m from the fault line, but not at the distance of 6000 m. It is thought that the dominant inertial force of the faulting directly affected the slopes and triggered failures near the fault. The peak of the slope failure area ratio was 2.2–3.5% at the distance of 2000 m, where the amount of the crustal deformation was 0.6–0.9 m along the NW(N) and NW(S) sides of the fault line. However, along the SE side, the peak of the slope failure area ratio was 5.8% at the distance of 6000 m, where the amount of crustal deformation was 0.5–0.6 m. Minimal crustal deformation might induce more failures on the central cones, because the slope is covered with loose pyroclastic deposits, which are susceptible to deformation due to the earthquake.

Keywords: Kumamoto, Slope, Failure, Aspect, Earthquake, Control point, Orientation bias

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Precursor of large rockslides and its application on landslide early detection

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Rockslides initiated from slope units with a high elevation and good vegetation coverage are challenging to detect early. This study used multi-temporal optical remote sensing (ORS) images to track the deformation characteristics and examine potential geomorphologic precursors of five large-scale rockslides in China. The image interpretation results were combined with available pre-sliding slope displacement data derived from synthetic aperture radar (SAR) or field monitoring to study the temporal variations of geomorphologic features along with slope deformation. The results suggest that all surveyed landslides had cracks near their future crowns before the sliding and increasing rockfall activities within the landslide source area as geomorphologic precursors. These precursors could be observed years or decades before the failure, which provides sufficient time for the landslide early detection in practice. The geological structure plays a vital role in the landslide early detection utilizing the geomorphologic precursors from ORS. For rockslides on dip slopes, the crown cracks and rockfalls do not vary significantly with time. The rockslides on anti-dip or magmatic rock slopes usually initiate after the crown cracks are connected. The rockfall area ratio, defined as the accumulated area of rockfalls within the landslide source area over the landslide source area, typically ranged from 0.33 to 0.92 before the catastrophic slope failure. Given the broad availability of ORS data in recent years, this study could shed light on the ORS-based landslide early detection.

Keywords: rockslide，precursor, remote sensing, temporal evolution, early detection

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Report on a landslide in Kyotango city, Kyoto prefecture

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This study describes field observations and mitigation measures implemented in order to stabilize a landslide with multiple slope directions inferred from field investigation. The landslide, located in Kyotango city in northern Kyoto Prefecture, Japan, was caused by an increase in groundwater runoff from snowmelt and rainfall. Field investigations revealed a linear depression at the top of the landslide, and the direction of movement could generally be inferred from this surface deformation. In addition, near the bottom of the landslide, there was a surface failure whose direction matched the dip of the ground. However, estimates of the direction of the landslide based on these features were not consistent. In order to clarify the true direction of movement of this landslide, we conducted a physical survey of the area using an inclinometer. Specifically, we surveyed the dip of a borehole that was located at the center of the landslide and determined that the current landslide direction was intermediate between the directions estimated based on the two main features of the landslide. This current direction was consistent with the shape of the contour of the slip surface in three dimensions. Based on these findings, we propose that the mechanism for this landslide was as follows: First, the landslide formed a linear depression on the slope. Subsequent surface failure removed the bottom part of the landslide mass. This changed the stress distribution of the landslide, resulting in a change in the direction of sediment movement. To design robust landslide mitigation measures, we set the main survey line along the present direction of movement and analyzed the stability of the landslide. These landslide mitigation measures included earth removal, improving horizontal drainage, sinking a drainage well, and pile work. After implementing these modifications, effective groundwater control was achieved and no new deformation or landslide activity has been observed at the site of the landslide to date.

Keywords: direction of movement, field observations, inclinometer, mechanisms, mitigation measures

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Three-dimensional shape of mountainous landslide and the ground deformation caused by snow melting - Jin’nosuke‐dani landslide, Mount Hakusan,Central Japan

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Mount Hakusan Jin’nosuke‐dani landslide, (Japan) consists of multiple landslide blocks. The largest block among them, “Chuukan‐one” Block, is a large‐scale mountain landslide that represents Japan with an extension of 1,200 m, width of 400 m, and maximum slip surface depth of 150 m. The annual displacement of the landslide reaches 20 cm, and the subsurface displacement data confirmed so far confirm the periodicity of repeated fluctuations and stoppages on an annual basis. The three‐dimensional structure of the landslide revealed from the borehole data and the deformation data of the underground structure that have been implemented so far is shown. In addition, based on the continuous data of underground displacement recorded over 10 years and the groundwater observation data, the variation situation of the mountain landslide will be discussed from the relation with the groundwater supply by snowmelt in the snowy mountainous area.

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Measuring colloidal forces between clay microparticles with optical tweezers

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The interaction forces between clay micro‐particles play an important role in the macroscopic strength behavior of clayey soils. Optical tweezers were used in the present study to explore the interaction between clay micro‐particles. This technology uses a highly focused laser beam to manipulate small objects and can also be used as a force transducer for the measurement of forces on the order of pico‐Newtons (pN). Polystyrene beads were first used to measure the surface interactions between polystyrene beads and clay particles for accurate calibration of the system because of their perfectly spherical shape and optical homogeneity, and were successful in obtaining force measurements within the range of 20 pN. Subsequently the interactive force was measured when a small clay particle was moved along the surface of a large clay particle. The force measured varies as the interaction of clay surfaces may evolve along their relative motion, leading to force measurements up to 40~80 pN. The present study shows a promising potential of optical tweezers in exploring the complex micro‐scale phenomena in clay minerals.

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Contribution of geotechnical engineering to climate change and IPCC

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Many aspects of climate change‐associated natural disasters have been reviewed by the IPCC, as indicated in the recent report AR5 published in 2014. Unfortunately, geo‐disasters have scarcely been described. Even the terms of landslide and land subsidence, which are popular and important in geotechnical practice, have not appeared, although water‐associated disasters such as sediment disasters, debris flow, inundation, and flooding were described. Some certain reasons exist for this situation. Through experience as a review editor of AR5 (2010–2014), scientists who have served most as authors and reviewers of earlier IPCC reports are less aware of the existence of geotechnical engineering as an academic field in engineering. Another important reason is that sediment disasters caused by movement of soil–water mixtures are regarded as water disasters in which sediments are regarded as fluid. Consequently, no principles of solid mechanics or geotechnical engineering are described in past reports or in their references since the first AR of IPCC was published in 1990. As described herein, based on a review of recent activities in Asia, North America, and Europe related to climate change‐associated issues in geotechnical engineering practices, the authors strongly emphasize the following as fundamentally important.

1) Researchers must develop multi‐phase flow mechanics to solve climate change‐triggered issues in the field.

2) Engineers and researchers must formulate measures against compound disasters in which two climate‐change‐associated factors or a climate‐change‐associated event coincides with a nonassociated event, producing an extreme event.

3) The International Society of Soils Mechanics and Geotechnical engineering (ISSMGE) must integrate knowledge and experiences in geo‐disasters and geo‐environments through study and practice closely related to climate change, for engineers and researchers to contribute to the coming IPCC activities and reports.

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Urgent Issues and New Suggestions for Geo-disaster Prevention in Japan

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Following the devastating damage caused by the heavy rains in western Japan in 2018, the Japan Geotechnical Society compiled and published recommendations for future disasters. This report introduces an outline of the recommendation on slope disasters. In particular, the recommendation emphasises the need for measures to evacuate residents from dangerous places before a disaster occurs. For this purpose, it is noted that it is important to identify potentially dangerous places and their characteristics in the long term based on past disaster information and to inform the residents of the identified areas. As a pioneering effort to achieve this recommendation, this paper describes the results of research conducted in Yamaguchi, Hiroshima, Tokyo, and Kumamoto in Japan, to clarify the frequency of the occurrence of debris flows and its utilisation measures. The main result is that debris flows occur once every few hundred years in weathered granite areas, whereas volcanic ash areas experience even more frequent debris flows than granite areas.

Keywords: Debris flow, Occurrence frequency, Risk assessment, Disaster history

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Lessons from Recent Geo-Disasters in Hokkaido Under Heavy Rainfall

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In the Japanese archipelago, four typhoons continuously hit during mid to late August 2016, which led to significant damage in wide areas of Hokkaido. Considering the social importance of this heavy rainfall-induced geo-disaster, the Japanese Geotechnical Society (JGS) organized "JGS Survey Team for Geotechnical Disasters in Hokkaido, Japan Induced by Heavy Rainfall on August, 2016," comprising experts from both industry and academia of the Hokkaido branch of the JGS. The aim of the survey team was to investigate the phenomena and factors contributing to disaster prevention/mitigation from both short- and mid- to long-term perspectives and provide academic advice to related organizations. This study summarizes the site investigation of a disaster-stricken area along the National Highway Route 274 around the Nissho Pass, as well as the endogenous and exogenous factors for slope failures caused by this historical heavy rainfall.

Keywords: Heavy rainfall, Geo-disaster, Climate change

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Lessons from Geo-Disasters Caused by Heavy Rainfall in Recent Years in Kyushu Island, Japan

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Recently, heavy rainfall events have induced several geo-disasters, floods, sediments, and debris flow at different regions around Japan which in turn have caused severe damage to life and properties. According to several reports from the intergovernmental panel on climate change and other research institutes, the localized torrential rainfall events frequency is expected to increase. Under such circumstances of the anticipated climate change, the increase in the geo-disasters inducing forces such as rainfalls, the deterioration of the social infrastructure, and the decline in the overall geo-disasters prevention capabilities as a result of the changes in social structure due to the reduction in the working power were considered in this study. By carefully comparing and analysing the situation of the repeated geo-disasters and reflecting the obtained results to the geo-disasters mitigation and prevention practice in Kyushu, Japan, developing innovative system and techniques that integrate the academic disciplines, in collaboration with the local residents and government is now strongly needed.

Keywords: Geo-disasters prevention and mitigation, Torrential rainfall, Sediments and debris flow

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Lessons from Recent Geo-Disasters in Hokkaido Under Earthquake

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The 2018 Hokkaido Eastern Iburi Earthquake caused a large amount of slope failures and landslides over a wide area. In particular, the enormous damage due to slope failures was centered in Atsuma and Abira town which are to the north of the epicenter. In Atsuma town, a seismic intensity (Japan Meteorological Agency) of seven has been observed for the first time in Hokkaido, Japan. The geology in this region was mainly formed from three kinds of pyroclastic fall deposits (fa) erupted from Tarumae volcano, Eniwa volcano, and Shikotsu Caldera. Especially, the serious damage was generated in these tephra stratus. In addition, a large scale slide of rock slopes composed of mudstone also occurred in the Hidaka-Horonai river basin in Horonai district in Atsuma town, and its debris flowed into the river and caused the blockage of the river channel. This paper summarizes earthquake-induced damages on natural slopes and mechanical properties of Tarumae pyroclastic fall deposits.

Keywords: The 2018 Hokkaido Iburi eastern earthquake, Slope failure, Pyroclastic fall deposits

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Lessons from Recent Earthquake-induced Geodisaster in Kyushu

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This study presents the physical properties of pumice fall deposits sampled at Takanodai area, Minami‐Aso village, Kumamoto Prefecture in JAPAN, where long travelling slope failures took place by the main shock from the 2016 Kumamoto earthquake. A series of box shear tests under various conditions such as constant stress, constant volume and cyclic shear has been carried out for undisturbed samples of pumice fall deposits to evaluate shear strength properties and seismic behaviors. Finally, the slope stability analysis and the soil runout analysis for Takanodai area are couducted. The main conclusions are as follows: (1) The single particle crushing strength of pumice fall deposit ranges from 0.1 kPa to 3.82 MPa. The single particle crushing strength of pumice fall deposit is one order smaller than that of carbonate sand, well‐known crushable sand, and two orders smaller than that of Toyoura sand, which is a typical silica sand. (2) The cohesion and internal friction angle of pumice fall deposit under constant‐volume condition are 61.1 kPa and 30.8 o for peak strength and 46.8 kPa and 50.3 o for the residual strength respectively. (3) From a series of cyclic box shear test, shear stress and vertical stress gradually decrease due to cyclic shearing under constant volume irrespective of undisturbed/disturbed and 1.0/0.5 mm cyclic‐shearing. Finally, stress path with cyclic loading under constant‐volume condition for pumice fall deposit shows cyclic mobility similar to the behavior of liquefied soil. (4) The seismic stability of pumice fall deposit layer shows rapid decreases because of the strength reduction induced by the soil particle crushing while pumice fall deposit layer has enough stability under normal condition. (5) From the result of the soil runout analysis, the strength reduction of pumice fall deposit under earthquake loading is considered to be one of the factors to cause long runout landslide observed at Takanodai.

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Starting International Joint Research for Landslide Disaster Risk Reduction: The Use of Japanese Warning Technology in Sri Lanka Considering the Social Differences

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After the series of landslide occurrence in the mid‐1980s, landslides have become a major natural hazard frequently occurred in Sri Lanka. As a result, many measures against landslide disasters have been developed especially by National Building Research Organization (NBRO), which is the key organization for landslide disaster risk reduction. The foreign landslide technologies have been also encouraged to be transferred. Japan has a long history of landslide disaster risk reduction and have developed many technologies. This research focuses on the Rain‐induced Rapid and Long‐travelling Landslides (RRLLs), which is a common landslide in Japan and Sri Lanka. The selected technology to be transferred is warning and evacuation based on the rainfall forecasting data. When the foreign technologies are transferred, recognizing the social differences in each country is also important, in addition to the availability of mastering the technology itself. Since a technology is developed based on the ability of engineers and social background of each country, sometimes the technology is not suitable for other countries' social background even engineers have the ability to master the technology.

In this research, the landslide measures in each country are reviewed, especially focusing on the hazard map, since the hazard map is the base of warning and evacuation. Then the difference of social background for the use of hazard map is reviewed. Based on the result of these literature review, a necessary survey is proposed.

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Support for Disaster Victims and Reconstruction Town Planning after the Large-Scale Landslide Disaster

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Japan is hit by large-scale disasters almost every year. So far, we have implemented disaster prevention education for elementary schools, junior high schools, and the elderly, and have endeavored to improve regional disaster prevention capabilities. In the Hiroshima area, large-scale landslides occurred in August 2014 and July 2018, causing large-scale damage such as many deaths, housing damage, and suspension of social infrastructure. Immediately after the disaster in July 2018, we provided support for accepting disaster volunteer centers (July to August) and disaster consultation activities from Hiroshima City and Hiroshima Prefecture (August to November) in collaboration with experts. These support activities helped the victims of the disaster to secure a safe life in the future.

At Ohara Heights in Kumano Town, Hiroshima Prefecture, the "Ohara Heights Reconstruction Association" was established (October 2018) with the aim of working to realize a housing complex where people can live with peace of mind in the future. This reconstruction group conducted a questionnaire survey and summarized what they are having trouble with now, what they hope for in the future, and their opinions and requests for the administration. As a result, there is a high need to prepare for the next year's heavy rain, and we planned five study sessions on disaster prevention. The first time, I explained the cause of the disaster and future countermeasures. The second time, I explained how to evacuate with caution, how to create an evacuation map, and the procedure. The third time, the residents walked around the disaster prevention town in the morning, confirmed the dangerous places and evacuation routes, and created an evacuation map in the afternoon. The fourth time, we confirmed the evacuation map created by the residents and proposed and explained the sediment-related disaster warning and evacuation manual. The fifth time, an evacuation drill was conducted using an evacuation map. By holding these five study sessions, we were ready for the rainy season one year after the disaster. It is thought that this has improved the evacuation procedure during heavy rains and the disaster prevention capabilities of the residents. After that, disaster countermeasure facilities such as sabo dams were completed, but we would like to continue to support the protection of safe and secure lives.

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Towards a probabilistic performance-based methodology for the vulnerability assessment of buildings subjected to seismically induced landslides

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The present work intends to provide the basis for the probabilistic assessment of the vulnerability of buildings in case of seismically induced landslides aiming to provide a significant step towards a better understanding and quantification of structural seismically induced landslide risk. The proposed approach combines the seismic hazard analysis with the displacement hazard analysis and the fragility analysis of the structure. First, a probabilistic seismic hazard curve for the selected intensity measure(s) is derived together with the associated information for magnitude and magnitude/distance disaggregation based on a traditional probabilistic seismic hazard analysis (PSHA). Then, a displacement hazard curve is obtained based on the associated seismic hazard analysis results and appropriate scalar or vector models to predict the seismically induced slope displacements. The final result is a damage hazard curve describing the annual rate of exceedance of different damage limit states of the structure. Various sources of uncertainty are taken into account including the inherent (aleatory) uncertainty in the seismic and displacement hazard, the structural demand, the definition of damage limit states as well as in the structure's capacity. Epistemic uncertainties and their quantification are considered through a logic tree approach to derive a weighted mean and different fractiles damage hazard curves. A sensitivity analysis is also suggested to identify the most influential logic tree parameters. The proposed approach is illustrated to a hypothetical site exposed to seismically induced landslide hazard where a low-rise RC building is assumed to be located next to the slope's crest. The importance of the yield coefficients and displacement predictive models to the slope's performance, structural response, and vulnerability are highlighted.

