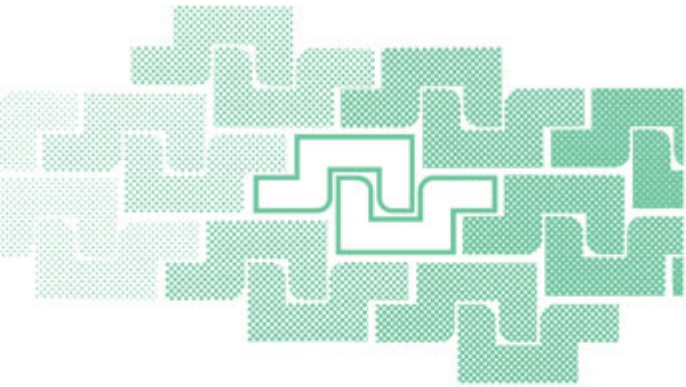

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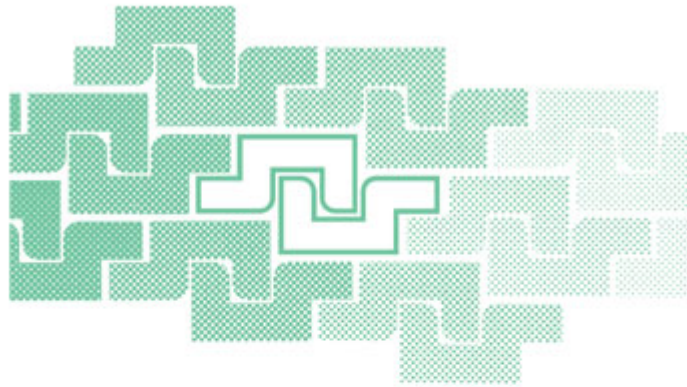
Landslides from Massive Rock Slope Failure



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Landslides from Massive Rock Slope Failure

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DEDICATION

EDOARDO SEMENZA (1927-2002)

Professor Edoardo Semenza passed away on May 31st, 2002 shortly before the NATO Advanced Research Workshop on Massive Rock Slope Failure. He was one of Italy's leading landslide researchers and put his distinctive mark on the understanding of the Alpine chain structure, bringing original and important contributions to the geology, tectonics and geomorphology of the Dolomites. His main scientific interest was the understanding of geological processes with reference to landscape evolution and slope stability conditions. His life and work were deeply influenced by the 1963 Vaiont rockslide. Professor Semenza was the geologist who realized, well before the first recorded movements, that an ancient landslide mass was present on the left slope of the Vaiont River valley and he was aware of the very high hazard posed to the dam then under construction. His studies and interpretation were considered of major interest and accuracy by successive Vaiont researchers such as Hendron and Patton. He spent more than 40 years of his academic career at Ferrara University as Professor of Engineering Geology. His geological insight, humanity and culture (he also wrote many poems both in Italian and the Latin language) remain in the memory of colleagues, students and the Italian scientific community. One of his fundamental teachings was the importance of the careful collection of field data as a basis for understanding slope stability conditions, for reliable modelling, and for designing effective remedial works. He strongly believed in the role of both geology and geomorphology as fundamental support to any civil engineering works and in the importance of effective communication among the various specialists involved in large civil engineering projects. This volume is dedicated to his memory.

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[1] * denotes Keynote Lecture

PREFACE

This volume contains contributions by experts who participated in the NATO Advanced Research Workshop on "*Massive Rock Slope Failure: New Models for Hazard Assessment*" which was held in Celano, Italy, in June 2002. This event has become known as the Celano Workshop.

