Introduction: Monitoring, Prediction and Warning of Landslides

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Abstract

The WLF3 B5.Session Monitoring, prediction and warning of landslides, as a part of WLF3 session Group B. Sessions for Methods of Landslide Studies, gathers the main elements in the landslides risk reduction and landslides sustainable disaster management: monitoring, prediction and warning of landslides. Sixteen contributions from eleven countries around the world have been submitted and, after review process, accepted for publishing. The best practice techniques and experiences on monitoring, prediction and warning of landslides caused by different triggering factors are presented in this Session. In this introduction to the WLF3 B5 Session Monitoring, prediction and warning of landslides, a short summary of each of the accepted papers is presented divided regarding to their general topics.

Keywords

Landslides • Monitoring • Equipment • Measurement • Prediction • Early warning system

Introduction

The WLF3 B5 Session Monitoring, prediction and warning of landslides, as a part of Group B Sessions for Methods of Landslide Studies, gathers the main elements in the landslides risk reduction and landslides sustainable disaster management: monitoring, prediction and warning of landslides.

In landslides risk reduction and sustainable disaster management, the main roles have three closely connected elements: monitoring, prediction and warning of landslides. The monitoring of existing landslides, as well as locations susceptible to possible landsliding, using different techniques to produce the basic data for landslide prediction. Predictions of landslide occurrences should be based on a deep understanding of all processes which lead to slope failures in soil and rock mass slopes and their relationships with available measured monitoring data. Early warning systems, based on landslide monitoring results and landslide prediction, are the most economical landslide risk reduction measure. In this Session, the states of the art, best practice techniques and overall experiences in monitoring, prediction and warning of landslides caused by different triggering factors in different parts of the world are presented.

Sixteen contributions from eleven countries (Brazil, China, Croatia, Hong Kong, India, Indonesia, Italy, Korea, Malaysia, Slovenia and United Kingdom) have been submitted and, after review process, accepted for publishing in this

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session. These contributions can be divided in the following general topics:

- Technological developments;
- Monitoring of landslides;
- Early warning systems based on measurements of landslide displacements and soil properties;
- Early warning systems based on rainfall monitoring and hydrological models;
- Warning and emergency management.

In this introduction to the WLF3 B5 Session Monitoring, prediction and warning of landslides, a short summary of each of the accepted papers is presented within previously defined general topics.

Technological Developments

Eyo et al. (2014) in their paper entitled "Application of low-cost tools and techniques for landslide monitoring" propose a low-cost landslide monitoring system using the Reverse Real-Time Kinematic (RRTK) technique. This is a server-based processing technique, which utilizes two-way communication channels for computation and the transmission of the user's accurate position. The basic infrastructure requirements for RRTK for a low-cost landslide monitoring application are described. In order to implement the proposed RRTK algorithm, real-time data of raw Global Positioning System (GPS) data of both the reference and rover stations are streamed to the control center. A high pass filtering technique was employed to detect outliers in the observations and the autocorrelation of GPS time series was investigated to validate the presence of white and colored noises in the GPS observations. The proposed new monitoring technique using RRTK principles and server-based processing methods was successfully tested using data from test sites located at the Universiti Teknologi Malaysia.

Segalini et al. (2014) report on the efficiency of a novel inclinometer type in the paper "Automated inclinometer monitoring based on micro electro-mechanical system technology: applications and verification". The new device, called Modular Underground Monitoring System (MUMS) is intended to be applied for natural and artificial slope deformation monitoring, and landslide dynamics control, assessment and forecasting. The paper compares the classic inclinometer devices and the new MUMS device, which can also be equipped with other electronic sensors. The paper also describes successful application of MUMS at three landslides in Italy: the Tiedoli Landslide, the Roccamurata Landslide and the Boschetto Landslide.

Wang et al. (2014) in their paper "Energy demodulation-based all-fiber warning system for landslides" present a new landslide warning technology. The system can measure the signal of energy change in the fiber caused by micro bending or breakage associated with the displacement of landslides, and sends alarms at once when the signal intensity in the fiber weakens to the threshold. In the paper, this energy demodulation-based all-fiber warning system is described in detail. Compared with conventional monitoring technologies, this technology has many unique advantages, such as a graded alarm system, real-time response, remote monitoring and low cost. At the present time this system is used in landslide warning in China and a successful application of the system at the Gaoqin Landslide is described in the paper.