Keywords: vulnerability assessment, displacement predictive models, seismically induced landslides, building structures, uncertainties

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Slope Behavior Improvement of Partially-Saturated Pyroclastic in Data Scarse Regions

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Field monitoring and non‐structural mitigation proposal are presented for an unsaturated volcanic pyroclastic of the Metropolitan Area of San Salvador. The pyroclastic is constantly affected by intense erosion, mass movements, collapse and liquefaction. Most of the slopes are almost vertical and temporally stable, but will collapse when wetted or during seismic events. It was observed that in its nature state some slopes with tilted surface avoid the infiltration. This allow that most of the time the slopes in this condition are dry and the safety factor is high. In order to propose a non‐structural mitigation since 2016 an experimental field started with slopes with different coverage and inclination. TMS3 devices were installed for monitoring temperature and moisture. This device uses electromagnetic waves to obtain moisture content. Angles on the top of the slopes varied from 3° to 20° and canalization was used to divert the rainwater outside. For the face of the slopes it was chosen angles of 90°, 60° and 45°. For protection of the slopes it was used grass, vetiver, lime combined with the pyroclastic and capillary barrier (double layers of intercalated layer of pyroclastic and gravel). The slopes that presented the best behavior had 20° on top of the slope and 90° on the face of slope with a capillary barrier losing humidity relatively quickly. It was observed the importance of the location, sun, vegetation, topography, protection, inclination, slope, percentage of humidity and rainy season with the behavior and stability of the slopes. The influence on humidity was observed due to the proximity of the trees and shrubs to the slopes (shade and roots), defining areas with higher humidity and a decrease in temperature.

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Geotechnical Investigation for Landslide Stabilization Works in Narayanghat-Mugling Road, Central Nepal

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The 36 - km Narayanghat - Mugling road section is considered as one of the most vital road links of Nepal as it connects the country's southern, eastern and western parts with tourist-hub Pokhara and Kathmandu, the capital city of Nepal. The road is being upgraded into two lanes while meeting the criteria for Asian standards. The hills have been slashed during the widening process, leading to increased occurrences and risks of landslides in the area. Due to weak and disturbed geological condition, a number of slope instabilities were encountered. Some new slope failures (11 sites) have occurred during the monsoon season of 2019. These instabilities needed to be treated to achieve a reasonable stability so that the highway can be operated as all - weather road with no interruption during the forthcoming monsoon season. Thus, it was essential to carry out topographic and geological mapping, geotechnical investigations, slope stability analysis and design of protection measures for improving the slope stability and for assisting in supervision of construction of mitigation measures during implementation. This presentation briefly describes the geotechnical investigations and analyses carried out for detail designing of landslide stabilization works in the Narayanghat - Mugling Road.

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Applying over ten years of experience in debris flow barriers to examples in South Africa and India for permanent protection

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Flexible ring net barriers against debris flow have been installed worldwide over more than a decade. Debris flow barriers are intended on one hand to retain the debris and let the water pass. On the other hand, they can be used for erosion control by correcting the inclination of the riverbed, thus slowing the following debris flows down. An increasing number of projects (over 50 in Switzerland and more than 100 worldwide) highlight the economic and environmental benefit of this solution. Special applications to retain very large volumes with single barriers have been successfully engineered for projects in Switzerland, Canada and Japan. This article illustrates the development of the standard debris flow barriers explained by 1:1 field test as well as finite element simulation. The existence of a European Assessment Document is highlighted, which leads to a CE Marking if all criteria are fulfilled. This CE marking can also be relevant for other regions except Europe as it allows the comparison of different products in regard to their capacity. Suggestions on the installation of this type of debris flow protection is briefly discussed as well as concrete examples. Technical and economic advantages as well as technical and environmental challenges will be discussed for two recent project sites in South Africa and India.

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Development of Engineering Techniques for Exploring Land Creep Susceptible Zones in South Korea

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In South Korea, 35 land creeps are officially reported and managed. Although it may be a small number compared to the frequency of shallow landslides or debris flows, the land creep is also well known for causing large-scale casualties and property damage in mountainous areas within urban areas. Korea's public interest and social consensus on the risk of such land creep has grown since the two largest earthquakes (2016 Gyeongju Earthquake w/ M_L 5.8 and 2017 Pohang Earthquake w/ M_L 5.4) caused unprecedented disasters. In this study, we developed an algorithm for exploring potential land creep susceptible zones throughout the Korean Peninsula. We first extracted 189,585 zones with elevation changes of more than 5.0 m over the past 10 years, based on the GIS technique using DEMs and contours extracted from a digital topographic map (1:5,000). We then conducted an AHP analysis to determine the weights of the factors involved in land creeps. At this step, we performed pairwise comparisons by categorizing all factors into natural- and artificial-factor groups, based on several previous studies that identified the cause of land creeps in Korea. The results showed that the AHP weights of the natural-factor group (including bedrock type, slope angle, soil depth, and distance from a fracture zone) and artificial-factor group (including distance from the development site) were 0.321 and 0.679, respectively, indicating that consideration of the possibility of land creeps is essential for artificial development activities in mountainous areas. Our findings could be contributing to the prioritization of field investigations and the establishment of criteria for risk assessment with the aim of developing systematic management and response technologies in Korea's land creep susceptible zones.

Keywords: Land creep, susceptible zone, Digital topographic map, Digital elevation model, AHP analysis

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Stability analysis for cut-slope collapse by earthquake

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A magnitude 5.4 earthquake occurred in Heunghae-eup, Pohang, South Korea on November 15, 2017. The earthquake caused 45 injuries and 165 private properties damage. This earthquake also caused ground disasters such as land creep, slope failure, and landslides in various parts of Pohang. A slope stability analysis was performed by selecting a representative area from among the potential collapse areas. The selected area has tensile cracks with a width of about 1 to 1.2 m, groundwater was flowing out causing surface soil erosion. In order to quantitatively measure these pieces of information, geology and topography characteristics were investigated with various survey techniques such as surface geological survey, drilling survey, groundwater level measurement, electrical resistivity survey. As a result of slope stability analysis for four sections using the surveyed information, all were considered as dangerous. In addition, it was determined that there is a possibility of a collapse in the rainy season. Therefore, it is suggested that appropriate countermeasures are needed to prevent potential collapse.

Keywords: soil creep, stability analysis, earthquake

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Quantitative Evaluation of Erosion Control Dam on Sediment Trapping Efficiency with a Simulation Approach

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Debris flows are extremely dangerous hazard events in mountain torrents over the world. It is known as the rapid downslope movement of slope materials that may include a combination of loose soil, rock, organic matter, and water, all of which are mobilized and transported as a slurry state along steep waterways. An erosion control dam has been known as the effective measure to retain and capture the moving sediment flow, and then to control sediment-related disasters in Korea, as well as other countries. The extend of its capacity is usually related to debris flow characteristics, location and the dimension of the dam. In this study, sediment trapping efficiency was numerically examined by using a debris flow simulation model, the KANOKO-type model. A simple numerical model was developed to predict flow characteristics along with a steep stream configuration and further validated against the debris flow event that occurred in the year 2011, Seoul, Korea. The effects of dams on debris flow movement and its retention capacity were quantitatively studied, regarding the number of dams, dam sizes and dam locations, and geomorphological characteristics of mountain torrents. The simulation results provided the spatial and temporal patterns of sediment deposition by erosion control dams. The study showed that a series of dams that were installed along the torrent seems to be effective for preventing mitigating debris flow hazards in steep, small torrents of Korea. This study can help to guide and plan the optimal allocation of erosion control dams.

Keywords: debris flow, Erosion Control dam, Debris Flow Simulation Model, Sediment Trapping Efficiency

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JICA's Support in Sediment Disaster Risk Reduction

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JICA's cooperation on disaster risk reduction is fully aligned with 4 priority actions of the Sendai Framework for Disaster Risk Reduction. Its cooperation on sediment disaster risk reduction is implemented under this policy. As good example of JICA's cooperation under the Sendai Framework, 3 projects on sediment disaster risk reduction are summarized. These projects are implemented respectively in Sri Lanka, Brazil and Honduras. The first project "Project for capacity strengthening on Development of Non-Structural Measures for Landslide Risk Reduction" is implemented in Sri Lanka. The Project focuses on non-structural measures such as development of risk and hazard mapping, establishment of early warning system and incorporation of these risk information into the land use plan. The second project "Project for Strengthening National Strategy of Integrated Natural Disaster Risk Management" is implemented in Brazil. This project also focuses on non‐structural measures against sediment disaster. These projects are aligned with the Priority Action 1 and 2. The last project example "Project for Control and Mitigation of Slope Disasters in the Central District in Republic of Honduras" is implemented in Honduras. This project implements not only non‐structural measures but also structural measures against sediment disaster as pilot. Therefore it contributes Priority Action 3 as well as Priority Action 1 and 2. JICA continues its cooperation on sediment disaster risk reduction under the Sendai Framework.

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Preliminary Report of Simple Hazard Mapping Methods for Slope Stability in Tegucigalpa, Honduras

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This report describes simple hazard mapping methods for screening the condition of target slopes, to assist engineers without expertise in sediment‐related disasters. The methods create simple hazard maps to understand the state of slope stability at study sites. We are preparing to create a hazard map and a risk map for the target slopes of Tegucigalpa, the capital of Honduras under the JICA Project, “Project for Control and Mitigation of Slope Disasters in the Central District”. Tegucigalpa extends along a basin with a diameter of 10 kilometers, and landslides frequently occur around the basin, especially in the northern slope. In general, to create a hazard map requires a high degree of expertise in slope stability. On the other hand, we think it is also necessary to have a method to roughly grasp the stability of the slope without any specialized knowledge. Therefore, we develop a simple mapping method, which allows the non‐specialized engineers to create a hazard map. As a first stage of this simple mapping method, it is essential to understand the overview of a hazard area through the process of the following activities: 1) Understanding the geology of the target area; 2) Classification of the stability of slopes; 3) Creation of survey sheets for each slope classification to easily evaluate their slope stability; 4) Creation of a landslide hazard map; 5) Creation of a landslide risk map. As the next stage, a detailed survey will be carried out and a plan of countermeasure construction may be done at each site if necessary. In this report we present the activities of 1) ~ 3) above; however, 4) ~ 5) are not explained in detail as these are activities to be included in the near future. In 3), the survey sheets list “topographical factors”, “geological factors", “hydrological factors”, and "the existence of countermeasures" as basic categories. Going forward, when creating a survey sheet, it is essential to select and change the items on the sheets according to the conditions of each target slope. We expect that this simple hazard mapping method can be applied to areas other than Tegucigalpa by selecting the most suitable items for each target site.

Note: In this report, the slope collapse phenomenon in the hazard and risk maps are regarded as "Landslide" and "Slope failure/Rock fall”.

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AHP Method Applied to Landslide Susceptibility Mapping in pilot sites of Tegucigalpa, 2016

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Since 2012, the Instituto Hondureño de Ciencias de la Tierra (IHCIT) form the Faculty of Sciences of the Universidad Nacional Autonoma de Honduras (UNAH), in its task to provide inputs with scientific value that become tools and instruments for decision‐making in favor of disaster risk reduction; establishes the first direct contact with the Japanese International Cooperation Agency‐JICA. In 2013, after strengthening relations between both institutions through the management of scholarships to improve the capacities of IHCIT professors / researchers, the execution of an action plan to strengthen the local capacities of two sites operated by JICA at that time to landslide control in Tegucigalpa: El Berrinche and El Reparto, with the IHCIT in charge of generating community strengthening at both sites through a Community Based Disaster Risk Management (CBDRM) Program. The good results of this synergy gave way to the signing of a new Project between IHCIT‐UNAH and JICA, this time aimed to strengthen research capabilities in landslides under the Project entitled: "*Assistance for Strengthening and Capacity‐building of Professional Techniques for the Control and Mitigation of Landslide in Tegucigalpa Metropolitan Area*", from which through training by Japanese experts, Honduran specialists learned new techniques for evaluating susceptibility to landslides, including the Analytic Hierarchy Process (AHP) applied to landslide evaluation, widely used in Japan and applied for the first time in Honduras. The present work summarizes the methodology and the results obtained in two pilot sites operated through the aforementioned Project.

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Coupling Antecedent Rainfall and Intensity‐Duration Thresholds for Landslide Occurrence in Tegucigalpa, Honduras, 2010

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Rainfall‐induced landslides occur on a yearly basis in Tegucigalpa, the capital city of Honduras. Every year, during the rainy season, thousands of inhabitants are at risk of suffering the negative consequences of landslides. For this reason, rainfall thresholds for landslide occurrence based on antecedent rainfall have been established for the city in previous studies. In this paper, the coupling of these antecedent rainfall thresholds and intensity‐duration thresholds for the triggering rainfall is analyzed. The year 2010 was chosen, since it exhibits the highest annual rainfall amount recorded in the last 15 years. The landslide database was constructed upon the information on landslide occurrence during 2010 derived from digital press archives from online newspapers, the Desinventar database and a few available technical reports. Hourly rainfall data from the National Autonomous University of Honduras (UNAH) meteorological station was used to construct the intensity‐duration threshold for the triggering rainfall. A total of 56 landslides occurring on 23 landslide days were reported for 2010. The evaluation of the antecedent rainfall thresholds alone showed that 12 landslide days were correctly predicted and 32 false alarms took place. However, it was determined that when landslide occurrence is predicted using the coupling of both thresholds, two new missed alarms are produced while the number of false alarms is significantly reduced to 22 (i.e. a 31 % decrease). The coupling of rainfall thresholds presented herein is an important alternative to enhance the prediction of rainfall‐induced landslides in the city and may contribute to the effectiveness of the city's early warning system.

Keywords: Landslide early warning system, confusion matrix, press archives, rainfall frequency contour lines, Desinventar online database

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Slope Disaster and Countermeasures in Honduras

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Tegucigalpa, the capital city of the Republic of Honduras is located in a valley, 800 to 1,000 meters above sea level and surrounded by mountains. In recent years, landslides and slope failures caused by urban development in the hill areas have increasingly occurred especially during the rainy season (May to October), which has led to serious damage to urban life. With Hurricane Mitch in 1998 resulting in over 1,000 deaths and missing, it is said that the ‘Slope Disaster Risk Reduction’ is an urgent task for the Central District of Honduras.

With the aim of reducing risk occurred through disasters, the authors have been implementing investigation and analysis for the slope disasters, and design and construction of countermeasures with the Alcaldía Municipal del Distrito Central (AMDC), Comité Permanente de Contingencias (COPECO), and Universidad Nacional Autónoma de Honduras (UNAH) serving as counterpart in Honduras, financed by Japan International Cooperation Agency (JICA).

In this paper, the procedures and results of 4 components, which are 1) investigation and analysis, 2) construction of structural countermeasures, 3) hazard mapping and risk mapping and 4) proposal of land use regulation, are elaborated.

On the 4 components, the authors prepare the manuals and the Action Plan, and implements seminars/workshops/conferences/training in Japan to transfer the technology and the knowledges to AMDC, COPECO and UNAH.

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Introduction of Preventive Measures in the Road Infrastructure Development of Tajikistan, in cooperation with a JICA Technical Project

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An important road transport hub for connecting the countries of Central Asia, the landlocked Tajikistan[1)] is surrounded by high mountains such as those of the Pamir Mountain range. Since gaining independence from the Soviet Union in 1991, Tajikistan has sought to boost economic growth through the transportation of agricultural products, making road transport the lifeblood of the Tajikistan economy. However, the country has suffered incessantly from natural disasters - including landslides, debris flows and rockfalls during the snow melting season. A technical cooperation project[2)] funded by JICA has contributed to capacity enhancement in road infrastructure investment in Tajikistan by introducing a preventive measure for roads as pilot work - which includes training and protection work against rock‐falls, failure of road slopes and debris‐flows – with the aim of establishing the idea of implementing such a measure to strengthen the road networks, in contrast to reactive measures in road maintenance. Four pilot cases were implemented in 2018‐2019 to demonstrate this concept to engineers in Tajikistan's Ministry of Transport[3)]. Following these, the institutionalization of the preventive measure was promoted by explaining cost‐benefit analysis in road infrastructure development in the seminars and pilot studies held during the project planning. The project was conducted as a joint venture with CTI Engineering International Co. Ltd., Kokusai Kogyo Co. Ltd., and OYO International Co. Ltd. of Japan, and local staff and Mr. Tabrez Tohirov (Design Engineer) in Tajikistan. Their contributions are highly appreciated.

1) Tajikistan Wikipedia, https://en.wikipedia.org/wiki/Tajikistan

2) JICA Technical Project, https://www.jica.go.jp/oda/project/1600245/index.html,

3) Ministry of Transport in Tajikistan, https://www.mintrans.tj/en

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Technical Cooperation Project by JICA: Landslide Adviser for Mauritius

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Mauritius is a small volcanic island located in the Indian Ocean, endangered by climate change. In particular, slope disasters are becoming an increasingly serious issue due to tourism and land development in slope areas. Although the Government of Mauritius wishes to formulate plans, understand risks and implement measures on scientific and technical grounds, it has not yet found a fundamental solution due to the lack of experts and engineers. The most serious landslide disaster in recent years was the 1986 La Butte landslide, with 1500 houses and a school sustaining damage. In response to this, landslide countermeasures were undertaken in 1998 at La Butte as urgent cooperation by the Japan International Cooperation Agency (JICA).

Against this background, the Government of Mauritius requested technical assistance from the Government of Japan, and the implementation of JICA Technical Cooperation Projects were approved. JICA implemented the 'Project of Landslide Management in the Republic of Mauritius' from May 2012 to July 2015 as a part of climate change adaptation and disaster mitigation program for Small Island Developing States. The next project, 'Landslide Adviser for Mauritius', was implemented as a successor project from January 2016 to March 2018.

This paper provides details about the series of technical cooperation projects in Mauritius by the Government of Japan.

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Structural and non-structural countermeasures against landslides implemented in Mauritius with the assistance of the Government of Japan

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Mauritius is a small volcanic island located in the Indian Ocean. As member of the Small Island Developing States (SIDS) - defined as “a distinct group of developing countries facing specific social, economic and environmental vulnerabilities” by the United Nations – Mauritius is particularly at risk to the vagaries of climate change. The scarcity of land available for construction, led to more development being carried out on sloping sites which are intrinsically more at risk to landslides and slope failures. During extreme precipitation regimes, some sites suffered damages as a result of ground movement. In 1986, a landslide occurred at La Butte, which caused damage to 1500 houses and disruption in the water distribution network. To stabilise the landslide at La Butte, the Government of Mauritius sought the assistance of the Government of Japan. Subsequently, extensive monitoring exercise was carried out and restraint works were implemented as part of the official development assistance by the Japan International Cooperation Agency (JICA). In the mid-2000s, other places were affected by ground slope stability problems which were also triggered by heavy rainfall and new technical projects were carried out. Besides control works, emphasis was also laid on non‐structural countermeasures. These included disaster education to the most vulnerable groups, setting up of early warning systems, proposal for hazard zonation maps and improvement of weather forecasting facilities. This paper provides the details of the countermeasures against landslides implemented in Mauritius with the assistance of the Government of Japan.