Landslides resulting from large-scale rock slope failures are a major hazard in mountainous regions. In the 20th century, disasters caused by massive rock slope failures have killed more than 50,000 people on a global basis with 20,000 of this total being killed in the NATO and Partner Countries (for details of NATO structure and Partner country designation see http://nato.int/science). In addition, hazardous conditions prevail at previous rock slope failure sites that pose considerable risk to communities downslope (in the case of cracked slopes adjacent to landslide scars, e.g., Frank, Canada) or downstream (in the case of potentially unstable landslide dams, e.g., Lake Sarez, Tajikistan) from initial failure sites. Furthermore, slopes that have not undergone major failure may show movement or surface features that indicate potential for catastrophic landslides. As an illustration of the hazard posed by such processes it is noted that during the preparation of this book a combined massive rock-ice avalanche and mudflow, tens of millions of cubic meters in volume, occurred in the Caucasus mountains of Russia's Ossetia Republic. It ran over 30 kilometres downvalley killing over a hundred of people.

The Celano Workshop was purposely organized to bring together earth scientists, engineering geologists and geotechnical engineers actively involved in a range of research topics related to massive rock slope failure, in order to undertake a critical assessment of the state-of-the-art concerning catastrophic rock slope failure and for defining future research directions. It was specifically dedicated to an examination of major mountain rock slope hazards, combining different experiences from different mountain environments of the world, as a contribution to the "Year of the Mountains", declared by the United Nations in 2002.

A highlight of the Celano Workshop was provided by the fact that the NATO Science Programme afforded a unique opportunity to solicit the participation of scientists from the former Soviet Union who introduced little known case-histories of massive rock slope failure in Russia, and the Central Asia Republics which are published in this volume for the first time.

This book is not intended as a simple "proceedings volume", *i.e.* a raw collection of papers summarising oral presentations in Celano concerning different aspects of large-scale rock slope failures. Rather, it was our objective to produce a self-standing volume whose contents display the most recent research within the international scientific community involved in the field of bedrock slope failure, framed in a logical order and with linkages to each other.

The structure of the book broadly reflects the main issues addressed by the Celano Workshop, even though there are some topics not as fully covered as was originally our expectation and plan. Topics related to risk assessment, such as consideration of vulnerability were intentionally not addressed, since at this stage we have focussed on

basic knowledge and models of massive rock slope failure processes and mechanisms. It is our belief that such specialized knowledge of hazard forms the foundation for any effective and successful risk management activity. Hopefully it will be the task of future meetings to address such themes, completing the loop that we have initiated in Celano.

According to our objectives, the book is divided in nine parts. The first includes an introduction to the phenomena associated with massive rock slope failure and an analysis of the frequency of catastrophic rock slope failures and their impact on society. Part two deals with processes and mechanisms which lead to the onset of failure in rock slopes, with particular reference to the contribution of numerical modelling. The third part is dedicated to recent monitoring techniques of rock slope movement specifically based on radar interferometry. In part four are presented different approaches and models for analysing post-failure behaviour and mobility of bedrock landslides, including results from monitoring of rock avalanches triggered by underground nuclear explosion. Part five is an overview of both well known landslide events and new case records, with a particular emphasis on the influence of geological factors on failure mechanism. A very broad topic, such as volcanic landslides, is partially treated in part six through contributions on recent collapses of active volcanoes, landslides along volcano flanks and use of 3D slope stability analysis in assessing flank collapse at stratovolcanoes. In part seven, regional studies from various areas of the world which are particularly concerned with spatial and temporal pattern of the events as well as the features of landslide deposits and related implications for the emplacement processes, are reported. Effects on landscape evolution induced by massive rock slope failures, either at local or regional scale, are discussed in part eight. The last part, containing a single chapter, highlights some of the most pressing problems in the understanding of massive rock slope failure and suggests new directions for future research activities in this field.

In all, the volume contains 32 papers by 63 authors from 16 countries. They consist of 15 invited key-note papers and 17 papers by invited discussants. All papers in the volume have been carefully reviewed by the editors and all have been thereby improved. We note that some of the chapters report the results of different research teams that agreed in producing joint papers which encompass different aspects of some crucial events. We are grateful to these authors for having accepted our encouragement in doing so.

Last but not least, the Workshop was held in the dramatic landscape of the Italian Appennines. This was significant because recent work, examined during the Workshop field trip, has uncovered the widespread presence of prehistoric rock avalanche deposits in the region. This situation exemplifies the poor state of knowledge of the distribution and occurrence of massive rock slope failure that exists in many populated mountain areas. It reminds us that a large amount of research work remains to be done in this field in order to better assess an underestimated mountain hazard.