Zhu et al. (2014) describe a landslide monitoring technique using distributed fiber-optic sensing technologies. The advances in distributed fiber optic sensing (DFOS) technologies enable automatic, remote and long-distance slope monitoring and early-warning of potential geological disasters. Compared with conventional geotechnical sensors and instrumentation, the fiber optic sensors have a number of advantages such as high accuracy and repeatability, better durability and enhanced integration capability. In their paper "Laboratory studies on slope stability monitoring using distributed fiber-optic sensing technologies" Zhu et al. (2014) present the quasi-distributed Fiber Bragg Grating (FBG) and fully-distributed Brillouin Optical Time-Domain Analysis (BOTDA) sensing technologies for monitoring of slope stability problems in laboratory model tests. The reliability of the DFOS-based slope monitoring systems has been verified through analyses of the strain monitoring results.

Monitoring of Landslides

Arbanas et al. (2014) in the paper entitled "A landslide monitoring and early warning system using integration of GPS, TPS and conventional geotechnical monitoring methods" present an advanced comprehensive monitoring system designed and used on the Grohovo Landslide in Croatia. The landslide monitoring results should provide a basis for development and validation of landslide numerical modelling and adequate hazard management. Equipment selection was based on scientific requirements and consideration of possible ranges of monitored values and sensor precision. Use of different geodetic and geotechnical sensors, in combination with hydrological monitoring equipment which should measure data on precipitation and pore pressures in the landslide profile, allows reconstruction of relationships between rainfall, groundwater level and consequent landslide behavior as a base for establishing an early warning system. The most important step in establishing an early warning system was linking sensor measurements and possible failure mechanisms with consequences that should follow the occurrence of sliding (landslide risk). This paper presents the main ideas and advances of the monitoring equipment fusion as well as weaknesses of the applied monitoring system at the Grohovo Landslide.

Krkač et al. (2014) in their paper entitled “Review of monitoring parameters of the Kostanjek Landslide (Zagreb, Croatia)” present initial results obtained from sensors and instruments of an advanced comprehensive monitoring system installed on the Kostanjek Landslide in Croatia. External triggers at the Kostanjek Landslide are measured with rain gauges and accelerometers. Displacements at the surface are measured by 15 GNSS sensors and 9 extensometers, while subsurface displacement is measured by vertical extensometers and an inclinometer. Hydrological measurements consist of groundwater level measurements, discharge measurements, and chemical and isotope analysis. The paper describes landslide reactivation due to external triggers in the winter period of 2012/2013, when during the period from September 2012 to March 2013 the total cumulative precipitation was 793.7 mm and horizontal displacements were in the range of 9–20 cm. The installed monitoring sensor network will provide reliable data for the establishment of relations between landslide causal factors and landslide displacement rates aimed at establishing threshold values for early warning system at the Kostanjek Landslide.

Kumar et al. (2014) describe monitoring systems installed on two of the most critical landslides on one of the important highways in India, which connects the north western Himalayan state of Uttarakhand to the rest of the country. The entire Himalayan road network suffers extensive damage from a large number of landslides of different shapes and sizes. A large number of the landslides on each highway have occurred repeatedly during every year for many decades, causing extensive risk to life of commuters, loss of revenue from direct and indirect losses and hardship for the people, thus influencing the socio-economic conditions of the region. In the paper entitled “Monitoring of critical Himalayan landslides and design of preventive measures” the very simple monitoring systems installed at the Kaliasaur Landslide and the Patalganga Landslide consisting of specially designed grooved steel pedestals, a total station and a Differential Global Positioning System (DGPS) are presented. The results of monitoring will encourage utilizing the same system for other Himalayan landslides of a recurring nature instead of investing in heavy-duty, costly and sophisticated monitoring instrumentation.

Early Warning Systems Based on Measurements of Landslides Displacements and Soil Properties

Chae et al. (2014) in their paper “Suggestion of a landslide early warning method using a gradient of volumetric water content” presents the study of a real-time landslide monitoring system to observe physical property changes in soils in a slope during rainfall events. This monitoring system proposes the measurement of volumetric water content, which was compared with the results of laboratory flume tests to identify landslide indicators in the soils. The response of volumetric water content to rainfall events is more immediate than that of pore-water pressure, and volumetric water content attains its maximum value for some time before a slope failure. Based on laboratory results, it is possible to suggest a threshold value of the volumetric water content gradient demarcating the conditions for slope stability and slope failure. This threshold can thus serve as the basis for an early warning system for landslides considering both rainfall and soil properties. The proposal is successfully confirmed by landslide monitoring on the Deoksan test site in Korea.