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Risk Estimation and Cost-Benefit Analysis of Road Geohazard Risk Reduction by comprehensive assessment for seismic and non-seismic hazards

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In road geohazard risk reduction, amid tight financial conditions under COVID-19, the importance is increased to identify an appropriate risk-reduction target (safety level of occurrence probability) to achieve the target to maximize the risk reduction effect and further investment efficiency.

JICA Technical cooperation project for the Project for Capacity Development of the Department of Climate Change Adaptation and Strategic Risk Management (DACGER) for Strengthening of Public Infrastructure Phase II (Namely Project GENSAI as the official name in El Salvador Government and the regional government of Central America) aims to reduce the geohazard risk of road infrastructure.

Project GENSAI developed spreadsheet tools for risk estimation and optimization of risk reduction investment through cost-effectiveness analysis for a roadside slope, a road location crossing watercourse, a bridge.

Spreadsheets tools are composing 1) probability rating checklists of a risk site, 2) loss estimation of a probable extent of a road damage event of a risk site, 3) risk estimation as potential annual loss of a risk site, 4) cost-effectiveness analysis of a countermeasure alternative.

The tools evaluate the safety degree of probability (SDP) of road geohazards for seismic and non-seismic events. Risk reduction measures effective for seismic and non-seismic geohazard risks can show cost-benefit effectiveness than only for seismic or hydrological risk analysis respectively.

In most cases, cost-effective viability is difficult for targeting a significant extent geohazard of low probability events. Therefore, it is necessary to consider preventing severe damage such as the collapse of bridges and allowing some deformation. It is also essential to consider the restoration of structures after damage.

Keywords: risk estimation, cost-benefit analysis, Geohazard, Risk Reduction, hazard

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Rockfall and Landslides Events and its Study in Los Chorros Segment of the CA01 Route, El Salvador

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Locating on a mobile belt and dominant Cenozoic volcanic geology, slope materials in the Salvadorian territory are prone to collapsing or sliding. The 18KM- 20 KM section of CA01 Route (Pan American Highway) in the Colon Municipality, in the Western Area of Metropolitan San Salvador (AMSS), is the most prone to rockfall or rock mass collapse in the El Salvador road network with steep topography and fragile geology. The 2 km section is winding road alignment and five lanes with around 53000 vehicles per day. A car driver lost his life in the rockfall incident in April 2017. The rockfall was induced by seismic, destroyed the rockfall protection barrier, and collided with a car.

The hard lava slope at-risk section is a maximum height of 30 meters from the roadway level and steeper than 70 degrees. Reddish and soft pyroclastic rock underlays the hard lava. The soft rock is a maximum 8 m thickness at the roadway level. The soft rock is relatively erodible than the hard rock overlaying. Therefore, the hard lava is somewhat overhanging at the boundary, which causes the rock mass collapse prone situation of the hard lava. The author conducted a rock collapsing simulation after observing discontinuities of rock slope using drone aero photos. The simulation result showed rock collapse blocks the five lanes of carriageways entirely in an extensive scenario. Ministry of Public Works and Transport conducted the shotcrete on the soft rock to protect further erosion, wire-mesh netting with rock bolts for the hard lava slopes, and high-energy absorbing rockfall barriers. A rock slope collapse blocked the whole lanes of a secondary priority road portion on the risk management where the government had not applied the countermeasures in April 2019. Again, the government discussed fundamental solutions. Finally, the government discarded constructing rockfall protection sheds considering the cost-efficiency and possible traffic disturbance. And the government decided to shift the road alignment to keep distance from the lava slope with a viaduct. The viaduct is six lanes to secure the heavy traffic. We are now discussing the geohazards risk and traffic safety on the new viaduct and traffic redundancy utilizing existing road alignment.

Keywords: rockfall, countermeasures, cost-efficiency, traffic redundancy

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Landslide Disaster Management and Capacity Development for Roadside Slope Risk Reduction in Bhutan

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Bhutan as a part of Himalayan region, landslides have been prominent and devastating natural disasters. The rain induced slope failure over geologically fragile slope is the most common geo-environment hazard in Bhutan. The landslide mostly happens in rainy season during the month of June to September. This is a direct correlation between the amount of rainfall and the incidence of landslides. The damage caused by landslides are catastrophic causing significant loss of lives, damage to infrastructure and loss of agricultural land. The most direct impact of landslide in Bhutan is on road infrastructures. Roads being constructed on mountainous rugged terrain, the road slopes are highly vulnerable to climate change impact. Providing climate resilient road features and effective road management are major challenges for the Department of Roads (DoR) in Bhutan. The mandates of DoR is to construct and maintain safe, reliable and excellent network of climate - resilient road infrastructure in the country to improve quality of life for our population through improved access to socio-economic facilities like market, health and education. However, constraint resources like technical expertise and limited budget, providing climate resilient road is a major challenge. The people of Japan through JICA has been providing Technical Assistance to develop technical capacity for Bhutanese counterpart to address challenges. In this project, JICA expert team provide hands on training to engineers of DoR starting from planning to execution of countermeasures on the ground. At the end of technical cooperation project for mitigation of road slope disasters in Bhutan, the department will be fully equipped to handle the challenges independently.

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Rockfall Protection on road in Bhutan

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A technical cooperation project for road slope disaster management is being implemented in the Kingdom of Bhutan. Rockfall prevention is one of the components of this project. Bhutan is located in the mountainous region of the Himalayas, and due to its steep topography, roads are the main means of transportation and distribution in the country. This road is a mountain road that runs through the foot area of the Himalayas. Slope disasters occur frequently every year on roads, which has a great impact on road users. Slope disasters are particularly susceptible to the climate change. In response of the situation, a trial construction for rockfall countermeasures is being carried out in collaboration with the Department of Road (DoR) as a road authority of the Bhutan. Roads in Bhutan often suffer rockfalls regardless of their size, which has a large impact on road traffic. On the other hand, due to topographical constraints, it is difficult to approach the source of rockfall on the road slope, and there is almost no space to install a protection structure for rockfall countermeasures. Due to this situation, many rockfall countermeasures have not been implemented in Bhutan until now. In this project, from the viewpoint of sustainability in Bhutan, a protection work for rockfall, which is not difficult to construct and using materials and equipment which are relatively easy to procure locally was examined. The model site of the trial construction for rockfall protection work was selected a slope with high risk based on the results of site inspection of road slopes conducted in advance, and to which the rockfall protection work can be applied. As a result, the site in Chendebji in Trongsa region was selected as a trial construction model site for rock fall countermeasures. Considering the local conditions and requests from DoR, a rockfall protection wall by the reinforced earth method using Geogrid, which has been used in DoR in the past was decided.

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Application on Slope Stabilization method aimed an Environment and Landscape Conservation

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In recent years, heavy rainfall caused by climates change has caused many damages in sediment disasters and floods all over the world. In Bhutan, where the development of social capital is in consideration of both development and conservation of nature, road development is being actively promoted, but slope failures often occur due to the topography, geology, and weather conditions. On the cut slopes and natural slopes due to the widening of the road at an altitude of about 3,000m, we installed a natural slope reinforcement method to protect the environment and landscape and stabilize the slopes. As a result of the monitoring survey, the vegetation mat's heat‐retaining effect and topsoil outflow prevention effect suppress weathering associated with freezing and thawing, and reinforcement with steel bars prevents the movement of unstable soil blocks. It was clarified that the restoration is in progress, and it was found that it can be applied even under the geographical and geoclimatic conditions of Bhutan.

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Generating Landslide Hazard Map on 2015 Nepal Earthquake, and Subsequent Training Activity

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2015 Nepal Earthquake was a gigantic one of M 7.8 that occurred on the 25th of April 2015 in the central part of Nepal. This earthquake caused a countless number of houses and slope collapses, killed more than 8,000 people. Through this presentation, we will report how we generated the hazard maps and provided them to the Nepal Government, as members of the project on Rehabilitation and Recovery from Nepal Earthquake (JICA). Additionally, two TOT (Training of trainers) workshops held in Kathmandu will be reported. The first seminar aimed at government engineers to utilize them for their public works. The second seminar targeted local engineers to generate hazard maps on their own. This paper will show our effort against the 2015 Nepal earthquake with the following aspects.

- Disaster damage study by utilizing satellite images
- Hazard map generating policy as easy to generate and use for Nepalese engineers.
- Interpretation of satellite image by comparison with site investigation.
- Hazard map generating method by using the quantification method.
- Hazard map display format aiming easy understanding for residents
- Technology transfer of how to utilize our providing hazard maps and how to generate new hazard maps of other districts.

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A case study of low-cost measures against landslides by river bank erosion in Nepal

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Since glaciated valleys with moraine and fluvio‐glacial deposits are often prone to landslides, a village called Tukuche in Mustang District in the High Himalaya region of Nepal has faced repeated occurrences of the slow‐moving landslide in such deposits. Though the houses mostly stand on the fluvial terrace consisting of gravelly deposits, the area where landslides occur consists of boulder clay deposits of glacial origin in the late Quarternary (Iwata, 1984). As riverbank erosion and subsequent retrogressive landslides were considered to be the present geomorphic processes based on the interview to villagers, combined measures for river stream control and stabilization of a landslide body were adopted in 1997‐98 under the Grass‐roots Grant of the Embassy of Japan. The adopted measures were gabion spurs to reduce the energy of stream erosion by Kaligandaki River and sand /silt sedimentation in the downstream side of the spur, which was expected to increase the stability of the landslide body. Gabion retaining walls with wooden piles were also adopted to protect the landslide head scarps. Though minor maintenance works were required, gentle slopes of the repeated landslides have been stabilized and used for pasture land until 2018. The results reveal that low‐cost measures for stabilization of slow‐moving landslides with shallow slip surface could be planned and designed taking present and past geomorphic processes into account and be implemented by the villagers using locally available materials for developing countries.

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Road Slope Disaster Countermeasures in Sri Lanka

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Sri Lanka has maintained impressive economic growth in recent years, and its road network has played a crucial role in this country's socioeconomic uplift. However, its economy has been hampered by natural disasters, such as floods and landslide disasters due to its geographical, geological, and climate conditions. Primarily, a substantial area in the hilly terrains of Sri Lanka is known as the landslide‐prone area, and approximately 38% of the total population of the country is living there. On the other hand, the Sri Lankan Government has set a goal of protecting the road network from such disasters, and in particular, strengthening its slope disaster management capacity in the mountainous and hilly regions most vulnerable to slope disaster. Under these circumstances, in March 2013, Japanese ODA Loan Agreement for "Landslide Disaster Protection Project of the National Road Network (LDPP)" was signed and carried out countermeasure construction on slopes on major national roads having a high risk of landslide with the Road Development Authority (RDA) and the National Building Research Organization (NBRO). Three types of disasters were mitigated through this project, such as landslide, slope failure, and rockfall. At the same time, capacity development programs were organized for RDA, NBRO, local consultants and contractors for landslide countermeasures, and it covers all stages of the countermeasures from the investigation, detailed design and supervision of construction. This paper describes the outline of the activities of the LDPP project and indicates some issues throughout the project.

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Identification of Debris Flow Hazards in Sri Lanka

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Debris flows are common types of fast‐moving landslides in the central highlands of Sri Lanka. They usually start on steep hillsides as shallow slope failures during intense rainfalls, then fast flow down hills and/or into channels, and finally spread widely on gently sloping lands. Such fast‐moving debris flows, because of their fast-moving velocity and long-travelling distance, generally claim many lives in addition to damage on residential houses and infrastructures especially along their flow paths and within their deposition zones. Even small debris flows have the high potential to cause damage to property and loss of life. One single event like the Aranayake debris flow of 2016 killed 145 people and destroyed more than 100 houses. It is thus essential to identify and predict debris flow prone site or stream in order to manage the loss of life and property damage risks from future debris flows. As part of a technical cooperation project between JICA and NBRO - Project for Capacity Strengthening on Development of Non‐structural Measures for Landslide Risk Reduction (SABO Project), an inventory survey of recent debris flow disasters was conducted to identify and clarify their actual occurrence conditions and damage situations, and thereby to develop an empirical topographical model for the identification of debris flow prone areas in Sri Lanka. The empirical model defines and characterize the topographical features of debris flows including three zones - initiation (or source) zone, flow path, and deposition zone, and can be used to predict areas prone to debris flow and associated affected area.

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Technical transfer for Landslide investigation and monitoring at central Asia Kyrgyz republic

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The Kyrgyz Republic is a mountainous country and this range is about 900km east to the west located north of the Tian-Shan range. Geological status is east-west geological divisions due to the geological tectonic movements that occurred from the Carboniferous to Jurassic, and these are cut by the right strike-slip active fault (Talas-Fergana fault) extending that was active in the Neogene. Many earthquakes had occurred along this fault at central to the southern area of Kyrgyz, and it is the reason for many slope failures. The IPCC estimates that these areas will have increased rainfall intensity in the future. Therefore, the risks of slope disasters will continue to increase with this estimation.

Japan International Cooperation Agency has started a project of international road improvement at central to a southern area since 2017. A task of technical transfer of road disaster prevention has been added to the project because of many latent non-collapsed portions and estimated impact of climate change in the future.

The personalities of the Kyrgyz engineers who worked together with us are described below. Many persons have a strong interest in new technologies and an emphasis on field experiences. They are suitable for site reconnaissance because they have excellent observing sense for slope status and they have physical strength on a steep slope. The target of technology transfer was the staff of the Ministry of Transport, Architecture, Construction and Communications as counterparts, but they were busy with management. Therefore, the technology of landslide investigation was transferred to the staff of the subordinate organizations of the Ministry. Based on their understanding of the purpose and mechanism, materials and equipment that could be procured locally were found and sustainable methods in Kyrgyz were found by the project.

As a result, local staff could obtain the capacity of monitoring the slope status and judgement of risks each rainfall even at the periods of Japanese engineer absences. This technology transfer is assessed as a sustainable status because monitoring equipment and drilling machine have been used effectively still now. On the other hand, there is a problem that technical transferred key man is easy to Job-change to other country because of Kyrgyz salary level is lower than other country. Disaster prevention technology is important for basic skills for national development. Securing a working place for each country will be necessary where the engineers can continue activities for sustainable basic technical skills and development of original skills at each country.

Keywords: technical transfer, road disaster prevention, landslide investigation, sustainable basic skills

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Landslide interpretation based on precise visualization method using high resolution geospatial data

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In Japan, where people's houses and infrastructure are concentrated in a narrow and steep land, many landslides and debris flows occur every year. In particular, there has been an increase in damage due to disaster factors that exist on the slope under trees, which is hard to find by field surveys. It is expected that geospatial data such as satellite images, aerial photographs, and topographical data will be utilized in order to efficiently and quantitatively evaluate these hazardous areas without leaking them. The authors have been working on disaster prevention and mitigation using topographic data obtained by aerial laser surveying. This paper introduces challenge cases such as micro landform interpretation and landform analysis for grasping disaster factors by visualization of landform data.

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Use of UAV‐SfM point cloud for emergency response to landslide disasters

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When a landslide disaster occurs, investigations and measurements are carried out to establish a warning and evacuation system and implement emergency measures. In this case, it is important to understand the overall picture of landslide disaster based on the three‐dimensional location of the landslide topography and its deformation, and to consider countermeasures. The point cloud obtained by UAV‐SfM can be used for this purpose. The point cloud helps us to understand the overall picture of the disaster because it can represent the shape and color of the terrain and objects in a three‐dimensional manner. The landslide model with point cloud is a "virtual landslide" that enables us to investigate the landslide situation from any viewpoint. It is important to share information with related organizations in disaster response. Sharing the landslide model will help us to understand the situation more quickly, and if we share the landslide model through web conference system, we can discuss with related organizations and get technical support from experts. In this paper, we report the results of the study on the use of UAV‐SFM point cloud data for landslide disaster response.

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Large Landslide Dam in Hidakahoronai, Hokkaido

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Causing by the 2018 Hokkaido Iburi Tobu Earthquake, many sediment‐related disasters occurred, resulting in enormous damage. Most of them were the shallow landslides, but the Landslide Dam at Hidakahoronai River is a large‐scale landslide movement. In this study, we carried out field surveys immediately after the disaster, outcrop surveys and boring surveys of the landslide to understand the structure of the moving mass and the slip surface of the landslide, and the runoff ratio was estimated based on the observation of changes in water level. Looking at the location of the landslide dam, the ridge on the right bank moved to the south, resulting in river channel blockage. Based on the LP data measured on September 11 to 12, the scale of the landslide dam is estimated about 52 m in relative height difference from the original riverbed in the blockage, about 800m in length, and 350m of the displacement. Around the front of the landslide, it piled up on the slope of the left bank and accumulated, and it is crushed. On the other hand, most of the landslide is not crushed on the outcrop, and large landslide masses are deposited in the topography before moving. Looking at the boring core (BV-2), the thickness of the crush zone of the assumed slip surface is about 17 cm, which is relatively thin, and the upper moving mass is not crushed. These observations suggest that a rock mass landslide was moved for 350 m without being crushed. In addition, the change in water level showed that the runoff rate was relatively low at 18‐30% in the Hidakahoronai River, and that the runoff tended to increase with each successive rainfall immediately after the earthquake. This rate is clearly lower than the landslide dam caused by the 2011 Kii region, which is the characteristics of the landslide dam caused by the earthquake.