Stephen G. Evans (Canada), Gabriele Scarascia Mugnozza (Italy), Alexander Strom (Russia), Reginald L. Hermanns (Germany)

Rome, May 2003

"L'acqua disfa li monti e riempie le valli e vorrebbe ridurre la Terra in perfetta sfericità s'ella potesse"

Leonardo da Vinci (1452-1519)

ACKNOWLEDGEMENTS

At the end of a long process such as the publication of this volume it is a pleasure and a duty to recognize all who contributed to the success of this enterprise, which was generated by the NATO Advanced Research Workshop on "*Massive Rock Slope Failure: New Models for Hazard Assessment"*.

First of all, we want to express our thanks for the financial support of the NATO Science Programme under whose auspices was possible to organize the ARW and thus to realize this book. In particular, we wish to acknowledge the precious help of the Scientific and Environmental Affairs Division - Environmental and Earth Science Technology Programme, namely Dr. Alain Jubier and his assistant Lynne Nolan. In addition we thank the NATO Science Programme Representative, Prof. Francesco Mulargia, who attended the workshop and further encouraged us in undertaking the publication of this book.

Of course, our deepest thanks go to all the authors who contributed to this volume. We are indebted to them for their personal commitment to this part of the NATO project and for their efforts in the Celano Workshop itself. We are particularly thankful to the keynote speakers who not only delivered stimulating presentations in Celano but produced excellent keynote papers for this volume.

The financial support of Italian Scientific Institutions and Local Administrations, who contributed significantly to a successful and effective workshop are gratefully acknowledged. In particular, we recognized the Italian National Research Council (CNR), the National Institute for the Scientific and Technological Development of the Mountain (INRM), the University of Rome "La Sapienza" and the Faculty of Sciences of the same University. We also acknowledge support by the Regione Abruzzo, the Comunità Montana Aventino Medio Sangro and the ARSSA (Regional Agency for Agriculture). Special thanks are due to the Municipality of Celano namely the mayor, Italo Taccone, and the Deputy for the Environment, Loreto Ruscio, who gave fundamental support in carrying out the workshop in the town of Celano.

The workshop itself could not have been held without the help of Gianluca Bianchi Fasani, Carlo Esposito, Alfredo Maffei, Salvatore Martino, Beatrice Salvati and Mario Floris. In addition, Gian Paolo Cavinato and Marco Petitta gave an important contribution in organizing and leading the field trip during the workshop.

Finally, a special thanks to our respective institutions for their support and encouragement. The GeoForschungsZentrum in Potsdam and the University of Rome "La Sapienza" hosted the meetings of the editorial committee during the preparation of this book.

SGE
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RLH
Rome, May 2003

PART 1. INTRODUCTION

LANDSLIDES FROM MASSIVE ROCK SLOPE FAILURE AND ASSOCIATED PHENOMENA

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Abstract

Landslides from massive rock slope failure (MRSF) are a major geological hazard in many parts of the world. Hazard assessment is made difficult by a variety of complex initial failure processes and unpredictable post-failure behaviour, which includes transformation of movement mechanism, substantial changes in volume, and changes in the characteristics of the moving mass. Initial failure mechanisms are strongly influenced by geology and topography. Massive rock slope failure includes rockslides, rock avalanches, catastrophic spreads and rockfalls. Catastrophic debris flows can also be triggered by massive rock slope failure. Volcanoes are particularly prone to massive rock slope failure and can experience very large scale sector collapse or much smaller partial collapse. Both these types of failures may be transformed into lahars which can travel over 100 km from their source. MRSF deposits give insight into fragmentation and emplacement processes. Slow mountain slope deformation presents problems in interpretation of origin and movement mechanism. The identification of thresholds for the catastrophic failure of a slow moving rock slope is a key question in hazard assessment. Advances have been made in the analysis and modeling of initial failure and post-failure behaviour. However, these studies have been retrodictive in nature and their true predictive potential for hazard assessment remains uncertain yet promising.

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