Fathani et al. (2014) in their paper entitled “An adaptive and sustained landslide monitoring and early warning system” describe the technical system to support landslide disaster risk reduction consisting of several technical components such as instruments for a landslide early warning system (extensometers, tiltmeters, inclinometers, raingauges, ultrasonic water level sensors, IP cameras) and supported by a smart-grid for landslide hazard communication, monitoring and early warning. Faculty of Engineering, Universitas Gadjah Mada Indonesia have developed simple and low-cost equipment for landslide monitoring and early warning since 2007. This real-time monitoring and early warning of landslides and debris floods has been implemented at eight geothermal areas in Sumatra, Java and Sulawesi Islands. The system is designed by using real-time landslide monitoring and early warning instruments, and also may involve human sensors—selected trained people in the local community, who have been dedicated in their commitment for doing ground checking and sending reports related to any observed warning signs of potential landslides.

The paper “Early warning and real-time slope monitoring systems in West and East Malaysia” prepared by Fung et al. (2014) presents the application of slope safety warning systems on two slopes along strategic roads in Malaysia: the first is located in Perak at the 46th km of the Simpang Pulai—Kuala Berang Highway and the second is an old fill embankment slope located at the 50.4th km of the Federal Road 500 between Penampang and Tambunan of Sabah. At the first location, monitoring and early warning were established by installation of a robotic total station, while at second location the automatic instruments include a rain gauge station, two sets of piezometers, tiltmeters, and two manual inclinometers to determine subsurface soil movements. Based on measured results (rainfall and movements), warning criteria were proposed. The data collected on site are managed by the same web-based data management system. The system is accessible to authorized users as a web service through the client software.

Early Warning Systems Based on Rainfall Monitoring and Hydrological Models

Komac et al. (2014) in their paper "A national warning system for rainfall-induced landslides in Slovenia" present a result of the project for forecasting the possible occurrence of rainfall-induced landslides in Slovenia (Masprem Project). The landslide hazard forecasting and warning system is based on three pillars—the landslide susceptibility model, the precipitation forecast and the triggering values related to specific rocks/soils. Triggering values were derived using two separate approaches. In the first an overlay of 29 different engineering geological units (rock/soil types) and the data on maximum 24-h precipitation with the return period of 100 years (ten classes of intensities; class span was 30 mm) was performed and the number of landslides statistically compared against the size of these unique areas. The second approach is rainfall event oriented, in which analyses of the landslide triggering values were compared with the landslide occurrence and its duration. After calculation of the most plausible landslide hazard probability model, it has to be relayed to the end-users: decision makers or the general public via the internet. The quality of the forecasted landslide hazard probability prediction was tested only for the 8 days period prior to a major landslide event that occurred on 5th November 2012 and resulted in a landslide hazard probability model for the area of Slovenia.

In the paper "Latest developments of Hong Kong's Landslip Warning System" Wong et al. (2014) present an overview of the major components of the Hong Kong Landslip Warning System and describe the technical basis of the System. The Geotechnical Engineering Office (GEO) has been operating a territory-wide Landslip Warning System, in conjunction with the Hong Kong Observatory (HKO), since 1977. The purpose is to alert the general public of possible landslide risks during periods of heavy rainfall. The GEO has been operating an extensive automatic raingauge network to provide real-time rainfall information for use in the Landslip Warning System. Computer programs are developed and implemented, together with other proprietary software packages, to acquire and analyze real-time rainfall data from the raingauges, display aspects of rainfall development and predict the number of landslides (based on 24-h recorded rainfall, 21-h recorded rainfall + 3-h forecasted rainfall, and 23-h recorded rainfall + 1-h forecasted rainfall respectively) using a rainfall-landslide correlation model. A revamped project of the GEO Raingauge System is in progress to further improve the system performance and reliability in order to better support decision-making on the issuing of Landslip Warnings. The probabilistic-based rainfall-landslide correlation model for man-made slopes, established on the basis of the most recent landslide and rainfall data, is being used in the current Landslip Warning algorithm.

Yang et al. (2014) in their paper "A multi-scaled early warning method for rainfall-induced mountain hazards" propose a multi-scale, real-time early warning method, which combines large-scale regional hazard maps as well as site-specific hazard site monitoring. The real-time early warning map for regional scale rainfall-induced mountain hazards was developed by considering the triggering factors of rainfall distribution in addition to pertinent environment factors. The probability-based prediction method of regional scale rainfall-induced mountain hazards was developed by combining the hazard zonation map with the probability of regional precipitation. The prediction model was established through the analysis of geological and hydrological factors of the specified area, combined with the analysis of mountain hazard occurrences and the corresponding regional precipitation data. A site-specific, real-time monitoring and early warning system was constructed for five mountain hazard sites, including three debris flow and two landslide zones along the Longmenshan fault in Dujiangyan and Pengzhou County, Chengdu City in China. A monitored artificial rainfall test was conducted on a natural slope and was used to identify the threshold value to elicit an early warning that provides guidance and an approximate time for evacuation and preparation for potential landsides by comparing monitored rainfall intensity and its duration.