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Development of methods to assess the annual expected loss of earthquake‐induced landslides

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Reducing the risk of earthquake‐induced landslides (EIL) is an ongoing challenging issue. While methodologies to map the susceptibility of EIL in a wide region have been applied, the methods to reduce the risks are yet to be developed. The risk herein is defined as the product of probability of the failure and the magnitude of the loss which will be expressed in terms of cost. There are two major prevention measures of risk reduction: (1) reduce the exposures to the hazardous areas, (2) implement countermeasures for a pre‐identified landslide if the potential loss is evaluated as unacceptable. There are no guideline or procedures, however, to design countermeasures such that a certain factor of safety (FS) is retained, taking into account the duration and amplication effects of the seismic waves. As an alternative to targeting a specific FS, we are studying a design concept to lower the expected annual loss (EL), which is the product of probability of failure and economic losses. A case study of landslides, that were induced by 1949 earthquake in Imaichi city, Japan was performed. Failure of a landslide, including the water pressure, was simulated by dynamic FEA(Finite Element Analysis) to find the limiting PGA (LPGA) that induces the failure. Subsequently, FEA was performed with reduced water level by 2 m, simulating the drainage work. The LPGA has become higher and EL has become lower than those in the case with original water level, since higher the LPGA the lower the exceedance probability.

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Effect of S‐Wave Velocity Structure of the Ground on Occurrence of Strain in Landslide‐prone Slopes during an Earthquake: A Case Study of Landslide along the Yamagata - Suifu Line, Induced by the 2011 off the Pacific coast of Tohoku Earthquake

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In recent years, landslides due to the seismic waves (earthquake‐induced landslides) have caused significant damages to residential area. In order to reduce the damage caused by earthquake‐induced landslide, it is important to identify the location and scale of such landslides prior to the occurrence. However, many geological features have remained unclarified, such as the mechanism of earthquake‐induced landslides and the depth of their slip surfaces. This is because there have been few cases of studying the slip surface depth of the earthquake‐induced landslides and the dynamic characteristics of landslide‐prone slopes. This study attempts to investigate the earthquake‐induced landslide on the Yamagata-Suifu line, where the strain is observed due to the aftershock of the 2011 off the Pacific coast of Tohoku Earthquake, to conduct the linear seismic response analysis based on the core samples and the PS logging survey in 2018, and to evaluate the possible slip surface by core samples observation and the effect of S‐wave velocity structure of ground on the strain in landslide‐prone slope during earthquake.

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Relationship between water quality and ground condition in earthquake-induced landslide areas

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The behavior of groundwater is an essential factor affecting the stability of landslides. Water quality investigation is effective to detect distribution and flow pass of groundwater in landslide areas. Ground condition in a landslide area is closely reflected in its water quality. The authors have been paying attention to the water quality of groundwater in landslide areas as a possible index to indicate activity of each individual landslide area. In 2004, a lot of landslides were induced in the mountain watershed of Imo‐River by the Mid‐Niigata Prefecture Earthquake. Those landslides can be classified into two movement categories, namely large displacement type and small displacement type. The authors have investigated the water quality in landslides of both categories. Especially electrical conductivity (EC) and ion concentration were measured in landslides. In addition, automatic measurement of electrical conductivity has been carried out in a targeted landslide. In general, water quality in landslides of large displacement type showed higher total ion concentration in comparison with the water quality of the small displacement type landslide in the same geological formation. It is suggested that the large displacement type landslide shows higher weathering activity than the small displacement type landslide. Furthermore, the results of automatic measurement of the electrical conductivity in the targeted landslide area shows that the EC value of the large displacement block is much higher than the EC value of the small displacement block in the same targeted landslide area. Both measured EC values show strong fluctuations corresponding to snow melt and rainfall. However, as general tendencies, the EC value of the large displacement block shows gradual decreasing, whereas the EC value of the small displacement block shows constant staying. It is suggested that the landslide mass of the large displacement block was highly disturbed and showed higher weathering potential just after its occurrence and showed gradual decreasing of weathering potential with the passage of time. To analyze spatial distribution and temporal variation of the water quality, especially electrical conductivity and ion concentration, in landslides areas could be useful for evaluation of susceptibility of landslide occurrences.

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Prediction of groundwater level fluctuation in deep-seated landslide area using genetic algorithm

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Deep-seated landslide is the phenomenon that generally comes into action by the influence of groundwater. It is common understanding that deep‐seated landslides occur mostly during periods of snowmelt and intensive rainfall. An increase of groundwater level due to snowmelt and intensive rainfall is considered to be one of the most essential triggering factors of deep-seated landslides. It is important to predict groundwater level fluctuation with sufficient precision to evaluate the stability of deep‐seated landslide and further to evaluate effectivity of countermeasures for deep‐seated landslide stabilization. In Japan, it is customary to use the observation groundwater level to evaluate the stability of deep-seated landslide and to evaluate the effectivity of countermeasures for deep-seated landslide stabilization. The author thinks it is appropriate itself performing these evaluations using the observed data. However, it is problem that these evaluations depend on the weather condition of the observation term. Therefore, the author thought that quantitative evaluation was necessary. Specifically, the author carried out the prediction of the groundwater level fluctuations and the stability analysis of the deep‐seated landslide block using the predicted groundwater level. As a result, coefficient of correlation between the observed data and the predicted data shows high value of 0.90. Difference between the observed groundwater level and the calculated groundwater level in the period of highest groundwater level ranges only from 0.19 to 0.22 m. The author thinks that prediction of groundwater level fluctuation is effective when quantitatively evaluate the stability of deep‐seated landslide and the effectivity of countermeasures for deep‐seated landslide stabilization. It is clarified that the proposed method using genetic algorithm can predict groundwater level fluctuation with sufficient precision if continuous observation data of groundwater level is observed.

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Relationship between Bamboo Rhizome and Surface Failure

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Recently, there has been concern about the occurrence of slope failure due to the expansion of bamboo forests on steep slopes. However, few studies have examined the relationship between the expansion of bamboo forests and slope stability and the mechanical slope stabilization effect of the rhizome of bamboo. The expansion of bamboo forests onto topographical conditions that may be conducive to slope failure is unclear. In this study, we clarify the slope inclination, the factors related to the occurrence of slope failures such as topographical irregularities and watershed areas, and the relationship with the expansion tendency of bamboo forest. In addition, we report a method for evaluating the risk of slope failure due to the expansion of bamboo forest using the index of geomorphic driving force (Okumura and Nakagawa, 1988). This study was conducted at Moso Bamboo Forest in the city of Miyazu, Kyoto Prefecture. Using a digital elevation model acquired by aerial laser survey, topographic conditions such as slope inclination and index of geomorphic driving force were analyzed using ArcGIS. In addition, to understand the expansion tendency of bamboo forests, a distribution map was created using aerial photographs. Using the index of geomorphic driving force, an index threshold for risk of slope failure was determined fromKazunori Hayashi

points of slope failure that occurred in the past. The percentage of slope failure risk area in bamboo forests, as assessed by the index of geomorphic driving force, has increased in recent years. The slopes with risk of slope failure were extracted. As the bamboo forest expanded, it tended to spread to dangerous slopes.

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Small and simple water drainage drilling method for landslide disaster prevention

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A new groundwater drainage method by using a small and simple equipment; SWDmethod, are suggested for landslide disaster prevention. Landslide disasters are frequently occurring due to heavy rainfalls associated with global climate change. Groundwater drainage works are one of the preventive or emergency countermeasures for landslide disasters. However, the cost of water drainage works by using a conventional drilling machine is relatively high because it tends to require large scale additional works and transportation of heavy equipment. SWD - method enables to effective groundwater drainage at low cost in case of difficult place to transport a conventional drilling machine or urgent situations.

We have experiences of effective constructions of drainage works as an emergency measures of landslide sites and preventive measures for landslides along the road. About 30m long water drainage hole can be constructed by using SWD - method at clayey soil and/or soft rock slopes in short term. On the other hand, it is not applied to slopes in hard rocks and/or low - cohesion sand layers. The detail of characteristics, workflow, availability and application examples of SWD - method will be introduced in this presentation.

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Performance Verification of sediment capture by Flexible Barrier

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After the Sediment‐related Disaster Prevention Law was enacted on May 1st 2001, the design method for mitigation works in steep slope failure hazard area has been clearly defined and formally announced for public use. The design requirements are shown below.

(1) A barrier is required to withstand the design impact force

(2) A barrier is required to withstand the retained sediment pressure at the back of the barrier.

(3) A barrier is required to be able to retain a volume of debris as determined by the slope profile higher than the design debris volume

In recent years, sediment‐related disasters have been occurring frequently in various places. Although voluntary evacuation is being emphasized, countermeasures by structures which can be adopt to upper terms are still important. We have developed a new type of protective barrier, which is compact and flexible, as one of the effective sediment capture works. This flexible protective barrier has been installed in various locations since its first installation in 2011 and has captured debris at some of the installation sites. In this report, we will introduce examples of these debris capture cases and pick one of the examples as a sample into detailed analysis. In the detailed analysis, the validity of the existing design method was verified with reference to the slope condition after debris capture situation. The items to be verified were (1) amount of sediment captured and (2) acting force on the components. As a result, the existing design method is confirmed to be reasonable and safe.

Key words: Flexible barrier, debris capture, performance verification

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The Geofiber Method - Protecting slopes with Environment - conscious continuous fiber reinforced Soil -

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The Geofiber Method is a hybrid method for slope protection, combining continuous fiber reinforcement effect with surface vegetation effect. This method can prevent erosion and weathering of the slope surfaces. The Geofiber Method is also used as the restraining method that allows plants to grow when combined with a slope stabilization method, e.g., soil nailing. Continuous fiber reinforced soil is made by homogeneously mixing continuous polyester fibers into sandy soil, where the friction between sand particles and continuous fibers creates pseudo-cohesion, resulting in high flexibility and good erosion resistance. The continuous fiber reinforced soil work is carried out by spraying. The fibers are shot with a dedicated machine to be mixed with sandy soil at a constant angle to the slope. The Geofiber Method is applied to cut or naturalize slopes in order to protect the slope surface, and to create vegetation and green landscape. This method has been applying at Japan and steadily becoming popular in Hong Kong and South Korea.

The Geofiber Method can also be employed in protection of historical and/or cultural sites where concrete structures are not desirable. Recently in Japan, slope disaster often occurs due to heavy rainfall. As a result, damage of important cultural properties including temples, castles and others are increasing enormously. Slopes surrounding important cultural properties that constitute "historical landscape" has been maintained for a long time as cultural assets buildings. Therefore, when collapsed slopes in the vicinity of important cultural properties are recovered, it is very important to consider not only "slope stability" but also "preservation of historical landscape". In this report, the examples of the recovered slopes using the Geofiber Method in the world heritage Kiyomizu-dera Temple, that has recently experienced the slope collapses sometimes due to heavy rainfall are demonstrated.

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Case Studies of Installation of Measuring Instruments on Overseas Landslide Countermeasures and Their Problems: Examples of Sri Lanka and Honduras

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In recent years, the climate of the world is changing drastically. Large number of slope disasters have been recognized not only Japan but also other countries and many human lives have been lost. In order to improve this situation, implementation of structural hardware countermeasures are effective. On the other hand, there is no specialist in designing countermeasures and no budget in many developing countries in the actual situation. Furthermore, the current speed of climate change exceeds the speed at which such hardware measures can be taken. Under such circumstances, slope monitoring systems are quite effective for protecting human lives of local residents. We are trying to spread our remote monitoring system for landslide to those countries now. However, the system it was developed suitable for Japanese situation cannot be applied directly, because the natural and social environment of each country are quite different from Japanese it. In this presentation, we introduce case studies of application of our landslide monitoring system at Sri Lanka and Honduras in JICA project, and suggest the point of view when applying it to these developing countries.

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Disaster risk coverage of TV media for citizens

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In 2019, Japan's public broadcaster, NHK, joined with scientists and citizens to create a real landslide television show. With the recent increase in heavy rainfall disasters, it is increasingly important to share information about disaster prevention with everyone. By connecting the power of scientists, government and citizens, with the television media acting as a hub, it has become a hopeful initiative to spread disaster prevention information in a fun way. As one of such efforts of NHK, we created a TV show in which a landslide experiment in an actual slope was done by scientists. The scientific aspects of this experiment are reported in Ochiai, et. al, (2020) in WLF5. In the TV show, we showed not only footage of the artificial landslide, but also processes from its preparation to the data analysis by the scientists. We made the following attempts in its production:

To hire comedians for facilitators to attract people's attention

To include children in the show to make into a family‐oriented program

To involve scientists to ensure correctness

To make dramatic story of experiment by focusing unpredictable behavior of soil

We believe that this show has inspired the public to take an interest in preventing landslide disasters.

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Creating an archive of landslide interpretation using the human eye via an eye-tracking system

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Landslide distribution maps are helpful for disaster prevention planning in mountainous areas. Aerial laser scanning, which can produce detailed landform maps using a high-precision digital elevation model, was recently carried out over a wide area. Complex geomorphological interpretation work is carried out using such topographic maps. As geomorphological interpretation tools rapidly become more advanced, geomorphological interpretation technology reaches a turning point. However, while there are continual improvements in geomorphological interpretation hardware, issues such as the aging of veteran specialist software users are becoming a problem. Therefore, to overcome this, it is necessary to develop a method to transfer veterans' knowledge of interpretation methods to young people and further cultivate human resources with advanced interpretation abilities. This study tried to visualize the process of the latter based on veterans' interpretations that were collected using an eye-tracking technique. Results showed that veterans first confirmed the outline of landslides and then looked along the boundary of landslide bodies. This presentation will introduce the results of the eye-tracking technique.

Keywords: geomorphological interpretation, airborne laser scanning, technical transfer, veterans' knowledge

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Microseism and Vibration Sensor Array Monitoring System

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Many research activities have been carried out based on the methods for determining and analyzing ground types and velocity structures by utilizing microtremors and seismic motions so far. Furthermore, a method to estimate the velocity structure from the horizontal and vertical spectral ratios of seismic observation records at one point on the ground surface based on the diffuse-field theory for plane waves was proposed as a past study using seismic motion. In addition to the above existing methods, the multipoint measurement technology proposed by the authors can be used to evaluate the geo-ground characteristics in the local area, therefore, microtremor and seismic motion observation of the geo-ground are applied as an effective mean. The authors have developed a real-time monitoring system that is small in size, power-saving, low-cost unit embedded with 1D accelerometer and 3D MEMS accelerometer (microtremor / seismic motion), and have been checking its field performance since 2019. In the microtremor measurement, comparing the Fourier amplitude spectrum results obtained by the new type of a 1D accelerometer with the conventional microtremor sensor at the same place, almost the same results were obtained. The field observation results of the MJ 6.9 earthquake in Miyagi prefecture that occurred on March 20, 2021, will be introduced as an example. It was confirmed that comparing the observation result of the embedded 3D MEMS accelerometer with the result of the conventional seismometer, it is possible and comparable to measure both the waveform and Fourier amplitude spectrum characteristics in a wide band by using the 3D MEMS accelerometer, which is comparable to the seismometer. Sensor units were set up at multiple points on the field slope, and observations were continued for two years. Furthermore, as a result of verifying the embedded accelerometer's accuracy, it was found that it can withstand long-term measurement with an accuracy comparable to that of a seismometer as described above. Based on the above results, it is considered that multi-point and reliable seismic technology and the use of the results will lead to the strengthening of disaster response capabilities when tackling ground disasters that are generally uncertain and difficult to predict.

Keywords: microtremor, seismic motion, geo-ground monitoring, multi-point measurement

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Process of Preparing Community Disaster Management Plan: Case Study of Communities on Ichinichi-Mae Project and CDMP that Have Experienced Recent Disaster

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Based on lessons learned from the 2018 Flood and the Typhoon Hagibis 2019, it is more important than ever for communities to build Community Disaster Management Plan (CDMP). It encourages local communities to improve their own disaster management capabilities in a spirit of self help and mutual help, to prepare for increasingly intensified and expanded disasters by heavy rain through the climate change. "Its characteristic is flexibility and CDMPs require the following 3 processes; understanding the disaster risks in that community, selecting the problems based on the characteristics of the community and discussing the countermeasures. Remarkably, one of the most important process is to understand the exposed risks and vulnerabilities in that community. It motivates for preparing the plan and accelerates to find out possible problems related with various residents. However, in the most of the existing plans, there are some descriptions of hazard map, estimation of damage and the record of past disasters, provided by local government, and it is uncertain what measures were decided to implement to solve the problems clarified as a result of the risk assessment. Now, in the communities that had been affected by recent disasters, it is effective to share the own experiences of various residents because they can discuss the practical measures to some specific problems in case of unexpected disasters. Additionally, for the other communities which have not experienced any disasters, that could be a valuable resource to prepare for their CDMP. The recordings and the archives of disasters in a community such as chronology, oral histories, photos, etc. are one of the effective methods to prevent the loss of recollection as a part of community history, but it would not assist a preparation directly for unexpected disasters. In those disaster archives it is not indicated how we can find out the countermeasures based on the risk assessment in that community. In this report, we discuss how local residents include experiences of recent disasters into the process of preparing CDMPs effectively through the collaboration of “Ichinichi‐mae Project” and CDMPs’ model project of the Cabinet Office of Japanese Government.

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Extraction of Subjects for Regional Disaster Risk Reduction by Teaching Materials Simulating Evacuation Behaviors

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Since the Great East Japan Earthquake, Japan's disaster prevention has been striving not only for protection by structural measures but also for disaster risk reduction by non‐structural measures. It is the local community that is expected to bear the disaster risk reduction. In other words, it is expected that the local community will clarify the issues in the disaster response in the regional area, think about how to solve the issues, and put them into practice. Therefore, the government has also presented various guidelines to local community. The government provided guidelines shows a general response manual, which is convenient. On the other hand, it is also diversified local communities that have issues which cannot be dealt with by the leveled contents. Although the guideline can show the direction of the measures, it has the side that it is difficult to make effective disaster risk reduction measures for diverse local communities. "EVAG: evacuation activity game", a teaching materials simulating evacuation behaviors, was developed to gain awareness of this issue. In this report, from the characteristics of teaching material and the result of the utilization on workshop, clarify the effectiveness of extracting the issues of regional disaster risk reduction in various societies by utilizing the teaching material.

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An easy way to learning rainfall-induced landslides and its prevention using analog modeling

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Reliable transport infrastructure is one of the backbones of a prosperous socio-economy, and it should be safe from natural disasters. If a natural disaster blocks road, it will have a severe impact on social life. Hence, sustainable development of transport infrastructures is particularly important. For the construction of the sustainable transport infrastructures, engineers protect roads from natural disasters and consider the following processes: Investigate the possibility of landslides (ground surface survey); Examine the landslide scale and explore the subsurface conditions (boreholes and geological mapping); Evaluate the amount of decreasing safety factor (stability analysis); Selection and design of landslide prevention methods. These processes are performed by slope engineers, and it is not transmitted to the general audience. Furthermore, slope failures are often rapid phenomena. They occur apparently without warning leading to a significant lack of understanding for the general audience. Therefore, in order to convey slope engineering to the general audience in an easy-to-understand manner, we have developed various analog modeling using familiar materials to explain an easy way to learn about disasters and their prevention for the general audience. In this paper, we convey the following:

1) Analog modeling for the cause of landslide (rainfall‐induced landslide),
2) Analog modeling of landslide countermeasures
   a. Groundwater drainage (drainage borehole)
   b. Embankment
   c. Steel pipe/ steel pile wall
   d. Ground anchoring
3) Investigation method for landslide
4) We are conducting several activities to convey the cause of landslides and its prevention to the general audiences.

These models will help understanding our knowledge of rainfall‐induced disasters, and disaster prevention awareness will be expected to rise. In this presentation, we will introduce the model teaching materials and examples using analog modeling that are useful for disaster learning for the general audience.

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The Workshop Program of Disaster Prevention Learning for Primary School Children and Junior High School Students

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In Kochi Prefecture, 86% of the prefecture area occupies a mountainous area, and there are about 18,000 sediment‐related danger areas. In addition, the average annual rainfall is 2,500 mm, and the land conditions are such that sediment‐related disasters are likely to occur. In addition, natural disasters from typhoons and heavy rains have become more frequent and severe. Consequently, the people of the prefecture have become more aware of sediment‐related disasters. Under such circumstances, Shikoku Geotechnical Consultants Association, Kochi Branch is working to support disaster prevention learning at elementary and junior high schools in the mountains as a corporate group engaged in sediment disaster prevention projects in Kochi Prefecture. The main activity is to support children's field work and data organization for the creation of “disaster prevention map”. This paper, along with the support activities undertaken so far, we will introduce examples of how these activities have contributed to the improvement of local disaster preparedness.

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Approaches and Actions for Information Dissemination and Education for Disaster Resilience in the Chubu Branch of Japan Landslide Society

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The Chubu branch of Japan Landslide Society covers seven prefectures in the central Japan. Large-scale sediment disasters in the Chubu region are recorded mainly during the rainy season and heavy rainfall caused by typhoons on the Pacific side, and many disasters caused by snow melting and earthquakes have been recorded on the Sea of Japan side. A lot of researches have been made efforts for exploration on the historical disaster records, therefore case histories of disasters which should be passed down to next generation gradually came to be known. This paper briefly introduces the approaches and actions of disaster resilience education of the Chubu branch as follows:

- Collection and issuing of local disaster history and folklore on annual reports of the branch;
- A play on management and utilization of Tenryu River performed by the elementary school pupils for buildup of local disaster management system.
- Study visit to landslide sites such as Sabo Field Museum in Komagane.
- To establish a registration system of voluntary experts to make education against disasters.
- Training for future leaders in Chubu branch after the Great East Japan Earthquake.

Furthermore, a new event “the landslide site festival at Obasute” is planned with the aim of spreading knowledge of landslide phenomena as well as awareness of disaster risk management. Main contents of the event will be 1) Lectures on protection of agricultural lands, landslide prevention, and water of terraced paddy fields, 2) Trekking with guides to know the relationship of landslide and history of terraced paddy fields, and 3) Experience of local foods as rice made in landslide site. The event will offer an opportunity to develop understanding of landslides based on a concept of “landslide & tourism”.

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Collaboration of the City of Yokohama and the JAGE's chartered engineers for geotechnical evaluation consultation with local residents

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Yokohama is well known as a hilly city with a lot of occurrences of landslides in Japan. Improvement of slope instability in Yokohama is recently in progress due to a unique support system to subsidize a part of the payment for landslide prevention works of the city residents by Housing and Architecture Bureau, the City of Yokohama from 2006. There were about 30 cases subsidized in 2020. On the other hand, dozens of landslides a year on average have occurred in recent years due to increased rainfall caused by climate change. Consequently, we are not only promoting a policy to reduce the damage caused by landslides but also considering new measures by utilizing "self-help, mutual assistance, and public help".

Given the background above, the Japanese Professional Engineers Society for Geotechnical Evaluation (JPSE), in which geotechnical engineers chartered by the Japanese Association for Geotechnical Evaluation (JAGE) who are interested in residential land disaster prevention belong to, signed an agreement with the City of Yokohama in October 2020. Since then, the city of Yokohama has started a system to introduce the JPSE Kanagawa branch to the citizens who want to receive a geotechnical evaluation consultation. As a result, the number of consultations at JPSE-Kanagawa in the second half of the fiscal year reached 43, which corresponded to more than 80 a year. Eighty-five percent of the consultations were for evaluations of natural cliffs and retaining walls, with the proportion of those divided equally between two slope types. Hereafter, based on a mission statement "Yokohama Declaration" by an NPO "Blue Earth" and JPSE-Kanagawa, collaborating with local governments, the JAGE's chartered engineers in Kanagawa will contribute to disaster-resistant community development by providing consultation service for local residents.

Keywords: City of Yokohama, geotechnical engineers, collaboration, geotechnical evaluation, landslide

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International Comparison of the Classification of Soils and Rocks for Determining the Stable Cut Slope Angles

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We compared the classification methods of soils and rocks for determining the stable cut slope angles in each country. Soil classifications on soil slopes are all based on the determination of grain size and compaction state of soils through visual observation and tactile sensation, and the stable cut slope angles are attained from these classifications. In Japan, the workability of construction is also used for soil classification: clay if it is easy to adhere to the bucket with many voids, sand if it is difficult to form a heap in the bucket. A similar classification method can be found in India. Rock classifications on rock slopes are often based on the rock type, the degree of weathering and fracturing. The stable cut slope angles of rock slopes are attained from these rock classifications except in Japan and India. In Japan, we classify rocks based on the workability of construction: hard rock if blasting is required, soft rock if ripper excavation is possible without blasting. In many cases in Japan, it is necessary to decide the stable cut slope angles immediately without the judgment of a geologist on the exposed bedrock faces at the site of excavation, where many types of rock and varieties of rock mass characteristics exist. Therefore, we use the classification of rocks based on the workability of the construction. When setting the stable cut slope angles, if it is difficult to classify the soil and the rocks of slopes by visual observation, we propose a method of the classification of soils and rocks based on the workability of the construction while checking the exposed rock mass and the degree of weathering and fracturing.

Keywords: classification of soils and rocks, stable cut slope angle, workability of construction

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Technical terms of Structure for Slope Protection

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Recently, there are many disasters in the world. Especially disasters will influence the lives of the people in poor countries. Meanwhile, Japan is located in a very dangerous area on the earth due to volcanoes, earthquakes, rainy seasons, Typhoons, and so on. So, there are many protection and mitigation methods and products against disasters in Japan. However, there are some protection methods that are widely used and highly effective in Japan but are not widely known overseas. Some of the same protection methods have different design details.

For example, a very popular method for the protection of slope failure is the concrete frame that was developed 50yaers ago and used only in Japan. The purpose of the concrete frame is to protect slopes from erosion, weathering, and small failure of slope surfaces. However, the author thinks the popular method will be shotcrete in another country for the same purpose as the concrete frame. What is the difference between each method? Shotcrete is used against erosion and weathering, but the concrete frame can also be used against small slope failure.

There are many kinds of mitigation measures against slope failures in Japan, however, it is thought the knowledge of the protection method for slope failure has not been understood by the engineer of other countries, and the situation of the protection techniques in other countries is similar for the engineers in Japan.

The author will introduce some of the main techniques for slope protection in the world comparing the protection methods of Japan with those of other countries.

Keywords: Slope protection, Shotcrete, Erosion, Weathering, Concrete frame

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International differences in methods for calculating the deterrent effect of ground anchor and soil nailing

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The basic definition of the stability analysis of the limit equilibrium method used to calculate the required deterrent force for anchor, etc. is as follows. The value (S/F) obtained by dividing the shear strength(S) of the slip surface by the safety factor (F) corresponds to the shear force(T) acting on the slip surface (S/F=T). Naturally, since strength and force are different physical quantities, they cannot be added or subtracted directly. In Europe and the United States, anchors, bolts, nails, etc. are collectively referred to as anchors. There is an idea to classify the active anchor that gives prestress and the passive anchor that does not give prestress because of the difference in the deterrent mechanism. The classic design method for active anchors is to divide the anchor force into the normal force and the tangential force on the slip surface, as in Hobst & Zajic (1983). The effect of increasing the shear strength of the slip surface by the normal force is the clamping effect R_S. The effect of directly suppressing by the tangential force is the straining effect of R_T. Conceptually expressed as $F=(\Sigma S+R_S)/(\Sigma T-R_T)$. Looking at the treatises published in recent international journals, etc., the treatment of this detention effect R_T in the stability analysis formula is not unified. In recent literature on passive anchors, there are both ways to subtract the detention effect from the denominator and to add it to the numerator. In SLOPE/W of Geo-SLOPE of the United States, which is used in some recent documents, anchor force, etc. is given as a concentrated load in the casting direction. The software employs a method to analyze the force balance within a slice. In SLOPE of GeoStru of Italy, the deterrent power of the active anchor and the passive anchor is expressed as design strength. The horizontal component is defined as anchor strength R_j, and different handling methods are adopted for active anchor and passive anchor. In this way, there are various calculation methods for the deterrent effect in international journals, etc., and they are not unified.

Keywords: Limit equilibrium method, Slope stability analysis, detention effect, Scalar and vector addition

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Vegetation Methods Based on the Japanese Standard Cut Slope in Bhutan

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This paper describes the vegetation methods for preventing erosion of cut slopes conducted by the JICA project in Bhutan. According to the soil classification of Japanese standards, the surface soil corresponds to "ordinary soil", so the target slope of vegetation at the project site in Bhutan is cut at a slope of 45°. Vegetation works were selected with appropriate seeds and vegetation methods on the slope by two steps. One is to do a germination test. The other is to select seeds for the vegetation works.

In the first work of bioengineering, germination tests were conducted on three materials: (1) *Paspalum atratum*, (2) *Brachiaria ruziziensis* (Ruzi grass), and (3) Mixed seeds (*Lolium multiflorum*－Italian ryegrass 30%, and *Dactylus glomerata*－Cock's foot 70%). Since the germination status was good in all three, the following vegetation types were used as test works. Type A: Sowing seeds in rows on the slope (upper: *P. atratum*, lower: *B. ruziziensis*). Type B: Sowing seeds all over the slope (upper: *P. atratum*, lower: *B. ruziziensis*). Type C: Transplanting seedlings with covering the slope (Mixed seeds).

All three types, A, B, and C, are placed on the wooden boards horizontally at intervals of 1 meter above and below the slope for spill prevention of soils. Type C is the so-called stripping method, in which the surface soil is stripped at the germination test site before planting.

Observations of vegetation works are currently underway, but the following has been revealed:

1. Type A has a dry surface on the slope, so there is little vegetation spread from the sowed rows.
2. Type B has a covered surface on the slope with sowing seeds. The vegetation is in good condition.
3. Type C stripping method was originally a method to prevent surface erosion of embankment work, but it was found that good vegetation can be maintained even on a cut slope like this time.
4. The cut slope remains stable with a gradient based on the Japanese standards.

Keywords: cut slope, vegetation, the soil classification, Japanese standards, Bhutan

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Definition of Technical Terms for Landslide Disaster Management

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Appropriate English terminology is difficult to be found for several technical terms commonly used in the field of landslide disaster management in Japan. The use and the meaning of terminology or a concept may vary from one country to another due to the difference in language, culture, practice and several other factors which may impact scientific and technological research and development.

A set of the slopes formed by a deep-seated slide consisting of a head scrap or depletion and a landslide body is usually defined in Japan. This is called “Jisuberi Chikei” (landslide topography) which often indicates susceptible slopes of landslide reactivation. However, an equivalent English term is hardly found. The micro-topography of a slope formed by deep-seated slides is often mapped for the planning of landslide mitigation measures. Micro-topography of a landslide body indicates different features such as landslide activeness, inactiveness, fracture condition and rock structure. These features are very useful for the planning and implementation of appropriate mitigation measures for the landslide. Despite this, micro-topographical survey and investigation of the landslide topography are generally not on the priority for the disaster management program in many countries. Slope failures with rapid movement (“Hokai” in Japanese) and slow-movement slides (“Jisuberi” in Japanese) may require different remedial measures for the protection of detachment slopes from further slope failure and for the stabilization of the landslide body respectively. Countermeasures against slope failures and slow-movement slides by the governments are implemented under the different laws in Japan. These two phenomena seem to be similar to those of disrupted landslides and coherent landslides in the classification of earthquake-induced landslides by Keefer (1984). In this session, nomenclature and definition of commonly used terms in landslide disaster management in Japan are one of the important issues to discuss.

Key words Landslide, technical term, nomenclature, slope failure, micro-topography

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Role of forestry conservation for landslide prevention

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Forests are distributed over a wide area in the mountains in Japan. Forests provide various goods and services such as ecosystem service, conservation, and formation of human living environment in addition to timber production. In order to enhance the function of forests that preserve the human living environment, a "protection forest" system had been created to manage and maintain forests. There are various types of protection forests such as windbreaks forests and health recreation forests. In particular, landslide prevention forests and watershed protection forests are important for human living and cover widely in Japan. In this presentation, we have organized research examples in Japan and an understanding of mountain restoration measures regarding the role of forests in reducing landslide damage.

Vegetation-covered slopes, including forests, reduce soil erosion and mass movement such as a landslide. In particular, forests are highly effective against soil erosion and significantly reduce sediment runoff. The effects of forests are the fixation of soil particles on the ground surface by roots, the covering of topsoil by fallen leaves and branches, and the reduction of surface flow by the formation of a highly permeable soil layer. As a result, the soil layer is easily maintained even on steep slopes. Forests are effective in reducing the risk of mass movements such as landslides. The toot system of the tree reinforces the shear strength of the soil layer and reduces the risk of landslides. It is highly effective in forests with a well-developed tree root. The distribution density of the root system is higher near the ground surface and smaller on the deeper side. The effect of the root system is small in the deep underground and slip surfaces of landslides are often seen deeper than the root system distribution. Therefore, it is necessary to understand that the landslide prevention by forest function is limited. Sediment outflow due to soil erosion often occurs on slopes without vegetation cover. In Japan today, bare slopes are mainly seen on landslides and artificial slopes such as cuts and embankments slope with civil engineering works. In disaster prevention work on these bare slopes, it is necessary to utilize the function of vegetation and forests in order to reduce soil erosion after the countermeasure work.

Keywords: landslide, erosion, forest, protection forest

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Outline of measures for sediment disaster by Sabo Department of MLIT, Japan

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Japan is prone to volcanic eruptions and earthquakes, as well as long rains and heavy rains caused by typhoons. Japan is also prone to disasters due to its fragile geology. In recent years, the number of sediment disasters in Japan is increasing, and climate change is thought to be the cause. In order to protect human lives and property from sediment disasters, it is important to build landslide prevention facilities such as a sabo dam. On the other hand, public works expenditure in Japan has been decreasing year by year, which is about 65% compared to 20 years ago. In order to carry out erosion control projects efficiently within a limited budget, we will promote the spread of remote-controlled unmanned construction technology nationwide in line with the future spread of 5G. In accordance with the Landslide Disaster Prevention Act, sediment disaster risk areas “Yellow zones” and special sediment disaster risk areas “Red zones” are designated to establish warning evacuation systems and to restrict development activities. Since the enactment of the law, the designation of zones has been steadily promoted, and as of the end of March 2021, approximately 660,000 areas have been designated as yellow zones and 550,000 areas as red zones. In addition, as part of our efforts to communicate the real-time changes in the risk of sediment disasters, when the risk of a sediment disaster increases, we issue a sediment disaster alert. We will continue to protect human lives from sediment disasters by combining hardware and software measures.

Keywords: sediment disaster, sabo dam, sediment disaster risk area, evacuation, sediment disaster alert

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Introduction of Construction Information Modeling / Management in the Yui Landslide Countermeasures

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We have some concerns that Japan will not be able to respond to natural disasters due to a shortage of civil engineers resulting from the population decline, but we believe that improving productivity will enable us to maintain social capital development. Ministry of Land, Infrastructure, Transport and Tourism (MLIT) will improve the productivity of the entire construction production system by introducing the full utilization of ICT (Information and Communication Technology) to construction sites so that it will become an attractive construction site. We call it "i-Construction". In this context, CIM (Construction Information Modeling / Management) is being introduced with the aim of further accelerating the efficiency and sophistication of this series of construction production systems. The introduction guideline (draft plan) was formulated in March 2017 for those involved in public works (owners and contractors) to introduce and utilize CMI smoothly, and it would have been used for landslide projects. The specialized landslide edition (draft plan) was revised in March 2021. It hasn't been long since the guidelines were formulated and only a few cases have been reported.