Warning and Emergency Management

Dourado et al. (2014) present the use of RADAR imagery in supporting rescue and recovery actions for landslide and flood disasters in Rio de Janeiro State, Brazil. In the paper "RADAR images supporting rescue and recovery actions for landslide and flood disasters—a Rio de Janeiro State case study" the images from optical sensors are described as very useful tools for identifying areas that suffered some impact during catastrophic events. The main advantage of using RADAR images is the possibility of monitoring areas of interest, even when there is cloud cover or at night. From RADAR images, in the post-disaster period, it could be easy to identify areas that suffered some kind of landscape change (mass movements, floods, etc.). The flood monitoring is based on the Normalized Difference Sigma Naught Index (NDSI), which compares the surface roughness of the image before the flood (Master Image) with the roughness in the same surface in the new image acquired during the flood (Slave Image). To monitor landslides, the methods for analysis of the data are Coherent Change Detection (CCD) and

Polarimetric Interferometry (Pol-InSAR) to map areas where there are landslide-generated changes in the roughness of the surface terrain (scars of landslides). Differential Interferometry (DInSAR) is used to map areas where the movement was not enough to significantly alter the landscape. If the system runs as planned, in an integrated way with the Civil Defense, it will become a very useful tool in rescue actions immediately after the disaster and as a tool in post-disaster planning.

Marino et al. (2014) in their paper "Geotechnologies for supporting regular surveys and catastrophic events of Rio de Janeiro Geological Survey—A case study" present a data management system related to the geological risk in the Rio de Janeiro State, Brazil, developed to support field teams and bring more practicality and organization during field assessment activities. The proposed methods combine a Geographic Information System (GIS), telecommunications networks and mobile devices to enhance the process from data acquisition by field teams, to organization and presentation for remote coordinators. The system consists of the assemblage of a georeferenced database to organize field-collected data related to mass movement assessments. The GIS VICON/SAGA—Vigilance and Control was designated to support the database. It provides interfaces for data collection, querying, filtering, report and map generation. The database was structured to store the event location, measure susceptible or affected areas, retrieve information such as the number of people affected or killed, and buildings affected or destroyed by mass movements. The GIS brings two specific interfaces for data input: from PC, using web browsers or from the field, using mobile devices, on an Android OS application. For information retrieval, some interfaces were developed, such as a query system for alphanumeric-tabular reports and others for spatial query procedures for map generation. Databases organize all information coming from multiple sources in real time and can be spatially visualized and analyzed using GIS. Each piece of information is grouped by type (evaluation of sliding, search and rescue) and standardized through predefined forms, providing filtered queries performed from search criteria. Reports and maps are generated for spatial analysis by any other analysis tool. As a final result, citizens and "Emergency Teams" consume information, logically organized and certified, from the manager. After compilation of all data, the manager in command can evaluate the situation and prioritize immediate response to the most dangerous cases in each situation and facilitate developing emergency actions.

Winter et al. (2014) present technical and perceptual evaluations of a novel form of landslide warning road signs known as 'wig-wags'. The 'wig-wag' signs incorporate a standard rockfall/landslide red warning triangle, flashing lights and a sub-plate that warns of 'higher risk when lights flash' (i.e. during periods of high rainfall) and they have been trialed at an important debris-flow site in Scotland. The paper "Evaluation of 'wig-wag' landslide warning signs" presents results of evaluation after a 2-year trial of such signs at the highly active A83 Rest and be Thankful site in Scotland. The following objectives are considered: technical evaluation to determine the efficacy of the wig-wag switch-off/switch-on protocol in terms of its alignment with actual events and also to assess the rainfall threshold used for the switch-on; and evaluation of drivers' attitudes and behavioral responses (perceptual evaluation) to explore the attitudes held by local and non-local drivers towards landslide wig-wag signs on the A83 in terms of their perceived meaning and their impact on road safety. The evidence from both the technical and perceptual evaluations indicated that the wig-wag signs trial has a satisfactory outcome and that the flashing lights prompt generally desirable behaviors in the majority of cases.

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