This article is a report of the Yui landslide countermeasure project utilizing CIM conducted by the Fuji Sabo Office. In conducting the landslide countermeasure project, the basis of survey results was clarified by constructing a geology/soil model with CIM. The groundwater level reduction effect was also visually grasped by creating a 3D model. The geological structure of the landslide was clarified with CIM, which was impossible with the conventional methods, and the information about the determination of the slip surface and the evaluation of the landslide countermeasure effect was quickly shared with those involved. This has improved productivity. In order to expand such pioneering efforts nationwide, PDCA should be implemented and further evolved toward the introduction of CIM in the landslide countermeasure works.

Keywords: CIM, Yui, Landslide, Countermeasures

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Mitigation works for the Aruse I-3 block landslide in Miyoshi, Tokushima, Japan

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This paper reports the planning and design of mitigations work for the Aruse I-3 block landslide, conducted by Shikoku Mountainous Region Sabo Office, MLIT. A large sub-block landslide in the Aruse landslide hazard designated area, begun to move after the heavy rainfall storm in July 2018. This landslide can obstruct streamflow, and emergency countermeasures by drainage landslide mitigation methods have been carried out. Because the possible cause of landslide movement is the rising of groundwater level. Deep wells with drainage pumps (Deep well method) were constructed at the upper outward of the landslide mass to remove water flowing into, and multiple horizontal drill holes were constructed to drain rapidly the groundwater from the landslide mass. Then lowering of groundwater level was observed in some observation wells, but the landslide still moved with heavy rain. To stabilize the landslide mass, additional drainage tunnels have been planned at the lower outside of the landslide mass to drain infiltrated water effectively. Other than those drainage works, various advanced landslide mitigation works are planned for the future.

Keywords: Aruse landslide, Emergency Countermeasures, Deep well method, Horizontal boring works, Permanent Countermeasures

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Efforts and results of mountain area conservation by Forestry conservancy projects

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Forests constitute about 70% of Japan's national land and are characterized by steep terrain and fragile geological conditions. Moreover, concentrations of heavy rain during the rainy and typhoon seasons and frequent earthquakes cause many forest area disasters across the country every year. The Forestry Agency of Japan has been taking forestry conservation measures, specifically, two major countermeasures consisting of the regulation of forestry-related activities under the Protection Forest System outlined in the Forest Act, and preventive and restorative measures taken through the placement of structures via civil engineering construction projects through forest conservation works, called "CHISAN," so as to protect the lives and properties of the public and ensure regional safety and security.

The agency's forest conservation efforts consist of stream works, which are intended to prevent erosion of banks and riverbeds and the outflow of earth and sands through the construction of check dams and other civil engineering structures, as well as hillside works, which are intended to reduce hillside slope gradients and disperse downflows of surface water through installation of structures such as retaining walls and through planting based on landslide characteristics for the purpose of recovering vegetation. Moreover, landslide prevention works provided to locations where landslides have occurred or are likely to occur consist of the following two types: control work, intended to mitigate landslide-causing factors by draining underground water, and restraining work, intended to directly stop soil movement. These measures enhance the water resource conservation function of forests and stabilize mountainside soils.

Recent examples in which the forest conservation works proved effective include the heavy rain in Kuma-mura (Kuma village), Kuma District, Kumamoto Prefecture in July last year, where driftwood and other debris flowed down a mountain stream but were captured by a check dam. Another example was heavy rain that fell on the Inadani Region, Nagano Prefecture that caused a far smaller number of forest disasters despite the higher amount of precipitation than that in the torrential rain disaster in 1961 thanks to such conservation works. These examples prove the effectiveness of long-term forest creation and conservation measures.

The agency of Japan will endeavor further to enhance the disaster-prevention functions in forests, promote projects for ensuring regional safety and security, and promote public relations and public-awareness-raising by publicly explaining forest conservation works through various means, including this presentation.

Keywords: forestry conservation, MAFF

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Examples of recent landslide countermeasures by conservancy projects

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At the Iwaigawa River, which is 36 km in total length and runs through Ichinoseki City, Iwate Prefecture, Typhoon Kathleen in 1947 and Typhoon Ione in 1948 caused large-scale landslides and slope failures. As a result, large amounts of earth and sand flowed into the river and seriously damaged the downstream urban area. In order to recover the disaster-affected mountain region, the Forestry Agency of Japan launched a forest conservation project under its direct control in private forests in the Iwaigawa River District in 1949 and instigated forest conservation measures centering on stream work such as check dam constructions. The project was completed in 1955. However, in 1969, due to the re-emergence of landslide activity in the region bringing increased probability for disaster – and in response to strong requests from Iwate Prefecture and Ichinoseki City – the agency once again launched a landslide prevention project under its direct control. The agency carried out the project systematically and as planned, so its effectiveness was adequately proven even in the face of the Iwate-Miyagi Nairiku Earthquake (M 7.2) in 2008 with almost no slope failure observed after the earthquake at locations targeted by the project. However, since many landslides occurred at adjacent locations not covered the project, the target range was expanded to include additional measures.

Measures taken in the Iwaigawa River District included control work for removing or reducing factors that may cause landslides, such as underground water drainage work (1,873-meter drainage tunnel work, the construction of 131 catchment wells, boring 3,455-meter culverts, etc.) and surface water drainage work, as well as restraining work for direct prevention of landslides by with structures (i.e., driving 408 piles and inserting 200 anchors). In addition, sites, where landslides took place, were provided with various measures including hillside retention efforts such as vegetation (seeding and planting) work to prevent soil loss.

The past projects spanning nearly a half-century have resulted in increased safety with no observable landslide activity. In 2017, the Tohoku Regional Forest Office of the Forestry Agency of Japan set up an exploratory committee consisting of landslide experts along with the deputy Mayor of Ichinoseki City and officials from Iwate prefecture to review past work approaches. The decision was made to terminate the projects at the end of March 2019.

In recent years, mountain disasters due to earthquakes or concentrated heavy rains have intensified, increasing the necessity of forest conservation projects for the recovery of damaged mountains and mountain streams. The agency of Japan will continue cooperation with local governments, such as Iwate Prefecture and Iwate City, and research institutions such as FFPRI to ensure regional and national safety and security.

Keywords: Landslide, MAFF, Iwai River, Tohoku Regional Forest Office

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Agriculture and landslides in Japan

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Landslide areas are distributed throughout the hilly and mountainous areas of Japan due to the steep topography and a large amount of precipitation. However, the distribution map shows several particularly dense landslide zones. The relatively flat areas in these zones have been used as paddy fields, dry fields, and settlements.

These areas have been known as landslide-prone areas through years of experience of people who live there. They have lived there paying attention to signs of landslides such as cracks on paddy fields and muddy river water. Abandoned fields have been increasing due to a significant decline of the power of community caused by population decreasing and aging. Accordingly, landslides have occurred in these fields more often recently.

Prevention of landslide disasters is important in hilly and mountainous areas not only to protect people's lives by reducing damages of landslides but also to utilize the lands sustainable including soil, water, and landscape conservation. Rural Infrastructure Department of Ministry of Agriculture, Forestry and Fisheries, therefore, have developed agricultural lands and agricultural infrastructures for living and cultivating in these areas, and national or local government have promoted countermeasures against landslides on agricultural lands. From August 2016, moreover, a political goal, which aims to maintain and enhance irrigation facilities strategically, has been established in order to make rural areas and agricultural activities resilient, and improving the service life of landslide-preventive facilities have been promoted.

As for these countermeasures against landslides on agricultural lands, it is necessary to consider regional characteristics and to protect the lands by maintaining these areas based on a viewpoint of risk management in order to conserve multifunctional roles of hilly and mountainous areas such as the conservation of the environment and natural resources.

Keywords: Landslide, Agriculture, Abandoned field, Land protection

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National Project for Landslide Prevention in the Takase Area

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The Ministry of Agriculture, Forestry and Fisheries (MAFF), the Government of Japan has directly executed the landslide prevention measures at 11 large-scale landslide areas in Japan. This presentation introduces a case of national projects for landslide prevention measures in the Takase area, which was completed in March 2019.

The Takase area is located in the northwestern part of Kochi Prefecture, Southwest Japan. The main agricultural product is green tea. The Odo dam, which is right below the Takase area, is the major agricultural water source for the leading facility horticulture. Once a landslide occurs there, a large amount of debris would flow into the reservoir. This would consequently cause damage to the farmland of 2,400 ha due to lack of water.

The Takase area is located in a landslide zone of fractured rocks associated with low-angle thrust faults. The annual precipitation in the area is about 2,600 mm on average and amounts to 5,000 mm in a highly rainy year. In addition, because many slope deformations such as continuous opening cracks and steps occurred in the area during the heavy rainfall in July 1999, a boring survey and movement monitoring were carried out. The survey results indicated that the Takase landslide area was roughly divided into four landslide blocks, including a large-scale landslide block. Accordingly, the MAFF decided to implement landslide prevention measures under its direct control. The largest landslide block (D block) was about 850 m long, 420 m wide, and 80 m deep. A maximum displacement of 10.3 mm/day was recorded during the observation period of the heavy rainfall in September 2004 (monthly precipitation 1,701 mm).

The landslide prevention project in the Takase area was carried out for 15 years. As landslide prevention measures for the D block, four drainage tunnels with a total length of 1,789 m were constructed to lower the current groundwater level by 13 m, thereby satisfying the planned safety factor and stabilizing the landslide. A total of 521 drainage borings was installed from these tunnels with a total length of 30,330 m. A total amount of about 10,000 m^3/day of groundwater was drained from the four drainage tunnels during heavy rainfall.

Following the completion of all drainage tunnels in the D block, the planned safety factor was satisfied even during heavy rainfall. The displacement at slip surface measured by the borehole inclinometers was less than 6 mm/year, and also not more than 2 mm/month continuously for 2 months. From these observations and stability analysis results, the D block was judged to meet the criteria of the landslide prevention measure completion.

Keywords: Large-scale landslide, agriculture, land conservation, drainage tunnel

World Tsunami Awareness Day Special Event

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Numerical simulation of landslide-generated waves during the 11 October 2018 Baige landslide at the Jinsha River

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Landslides at river embankments can block watercourses, imperiling the safety of vessels and downstream hydropower stations. The Baige landslide, which occurred on 11th October 2018, is taken as an example to study the landslide motion and landslide-generated wave evolutions. The elasto-viscoplastic and renormalization group (RNG) turbulence models are employed in the FLOW3D software, treating the motion of the Baige landslide as a viscous flow. Numerical results show that the maximum velocity of the slide was approximately 75 m/s when entering the Jinsha River. Further, the waves triggered by massive debris avalanches at three different locations are investigated. The maximum velocity of the landslide-generated wave and the maximum run-up in the Jinsha River reached 45 m/s and 53.9 m, respectively, on the slide axis. The maximum run-up terrain elevation of the wave was 3039.7 m. The simulation results are basically consistent with the actual field observations and fit well with high-speed flow-like landslides. In this case, the displaced water was dominant due to the significant volume of the failure mass and the shallow watercourse of the Jinsha River. The run-down waves located on the source region axis contribute to the rise of water level downstream and upstream. The results from this case study serve as a practical inspiration for research on disaster processes.

Keywords: Baige landslide, Mass movement, Landslide-generated wave, FLOW3D

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On the landslide tsunami uncertainty and hazard

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Landslides are the second most frequent tsunami source worldwide. However, their complex and diverse nature of origin combined with their infrequent event records make prognostic modelling challenging. In this paper, we present a probabilistic framework for analysing uncertainties emerging from the landslide source process. This probabilistic framework employs event trees and is used to conduct tsunami uncertainty analysis as well as probabilistic tsunami hazard analysis (PTHA). An example study is presented for the Lyngen fjord in Norway. This application uses a mix of empirical landslide data combined with expert judgement to come up with probability maps for tsunami inundation. Based on this study, it is concluded that the present landslide tsunami hazard analysis is largely driven by epistemic uncertainties. These epistemic uncertainties can be incorporated in the probabilistic framework. Conducting a literature analysis, we further show examples of how landslide and tsunami data can be used to better constrain landslide uncertainties, combined with statistical and numerical analysis methods. We discuss how these methods, combined with the probabilistic framework, can be used to improve landslide tsunami hazard analysis in the future.

Keywords: Tsunamis, Uncertainty, Landslide dynamics, Hazard analysis, PTHA

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Analysis and modeling of a landslide-induced tsunami-like wave across the Truong river in Quang Nam province, Vietnam

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Landslide-induced waves are one of the most disastrous hazards that can post a great threat to human lives and properties. At about 4:00 pm, 5 November 2017, a landslide-induced tsunami-like wave suddenly occurred across the Truong river in Bac Tra My District, Quang Nam province, Vietnam. The water wave destroyed six houses at the opposite bank and caused one person dead and three others injured. This study seeks to investigate the initiation mechanism and process of the landslide and its impulse wave. First, we examined landslide characteristics through site investigations, unmanned aerial vehicle (UAV) surveys, and laboratory testing with a series of standard geotechnical tests on collected soil samples. Then, the initiation and motion of the rainfall-induced landslides were reproduced by the integrated landslide simulation model (LS-RAPID). Finally, a combined computer simulation of the landslide motion and its impulse wave was performed by using a landslide-induced tsunami simulation model (LS-Tsunami). In which, output data from the LS-RAPID was used as input parameters for LS-Tsunami. The analysis shows that the rainfall with very high intensity in a short-time period was the triggering factor of the landslide, which is common factor in the study area. The 12-, 24-, and 48-h accumulative precipitation prior to the landslide recorded to 530, 760, and 950 mm, respectively. In addition, the rainfall trigger presented a typical pattern of rainstorm events in a long duration. Simulation results show that the impulse wave was generated by the landslide mass rapidly entering the river, crossing the river, and directly causing the disastrous damage to the resident area opposite site of the fail slope. The landslide moved down at a maximum speed of 16.4 m/s when its body approached the water surface and generated a maximum wave height of 5 m. There is good agreement between the observed geomorphic evidences and water traces on the site and simulation results of the landslide and its impulse wave. The paper provides a good case study on the understanding of the mechanism and dynamic process of the whole event that significantly contribute to potential landslide hazard assessment and future disaster mitigation in the area.

Keywords: Landslide dynamics, Impulse wave, Heavy rainfall, LS-RAPID, LS-Tsunami

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Tsunami from the San Andrés Landslide on El Hierro, Canary Islands: First Attempt Using Simple Scenario

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This paper presents the first attempt to model a tsunami genesis and propagation from an incipient volcano slope failure termed San Andrés Landslide located on the El Hierro Island, Canary Islands, Spain. A rather conservative landslide scenario compared to other studies is proposed. The scenario comprises a subaerial failure of a block more than 2.5 km long and 7.5 km wide with volume of almost 6 km3. The initial wave from this landslide reaches 80 m and its propagation through Atlantic Ocean has been modelled using DELFT 3D model. Results show that even a conservative scenario can have very severe consequences, especially in the adjacent islands. High to moderate waves are expected to affect also European SW and African NW coasts. As in any tsunami simulation however, the maximum slide speed is crucial for generating a tsunami wave. For that reason, future attempts should focus on more accurate landslide dynamic modelling to obtain realistic behaviour of the sliding mass to assess possible tsunami scenarios.

Keywords: Volcanic flank collapse, Tsunami modelling, Hazard scenario, San andrés landslide, El hierro, Canary islands

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The Link between Upper-Slope Submarine Landslides and Mass Transport Deposits in the Hadal Trenchs

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Sediment gravity flow is a density current that moves down a slope due to the gravitational force. Submarine landslides are a trigger mechanism for sediment gravity flows, and the movement of a large amount of sediment mass has the potential for generating tsunami. An oceanic trench is a terminal depression in the hadal environment that receives mass transport deposits (MTDs) from the slope. Thick, acoustically transparent layers were found in small basins along the northern Japan Trench. Sediment cores obtained from these basins were composed of thick, homogeneous mud, suggesting the presence of distal MTDs. Radiocarbon dates obtained using bulk organic carbon from the sediment indicated that these MTDs were formed around 2000 years ago and were correlated with each other. Benthic foraminiferal assemblages in the MTDs contained upper-slope species. There are many submarine landslides distributed along the upper slope of the Hidaka Trough; thus, the upper slope of this trough is important not only as a sediment source but also as a source of carbon for the Japan Trench, which is an effective sink of organic carbon. However, the exact locations of the submarine landslide on the upper slope have not yet been determined. Furthermore, from the geohazard point of view, the upper slope is an area of large sediment movements, which should be considered in the context of tsunami hazard mitigation.

Keywords: Submarine landslide, Mass transport deposit, Foraminifera, Japan Trench

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Review of Submarine Landslide-induced Tsunamis: The importance of cascading mechanisms and multi-phased physics

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The Fifth World Landslide Forum and Thematic Issue of the Journal Landslides contributed a total of twelve relevant papers for the landslide-induced tsunamis session and the World Tsunami Awareness Day Special Event. Some latest advances are concisely reviewed. The topics range from numerical modelling and analysis of landslide-generated waves in rivers, to tsunami uncertainty due to landslide dynamics, using statistics to understand submarine landslide processes and hazard, tsunami from submarine landslides on islands, Simulation of tsunami waves induced by coastal and submarine landslides, tsunami generation by volcanic flank collapse, underestimated tsunami hazard from submarine landslides, landslide-induced icy tsunami in reservoir, tsunami early warning system, and tsunami disaster caused by earthquake-induced submarine landslides.

Recent research advances on liquefied gravity flows and their consequences are also concisely summarized, with emphasis on the coastal and submarine landslides-induced tsunamis. The review of large-scale coastal mass movements worldwide highlights the importance of such liquefied sediment flows on tsunami generation. The dynamics of liquefied gravity flows is characterized by the multi-phased physics involving the phase change process in which the transitory fluid-like particulate sediment reestablishes a grain-supported framework during flowage. The integration of fluid dynamics and soil mechanics approaches is indispensable for a rational prediction of the relevant concurrent phenomena. The cascading mechanisms behind the 2018 Indonesia Sulawesi earthquake and tsunami disasters may facilitate a better understanding of the richness of the physics involved and promote multidisciplinary studies for disaster prevention and mitigation.

Keywords: Submarine Landslide, Earthquake, Tsunami, Liquefaction, Cascading Mechanisms

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Dealing with Mass Flow-Induced Tsunamis at Stromboli Volcano: Monitoring Strategies Through Multi-Platform Remote Sensing

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Volcano landslides or explosions-induced mass flows constitute an important trigger of tsunamis. Even if landslide-induced tsunamis can produce more local impacts comparable earthquake-induced tsunamis, large volume failure of volcanic edifice may cause tsunamis with widespread effects. Considering this, successful strategies for volcano slope instability detection must involve the integration of different methodologies for mapping, monitoring, and automated approaches for early warning, integrating field-based studies, geomorphological mapping, remote sensing data, geophysical and geochemical investigations, and/or numerical modelling. In this contribution, the applications of different remote sensing techniques products for the identification, mapping, and forecasting mass movements in the island of Stromboli are presented. The integration of space-borne and ground-based Synthetic Aperture Radar displacement data with the analysis of (topographic- and SAR amplitude images based) change detection allowed the identification the evolution of the slope instability phenomena and the geomorphological processes affecting the Stromboli unstable slopes. Ground based SAR devices are the key-instruments for the operational approach to mitigating landslide risks, being used to monitor the slope instability and to detect the inflation/deflation of the crater area.It is crucial to emphasize the importance of smart integration of space borne-derived hazard information with permanent-sited, operational monitoring by GBInSAR devices to detect areas impacted by mass wasting and volcanic activity.

Keywords: Volcano slope instability, Landslide-induced tsunami, InSAR, GBInSAR, Topographic change detection, SAR amplitude, Stromboli

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Simulation of Tsunami Waves Induced by Coastal and Submarine Landslides in Japan

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Members of the International Consortium on Landslides (ICL) together with Kyoto University have developed the undrained dynamic-loading ring-shear apparatus (UD-RSA) and the integrated simulation model (LS-Rapid) for the evaluation of the initiation and motion of landslides using landslide dynamic parameters for landslide hazard assessment. In order to develop the landslide-induced tsunami hazard assessment technology based on underwater landslide motion simulated by UD-RSA and LS-Rapid, a new landslide induced tsunami model (LS-Tsunami) has been developed. It is verified using the world's largest well-documented landslide induced-tsunami disaster with 15,153 deaths in Unzen, Nagasaki, Japan in 1972. The LS-Tsunami simulation results agreed with the observations in the historical records. The study of the hypothetical Senoumi (stone flower sea) submarine landside in Suruga Bay, Japan based on the UD-RSA testing of the sample (volcanic ash) cored from 200 m deep under the sea floor (by the International Ocean Discovery Program-IODP) was implemented. As there is no historical record and the date has not yet been identified, this submarine landslide is called "hypothetical." The initiation and motion of the landslide was simulated by LS-Rapid. LS-Tsunami model was applied to the Senoumi submarine landslide and used to estimate the tsunami height at the excavation site along Ota River in Shizuoka Prefecture where three layers of tsunami deposits have been found by Fujiwara et al. (Quat Sci Rev, 2019). LS-Tsunami analysis presented that tsunami wave caused by the Senoumi submarine landslide had an inundation depth of around 1.5 m (3.5 m tsunami height above sea level) at the excavation site. In 2009, a Mw 6.4 Suruga Bay earthquake occurred triggering a small submarine landslide within the Senoumi area. The submarine landslide induced a tsunami (Baba et al. in Advances in Natural and Technological Hazards Research. Springer, pp 485–494, 2012). Using LS-Rapid and LS-Tsunami, three conditions for triggering the tsunami wave were considered: (1) caused by fault motion only, (2) caused by landslide motion only, and (3) wave caused by both landslide motion and fault motion. Each mode was compared to monitored tidal wave forms along Suruga Bay. LS-Tsunami simulation result agreed with the monitored results including a very big tsunami wave monitored by the Yaizu tidal gauge. Application of LS-Tsunami for three cases in Japan: the 1792 Unzen coastal landslide, the Senoumi submarine landslide, and the 2009 Suruga Bay submarine landslide has proved the precision and reliability in both the maximum tsunami height and time variation of the tsunami wave. Accordingly, this technology is applied to hazard assessment for the potential retrogressive landslides of the Senoumi landslide in Suruga bay which are likely triggered by earthquakes along the Nankai Trough in the future. The result showed 20–50 m inundation depths of Tsunami in Yaizu city.
Keywords: LS-tsunami, Suruga Bay, Ring shear test, Unzen–Mayuyama megaslide, Submarine landslide

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The Impact of Climate Change on Landslide Hazard and Risk

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The gradual increase in temperature recorded all over the world over the past fifty years and the more frequent occurrence of extreme weather events demonstrate that climate change no longer is just an idea born in the mind of some crazy scientists, but is a reality and a challenge that mankind needs to manage within the next few years. Climate change can have severe consequences for mankind, including the increase of geo-hydrological hazards. In some areas of the world landslide risk will grow significantly, even potentially adopting new forms, which the landslide profession and the exposed population community need to be prepared. Unfortunately, in spite of the commitment and the efforts of many mindful scientists, who are well aware of the potential risk increase, the response of stakeholders and politicians is still too slow. This paper describes the effects of climate change on landslide susceptibility, hazard and risk, summarizes the state of slope safety preparedness around the world and proposes steps for enhanced landslide risk management.

Keywords: Climate change, Extreme weather events, Snowmelt, Landslide hazard, Risk mitigation

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SATREPS Project for Sri Lanka with Regard to "Development of Early Warning Technology of Rain-Induced Rapid and Long-Travelling Landslides"

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Influenced by the recent global climate change, extreme rainfall events have become more frequent worldwide and resultant hydro-meteorological hazards are creating more deaths and devastations. One of the most remarkable disasters of rain-induced rapid long-travelling landslides (RRLL) in Sri Lanka took place at Aranayake, 70 km east of Colombo in 2016 (JICA Survey Team 2016) (JICA Survey Team in Survey results of Aranayake Disaster, 2016). The fluidized landslide mass ran over an about 2 km distance claiming the lives of 125 people. This tragic event has thus highlighted the importance of sophisticated early warning and disaster management mechanism even more than ever, because the presence of these hidden unstable soil masses as well as their run-out distances are very difficult to predict, and once they start sliding, it is almost impossible to stop them. Both the National Building Research Organisation, Sri Lanka (NBRO) and the International Consortium on Landslides (ICL) have jointly compiled a research proposal within the framework of SATREPS, standing for "Science and Technology Research Partnership for Sustainable Development," a Japanese government program that promotes international joint researches, and it passed the final round of selection on May 16, 2019. Thus, the new 5-years SATREPS project for Sri Lanka with regard to "Development of early warning technology of Rain-induced Rapid and Long-travelling Landslides (Project RRLL)", starts in 2020. This article reports on the outline of the project including its goals, plans of plots for developing individual technologies for the early warning system, etc.

Keywords: Rain-induced rapid long-travelling landslide, SATREPS, Sri Lanka, Early warning

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The Continuing Underestimated Tsunami Hazard from Submarine Landslides

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Tsunamis generated by submarine landslides are, relatively, a recently identified hazard, which resulted from the Papua New Guinea event of 1998, when 2200 people died. Recognition of the tsunami hazard from submarine landslides has been possible mainly because of the recent development of advanced technology, such as multibeam echosounders, now available to image the seabed to high resolution. In addition, the architecture of submarine landslides developed from the marine mapping has been the basis for new numerical models of tsunami generation from seabed sediment movement. Tsunamis, post-dating PNG, where an earthquake mechanism was not realistic, have been considered in this recent context, and new relationships identified. These relationships have been particularly with strike-slip and large magnitude (great) earthquakes, as well as with small magnitude earthquake events where a dual mechanism (earthquake and landslide) is most likely. As a result, submarine landslide tsunamis are now recognised from all geological environments; passive, convergent and strike-slip margins as well as volcanoes. Despite these new advances in understanding, however, recognition of the hazard from submarine landslide tsunamis is still limited.

Keywords: Submarine landslide Tsunami Hazard Earthquake

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December 11, 2018 Landslide and 90-m Icy Tsunami in the Bureya Water Reservoir

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On December 11, 2018, a large (with an estimated volume up to 25 million cubic meters) landslide occurred in the middle part of the Bureya water reservoir (Russian Far East). The landslide has completely blocked the river bed and prevented the replenishment of the Bureya HPP reservoir from a large part of its catchment area. In the deep (down to 70 m) reservoir, the landslide generated a destructive tsunami-like wave whose impact on the shore was emphasized by a thick (up to 20 cm) ice cover. The maximum run-up that was reached at the point 2.8 km away from the landslide on the right bank of the Sredniy Sandar river which flows into the reservoir just against the landslide, turned out to be equal to 90 m. The maximum penetration of the wave along the Srendiy Sandar valley was 3.75 km, the water stopped at an altitude of 78 m above the initial water level leaving a pile of tree trunks up to 2 m in height. The maximum run-up reached on the gentle slope of the right (northern) bank, faced directly to the landslide, was up to 62 m, with an inundation distance up to 650 m from the water edge. All the trees and soil cover in this area were completely removed. The height of the mound of broken trees left at the inundation limit in this area reached 5 m. The run-ups on the left (southern) slopes, at a distance of up to one kilometer from the landslide, were within 35–45 m in upstream direction, and within 25–35 m in the downstream direction. Field surveys found that the actual run-ups were by 5–10 (sometimes up to 15) meters higher than the trim line of complete forest and soil destruction visible in air photos and satellite images of the affected area.

Keywords: Tsunami, Landslide, Run-up, Inundation, HPP water reservoir, Tsunami hazard

Thematic Issue Papers

The Fifth World Landslide Forum Abstracts
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Regional landslide susceptibility following the 2016 Kumamoto earthquake using back-calculated geomaterial strength parameters

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The 2016 Kumamoto earthquake first occurred on April 14, 2016 with magnitude 6.5 in Kumamoto, Japan as a foreshock. Subsequently, after 28 h, an even larger earthquake occurred with magnitude 7.3 as the main shock on April 16, 2016. These earthquakes were caused by two active faults: the Futagawa and Hinagu faults. This paper proposes a landslide susceptibility calculation method that considers the geomaterial strength reduction from peak to residual state and ground motion directivity. Although there is a lack of information regarding the strength parameters of geomaterials in the slopes, a parametric analysis with various strength parameters of friction angle and cohesion was carried out. To simulate the actual landslides triggered by the 2016 Kumamoto earthquake, the best combination of friction angle and cohesion in each lithology was optimized by a proposed weighted prediction rate. Based on the calculated permanent seismic displacement, a landslide susceptibility map was produced to show the degree of susceptibility over a wide area comprising 100 km^2. The proposed regional landslide susceptibility map will be valuable for estimating the locations of possible slope failures and the extent of damage, as well as for planning field reconnaissance and preventing secondary disasters immediately after earthquakes.

Keywords: Slope stability, Strength reduction, Earthquake-induced landslide, Landslide susceptibility, Permanent seismic displacement, Newmark method

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Experimental investigation on the formation process of landslide dams and a criterion of river blockage

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River blocking caused by landslide dams is a common geological disaster in mountainous regions worldwide, threatening the safety of human lives and infrastructure. However, studies on the formation process of landslide dams and the criteria of river blockage are still at an early stage. This paper built a laboratory-scale experimental apparatus for simulating the formation and evolution process of landslide dams, and then carried out a total of 29 experiments. It analyzed the common evolution stages of river blocking, including landslides, dam formation, and dam breaching in detail. Then, we investigated the influences of the landslide volume, the landslide discharge, and the water flow rate on a criterion and the time length of river blockage. The experimental results suggest that the formation condition of a landslide dam is related to the ratio of the landslide discharge to the water flow rate. Based on this understanding, we proposed a dimensionless River Blockage Criterion (RBC) to judge the formation of landslide dams. The criterion indicates that when RBC > 1.5, a landslide dam may form; otherwise, a landslide dam may not form. Additionally, the time length of river blockage was found to be related to the landslide volume and the water flow rate. Subsequently, we proposed a model for predicting the time length of river blockage and verified it by the 29 experimental results. The Baige River-blocking event, which occurred on the Jinsha River, China, in 2018, was used as a case study to further verify the RBC and the proposed model. The results show that the proposed RBC agreed well with reality, and the percentage difference between the calculated and the actual time length of river blockage was 11%. The findings of this study could contribute to the early warning and emergency response of river-blocking disasters.

Keywords: Landslide dam, River blocking, River Blockage Criterion (RBC), Experimental modeling, Evolution process

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The Hooskanaden Landslide: historic and recent surge behavior of an active earthflow on the Oregon Coast

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This paper presents an analysis of the Hooskanaden Landslide, an earthflow, which experienced a dramatic surge event beginning on February 24, 2019, closing US Highway 101 near mile point 343.5 for nearly 2 weeks. This ~ 1 km long surge event resulted in horizontal displacements of up to 45 m and uplift of 6 m at the toe located on a gravel beach adjacent to the Pacific Ocean. The Hooskanaden Landslide, likely active since the eighteenth century, exhibits regular activity with a recurrence interval of major surge events of approximately every 20 years, transitioning from slow to relatively rapid velocities. During the 2019 event, maximum displacement rates of approximately 60 cm/h were observed, slowly decreasing to 15 cm/h for a sustained period of approximately 2 weeks before the eventual return to baseline conditions (< 0.02 cm/h).

Keywords: Landslide, Earthflow, Surge, Landslide activity

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Recent rainfall - and excavation-induced bedding rockslide occurring on 22 October 2018 along the Jian-En expressway, Hubei, China

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On 22 October 2018, at 17:20 (UTC+8), a bedding rockslide occurred on the right bank of the Jian-En expressway in Jianshi County, Hubei Province, Central China. Fortunately, a systematic displacement monitoring network provided an early warning. Thus, no casualties were caused by the rockslide, although two transport vehicles and three houses were damaged. To deduce the triggering factors and failure mechanism of the bedding rockslide, the geological characteristics, hydrogeological characteristics, slope excavation scheme, and rainfall data statistics were systematically investigated based upon field investigations, UAV photography, geological drilling, and laboratory tests. It was found that the bedding characteristics, presence of well-developed joints, and properties of the weak interlayers were the internal factors inducing the rockslide. The free face in front of the slope, the weak interlayer with low shear strength, and the through-going joint that formed the back boundary of slope constituted the boundary of the rockslide. The combined effects of improper slope excavation and concentrated rainfall were external factors that directly triggered the rockslide. The well-developed joints provided an effective infiltration channel for rainwater, and continuous rainfall deteriorated the shear strength of the weak interlayer ultimately causing the rockslide.

Keywords: Bedding rockslide, Failure mechanism, Triggering factor, Boundary condition, Displacement monitoring, Rainfall, Slope excavation

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Dendrogeomorphology of landslides: principles, results and perspectives

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Landslides are dangerous and destructive geomorphic processes that cause annual damage to human infrastructure or even loss of life. As recovery is very costly, knowledge of past landslide activities, a detailed analysis of triggers and prediction of future landslide development are important. Dendrogeomorphic (tree-ring-based) dating is the best solution of chronological data obtaining in forested areas, where trees annually produce increment rings. A moving landslide mass affects trees that grow on its surface. Trees respond to this influence in different ways that are recordable and subsequently visible in tree ring series. Thus, tree rings represent an ideal natural archive of past landslide behaviour. Depending on the tree species, the length of a landslide chronology can be several centuries with sub-annual resolution. Although dendrogeomorphic approaches have some limitations, provided data are unique because they represent insight into the past without the need for long-term monitoring. Nevertheless, trees as landslide archives are suitable for medium-magnitude events because excessively small movements can be disregarded and catastrophic movements destroy trees. This review introduces details regarding tree-landslide interactions, provides a historical overview of applied methods, presents and assesses methodical approaches and summarises basic advantages and contributions to the knowledge of landslide chronology, spatial behaviour and triggers. Finally, limitations, the potential for subsequent research directions and calls for future fundamental studies in new world regions are presented.

Keywords: Dendrogeomorphology, Landslide, Spatio-temporal reconstruction, Limitations, Outlook

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Characterization of displacement and internal structure of landslides from multitemporal UAV and ERT imaging

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Preliminary knowledge of the surface movement and internal structure of a landslide is essential to improve the understanding of landslide behavior as an initial step to develop suitable mitigation measures. This paper characterizes displacement and internal structure of landslides using multitemporal unmanned aerial vehicles (UAV) and electrical resistivity tomography (ERT) imaging. Multitemporal orthophotos, digital elevation model (DEM) profile lines, DEMs of difference (DoD), and ERT images allowed us to measure the landslide morphometry and areal changes, detect the trend of surface displacement, calculate the surface movement rate and direction, characterize the spatial variability in surface movement rates, and relate spatial variation in displacement to the internal structure of the landslide. The Kalisari Landslide experienced retrogressive movement where the scarp of landslide moved backward 38 m from 2015 to 2019. The surface movement ranged from 0.7 to 8.1 m with the direction mostly to the northeast. The depletion and accumulation ranged from 0.1 to 5 m, with the most active change located northwest of the landslide. The variability in movement was influenced by the spatial variability in the subsurface material inferred from the ERT images, i.e., surface material, clay, weathered breccias (possibly altered), and breccias. The interpretation from multitemporal UAV and ERT images indicates that the Kalisari Landslide has a nonhomogeneous multiple retrogressive behavior with a curved slip surface located at the clay layer.

Keywords: Displacement, Internal structure, Rotational, Multitemporal UAV, ERT

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Characterization of displacement and internal structure of landslides from multitemporal UAV and ERT imaging

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Several landslides and floods were triggered by unprecedented, incessant heavy monsoon rainfall from 4 August 2019 to 8 August 2019, along the northern slopes, at Kavalappara, in the Malappuram district and Puthumala, in the Wayanad district of Kerala, India. The geological and geomorphological field settings were analyzed within the sub-basin wide catchment areas, for a preliminary evaluation of the causative factors of the landslides. This paper provides insights into the causative factors of landslides, together with suggestions on appropriate land use planning and deployment of real-time flood and landslide monitoring systems, besides building an adaptable community resilience model in high landslide-prone areas. The structurally disturbed weakened bedrocks and generally incompetent residual alteration products, exacerbated by nonchalant human interventions, reduction of cohesive strength, on super-saturation of underlying earth material, were inferred to be the primary causes of major landslides, triggered during 5 days of excessively heavy rainfall (400% over the normal average). Additionally, massive toe erosion was observed by streams gushing with course clastic sediments and debris. The destructive nature of such multi-hazards was evoked by unscientific modifications of slopes, mismanagement of water drainage, unplanned residential developments, across the channel courses and within active floodplain of rivers, and lack of early warning schemes for landslide.

Keywords: Landslides, Floods, Multi-hazard, Chaliyar River basin, Kerala

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Ultimate lateral pressures exerted on buried pipelines by the initiation of submarine landslides

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Submarine slope instabilities are considered one of the major threats for offshore buried pipelines. This paper presents a novel method to evaluate the ultimate pressure acting on a buried pipeline during the liquefaction of an inclined seabed. Small-scale model tests with pipes buried at three different embedment ratios have been conducted at an enhanced centrifugal acceleration condition. A high-speed, high-resolution imaging system was developed to quantify the soil displacement field of the soil body and to visualize the development of the liquefied zone. The measured lateral pressures were compared with the hybrid approach proposed for the landslide–pipeline interaction in clay-rich material by Randolph and White (2012) and Sahdi et al. (2014). The hybrid approach is proved to be able to predict later pressures induced by the movement of (partially) liquefied sand on buried pipelines. It is found that the fluid inertia (fluid dynamics) component plays an important role when the non-Newtonian Reynolds number >~2 or the shear strain rate > 4.5×10^{-2} sec^{-1}.

Keywords: Underwater infrastructure, Submarine landslides, Liquefaction, Soil–pipeline interaction, Pipelines, Image analysis

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Successful disaster management of the July 2020 Shaziba landslide triggered by heavy rainfall in Mazhe Village, Enshi City, Hubei Province, China

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From June to July 2020, southern China suffered from continuous rainfalls far heavier than those of previous years (Wei et al. 2020). The heavy rains resulted in natural disasters such as floods and landslides in many places. According to the monitoring data supplied by the Hubei Provincial Bureau of Hydrology and Water Resources, between 8 June and 19 July 2020 (the so-called Plum Rain Season), the average rainfall in this period reached 692 mm in Hubei Province, which is 2.45 times that of the same period in the last 10 years (282 mm)-the heaviest rainfall recorded in this region since 1961. Enshi City, located in the southwest region of Hubei Province, also experienced extremely heavy rainfall (Fig. 1a). The accumulated rainfall from 8 June to 19 July 2020 was 823.8 mm, and the maximum daily rainfall was 81.9 mm (17 July 2020). The accumulated rainfall from 16 July to 18 July was 165.5 mm overall (Fig. 1b). These heavy rainfalls have increased the risk of landslides in Hubei Province. The largest to occur as a result was the Shaziba landslide in Mazhe Village, Enshi City. The landslide is located at the upper reaches of the Qingjiang River, a tributary of the Yangtze River, with coordinates of 30.36° N and 109.30° E (Fig. 2).

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Landslide risk management in Hong Kong

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The combination of dense urban development, hilly terrain, and intense seasonal rainfall has caused acute landslide problems in Hong Kong, which are manifested by a death toll of over 470 people since the late 1940s. Tackling landslide problems in an urban setting, in particular under the effect of climate change, calls for a development and implementation of a holistic risk management strategy. It entails the use of engineering and non-engineering approaches, involving policy, legislative, administrative, innovation, technical, educational, community-based, and emergency-preparedness provisions. In this paper, these two approaches are showcased by the slope safety system that has been developed and promulgated in managing landslide risk for building Hong Kong as a world-class smart city.

Keywords: Landslide risk, slope safety, climate change, innovation, technology, extreme rainfall

E-Poster

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Dendrogeomorphic dating vs. low-magnitude landsliding

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Landsliding is a major natural hazard; therefore, understanding its activity is an important objective worldwide. For the investigation of the current landslide events, dendrogeomorphic methods are commonly used as they allow quite a precise dating of individual events. Nevertheless, there is still a question of whether dendrogeomorphic methods can successfully work for landslides with low-magnitude movements. To determine their usability and shortcomings, four commonly used dendrogeomorphologic approaches were put to the test: Approach I is based on the detection of abrupt growth suppression; Approach II is focused on the determination of compression wood; and Approaches III and IV that work with eccentric increments. For the detection of landslide events itself, It index thresholds and spatial statistics were used. In total, 329 individuals Picea abies (L.) Karst. growing on a seemingly dormant landslide in the Outer Western Carpathians were sampled and processed. Overall, obtained landslide chronologies varied considerably although the same trees were used, which allowed pinpointing of the main limitations of each approach. Approach I showed a high sensitivity to water shortages, causing false noise signals. Approach II was not sensitive enough to low-magnitude movements. In contrast, Approaches III and IV recorded many possible landslide events, but most of the events were just noise signals induced by creep movements (and non-geomorphological influences). These conditions made it impossible to filter the real landslide events based on It index thresholds; however, as a substitute, spatial statistics combined with a detailed analysis of real landslide morphology were successfully used. Last but not least, a sensitivity of trees to record possible landslide movements in various stages of their lives was analysed for each approach. Except for Approach IV, all approaches showed high variability in changing sensitivity during a tree's life; thus, during a certain period of the tree's growth, landslide events can hardly be detected. All things considered, findings in our study are crucial for the strategy of the dendrogeomorphic sampling conducted on landslides with low-magnitude movements.

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Understanding Complex Slope Deformation through Tree-Ring Analyses: Case from the Vsetínské Vrchy Mts (Outer Western Carpathians, Czech Republic)

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Dendrogeomorphic methods are frequently used for the analysis of past landslide behaviour and have become the standard approach used to date landslide activity. Unfortunately, many questions related to the application of tree-rings to landslide analysis remain unsolved. This study points to the significance of dividing a large complex slope deformation area into homogenous zones to obtain as much relevant chronological data as possible and to help with a more precise landslide hazard assessment. The multidisciplinary approach included geophysical measurement and geomorphic mapping. The clay mineral content in weathered slope sediments was analysed to verify the presence of expanding minerals contributing to slope instability. Furthermore, 713 samples from 271 trees and 18 tree roots were analysed to create event chronologies for each zone. The results provided evidence about the different behaviours of each zone. The intensity of tree responses to slope movement significantly changed even within one isolated zone. Chronological data were used to identify landslide triggers using rainfall characteristics and indices for climate variability and extremes. The results suggested a significant contribution of spring rainfall to landslide activity. In addition, shallow landslides movement was dependent on above-average rainfall characteristics compared to the movement of deep-seated blocks. Tree-ring-based chronologies of individual zones were used to characterise the general concept of complex slope deformation development.

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Avalanching of variously shaped DEM-particles

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In the majority of particle simulation methods, round particles still do-minate, while in granular materials, as in the case of landslides, the par-ticles are angular or even non-convex. In this research, we compare the characteristics of avalanches in a rotating drum to under-stand how the particle shape influences the characteristics of avalanching (and there-fore landslides) in a mechanical quasi-equilibrium.
``All things being equal", we find in particular a higher angle of marginal stability for non-convex particles, even if the angle of repose is the same.

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Landslides induced by heavy rains in July 2018 in Shikoku Island, Japan

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The heavy rains in July 2018 caused landslides and sediment disasters in various parts of Shikoku island.
River basins in Otoyo and Motoyama towns, Kochi Prefecture (hereinafter, Area A, where maximum hourly rainfall of nearby rain gauge was 111mm/h and the cumulative rainfall was 1,790mm) and around Ozu and Uwajima cities, Ehime Prefecture (hereinafter, Area B, where maximum hourly rainfall was 91mm/h and cumulative rainfall was 701mm), landslides, debris flows and slope failures occurred simultaneously.
Based on the airborne LiDAR data in the Area A and B before and after the heavy rainfalls, characteristics of landslides, especially focusing on the collapsed area, have been analyzed.

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The study of rainfall-induced landslide dynamic warning system and innovative landslide investigation

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For this reason, government agencies commit to improving the efficiency of disaster mitigation in recent years. Based on results from the previous project, this project aims to improve the rainfall threshold and susceptibility of rainfall-induced landslide, update environmental geological maps and establish multiple-stage remote sensing landslide survey approach for disaster mitigation during rainfall period. Furthermore, the analysis of the project will contribute to upgrading the national-wide environmental geologic map and provide competent authority to make decisions reducing the geo-hazard risk.

There are 78 rock slides were interpreted from 16 1/25,000 frames in high mountain and average area is 14.2 ha. The environmental geological map updated through historical landslide inventories from CGS and the susceptibility of different landslide type were classified. There are 30 cases of landslide were collected and 11 landslides had surveyed in the field. Region landslide rainfall threshold were updated through landslide analyzed investigation. The layout of the environmental geological database had prepared for publish in the future.

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Sediment dynamics monitoring at the Osawa Failure of Mt. Fuji

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The Osawa Failure is one of the largest collapse sites in Japan; its dimension is about 2,000m in length, its maximum width is 500m, and its maximum depth is 150m. It is located on the upper western slope of Mt. Fuji, the highest mountain (3,776m) in Japan. At the Osawa Failure, an average of 110,000m3 collapse occurs annually, and the sediment deposited on the streambed causes debris flows and slush avalanches. During the debris flow that occurred on 21 March, 2021, about 470,000m3 (provisional value) sediment was captured in the alluvial fan (sand pocket) constructed downstream the Osawa Failure. Since its opening in 1970, the Fuji Sabo Office has been conducting aerial photogrammetry and field surveys to monitor the sediment dynamics at the Osawa Failure. In recent years, with the development of aerial surveying technology, monitoring has been carried out using various observation methods such as airborne LiDAR. This paper reports the results of various measurements and discusses the mechanisms of collapse and sediment dynamics.

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Variation of Performances of Horizontal Drains and Slope Stability with Perforation Arrangement and Envelope Permeability

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Horizontal Drains (HDs) are widely used for drainage management in slopes to enhance the stability. Entrance resistance (α) which is depend on the perforation arrangement (PA) and envelope permeability (EP), plays a vital role in the performance of HDs. However, HDs are treated as ideal drains without entrance resistance in the current design practice. Therefore, this study was done to emphasize the importance of the α on the design and performance of HDs. A numerical model, which was validated with a sand tank model was used to find the αs of HDs having two common PAs with similar perforation area; Circular Holes (CH) and Longitudinal Slots (LS), which are wrapped with an envelope having relative permeabilities (k_r) from 1 to 100. The α of CH was smaller than that of LS and α reduces with the increasing k_r. Then stability analysis was done as a case-study to find the factor of safety (FS) of a hypothetical slope subjected to constant rainfalls with relative intensities (n) of 0.1 and 0.3. Stability analysis showed that FS of the slope was substantially higher in CH than LS. When the k_r is increased, the FS was increased in both PAs and difference between FSs was reduced. This was only significant when n is 0.3. These results highlight the importance of selecting a suitable PA and EP for HDs, especially for the slopes with high n values.

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Shaking table test on gentle slope failure induced by the 2018 Hokkaido Eastern Iburi Earthquake

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The 2018 Hokkaido Eastern Iburi earthquake induced many failures even on gentle slopes. It is reported that most of these are surface failures, and the slip surface is composed of the pyroclastic fall layers that contain a lot of water(1). In the Towa district of Atsuma Town, Eniwa-a pyroclastic falls (En-a) which was erupted from Eniwa Volcano about 20,000 years ago was exposed on a slope where failure on gentle slopes was prominent. Field investigations and soil tests showed that this En-a was a slip surface. Therefore, shaking table tests using seismic waveforms and slope stability analysis on En-a were conducted. When the cohesion and internal friction angle are 12.3 and 6.73, respectively, the safety factor shows 0.853 at the maximum acceleration.

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Landslide distribution and its geological background in mountainous areas of northern Vietnam

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In the mountainous areas of northern Vietnam, many landslides occur every year during the rainy season and typhoon season. In order to reduce the risk of future landslide disasters in Vietnam, the State-funded Landslide Project (SFLP) was launched in 2012, mainly for landslide mapping and risk assessment. As a result, many data, including about 20,000 landslides and their locations and scale, etc., have been collected and reported (Hung et al.2017). These data are expected to be analyzed in various ways in the future.
The purpose of this study is to clarify the geology, distribution shape, and movement type of landslides in northern Vietnam based on these SFLP data and our own field survey.

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Method for observing the pore water pressure at the slip surface by repurposing a broken borehole inclinometer

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For evaluating the stability of a landslide, observation of the pore water pressure at the slip surface is extremely important. However, the pore water pressure at the slip surface is rarely observed. Because the cost is high in this case, the first borehole is made as all screens and in many cases water level observation is accomplished. Moreover, the position of the slip surface sometimes cannot be determined accurately from core observations.

Typically, the slip surface position and displacement are observed by a borehole inclinometer in an active landslide. If the borehole inclinometer suffers some degree of damage, the observation ends, and the borehole is abandoned. In this research, we propose a technique for observing the pore water pressure at the slip surface by repurposing the damaged part into a strainer.

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Features and measurement example of “Pipe Inclinometer” underground displacement measurement technology using gravitational acceleration sensor

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In slope surveys for landslides, underground measurement provides important information on slip surface depth and displacement. In recent years, gravitational acceleration sensors using MEMS technology started to be used in underground displacement measurement methods. Herein we will introduce a Pipe Inclinometer that use gravitational acceleration sensors for underground displacement measurement.

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Shear band formation observed in a rainfall-induced landslide in a flume experiment on weathered granite sand

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In landslides, determining the position of the failure surface is very important. The failure surface formation is related to the shear band formation in the slope. It is very difficult to observe shear band formation in the underground of the sliding mass. Many laboratory experiments have been performed to simulate and record shear band formation. Common methods are direct shear tests (Nitka and Grabowski 2021), triaxial tests (Desrues and Chambon 2002), plane strain tests (Alshibli and Sture 2000; Kwak et al. 2020), ring shear tests (Sadrekarimi and Olson 2010), and sandbox experiments (Wolf et al. 2002). These tests are all small size and using an external force to produce deformation in an orientation direction. In this study, we used a large-scale flume experiment with an artificial rainfall. To the best of our knowledge, this is the largest scale experiment ever conducted to calculate the shear band. The soil covering the slope is a weathered granite sand from Hai Van mountain landslide, Central Vietnam. Markers' movement with the soil mass were videotaped. From the movement of markers over time, shear strain was calculated. The maximum shear strain contour has been plotted in time increments. During the last 247 seconds before the rapid landslide occurred, a shear band was formed and detected from the maximum shear strain contour.

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Relationships between antecedent rainfall and volume of earthquake-induced landslides in historical era in Japan

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Dellow and Hancox (2006) indicated strong influence of rainfall on earthquake-induced landslides. The author also confirmed closely relationships between antecedent rainfall, snow piles and the volume of the earthquake-induced landslides in Japanese historical examples.

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Repair and Regeneration Technology of Load Cell

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Strain gauge load cells are the typically used type for anchor of highway in Japan. In recent years, there has been an increase in the number of cases where strain gauge load cells installed to manage anchor tension have failed due to aging or lightning strikes. Replacing a malfunctioning load cell required a great deal of labor and expense, including temporary removal of tension and the need for extensive equipment.
For this reason, three companies (West Nippon Expressway Engineering Chugoku Co.,Ltd. & Toyoko Elmes Co.,Ltd. & Central Nippon Highway Engineering Nagoya Co.,Ltd.) have jointly researched and developed the strain gauge replacement technology (a technology to easily and cheaply repair and regenerate strain gauge load cells while maintaining the anchor tension).
Based on the results of various tests, the strain gauge replacement technology has the same performance as the product (high accuracy and long-term stability) and can be easily repaired and reproduced.

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A Study on the Bedload Transport Characteristics of Damaged Forest Watershed in the Republic of Korea

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In Korea, forest fires occur every spring, and landslides occur in the rainy summer. The occurrence of forest fires and slope failure areas increases the risk of soil erosion. Importantly, heavy rainfall could inflict secondary damage such as soil erosion in forests already damaged by forest fire in the springtime. Erosion control works are carried out to rehabilitate damaged forests. Most works are the construction of structures and vegetation planting. Long-term monitoring for the identification of sediment discharge characteristics in such areas is needed in order to determine the scale of emergency rehabilitation and to establish long-term restoration plans. This study is the result of basic research for the quantitative calculation of sediment discharge and its characteristics that.

In this study, we analyze the rainfall characteristics that initiate bedload transport in areas damaged by forest fires, slope failures, and unaffected forested watersheds. We also aimed to identify the effects of forest fire and slope failure damage on the rainfall threshold of bedload transport.