Landslides

Landslides cause tens of billions of dollars' worth of damage throughout the world every year, and losses are increasing due to a growing population and new development in potentially unstable areas. Fundamentally they have geological causes but can have natural triggers such as rainfall, snowmelt, erosion, and earthquakes, or can be triggered by human actions such as agriculture and construction. To reduce the threat that landslides pose to public safety and property, research aimed at providing a better understanding of slope stability and failure has accelerated in recent years. This acceleration has been accompanied by basic field research and numerical modeling of slope failure processes, mechanisms of debris movement, and landslide causes and triggers.

Written by 78 of the leading researchers and practitioners in the world, this book provides a state-of-the-art summary of landslide science. It features both field geology and engineering approaches, as well as modeling of slope failure and runout using a variety of numerical codes. The book is illustrated with international case studies that integrate geological, geotechnical, and remote sensing studies, and include recent slope investigations in North America, Europe, and Asia.

This comprehensive and complete one-stop synthesis of current landslide research forms an essential reference for researchers and graduate students in geomorphology, engineering geology, geotechnical engineering, and geophysics, as well as professionals in the field of natural hazard analysis.

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Preface

JOHN J. CLAGUE AND DOUGLAS STEAD

A series of well-publicized disasters and catastrophes during recent years, including a cyclone in Myanmar, earthquakes in China, Haiti, Chile, and New Zealand, and an earthquake and tsunami in Japan, underscore the importance of efforts to reduce risk from natural hazards around the world.

Landslides, floods, drought, wildfire, storms, tsunamis, and earthquakes continue to take a heavy toll in lives and infrastructure. In the past decade, disasters have killed over 750,000 people and caused damage costing hundreds of billions of dollars (Centre for Research on the Epidemiology of Disasters, 2011). Most of the loss of life was the result of earthquakes, tsunamis, and tropical storms; loss of life from landslides was only a small percentage of the total. Nevertheless, landslides are responsible for much primary and secondary economic damage – in the USA alone, landslides cause damage costing $1–2 billion and more than 25 fatalities each year (US Geological Survey, 2011).

Fig. 1. Rockslide on the "Sea-to-Sky Highway" (Highway 99) north of Vancouver, British Columbia. This landslide interrupted traffic along a major transportation corridor connecting Vancouver and Whistler, site of the 2010 Winter Olympics. (Photo courtesy of Erik Eberhardt.)

As the global population continues to increase, more people will be at risk from landslides. Even small slope failures are a threat to transportation infrastructure, as they disrupt the movement of goods and are costly to clear (Fig. 1). However, the economic costs of landslides are not limited to roads and railways. Underwater landslides have destroyed coastal infrastructure; catastrophic landslides may enter the sea and lakes, triggering destructive tsunamis (Fig. 2); landslides have blocked rivers, producing upstream flooding and reservoirs (Fig. 3), which are subject to sudden emptying and resulting downstream floods; and landslides may enter settled areas, causing death and injury.

Because of the threat that landslides pose to public safety and infrastructure, research aimed at better understanding slope stability and failure has accelerated in recent years. This acceleration is reflected in more basic field research, numerical modeling of slope failure processes, and improvements in understanding the mechanisms of debris movement, and landslide causes and triggers. This book summarizes recent advances in the study of landslides, written by 78 leading specialists from around the world.

The book is broadly divisible into three parts. The first part of the book comprises 12 chapters that deal with landslide types and mechanisms. John Clague and Nick Roberts provide an overview of landslide hazard and risk, set in the context of other hazardous natural processes. This chapter is followed by an overview of landslides in the Earth system by Oliver Korup, which sets the stage for a series of chapters that deal with different types of landslides and that collectively showcase recent developments and emerging technologies. Niels Hovius and Patrick Meunier examine patterns of landslides resulting from different earthquake ground motions. Chris Waythomas then discusses the factors responsible for large-scale instabilities on active stratovolcanoes. Tim Davies and Mauri McSaveney explore theories proposed to explain the long runout of rock avalanches, arguing that only dynamic rock fragmentation can account for the high mobility of this group of landslides.

Fig. 2. The Chehalis Lake rockslide (3 million m³) occurred in December 2007. It entered the lake and triggered a tsunami that removed forest up to 30 m above the lakeshore.

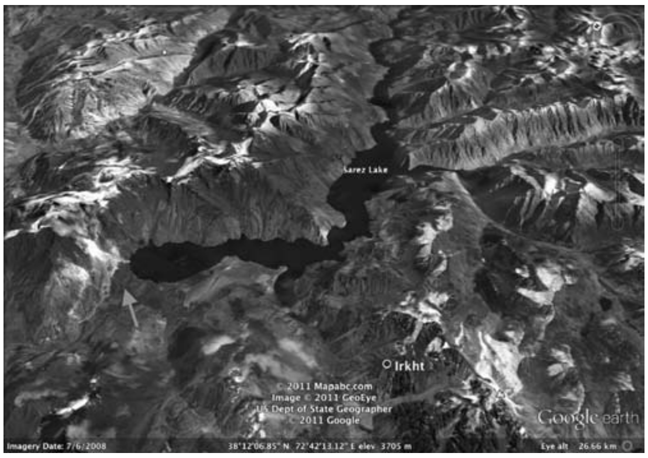

Fig. 3. Lake Sarez, impounded by the Usoi landslide dam in Tajikistan. The lake is 56 km long and holds about 16 km³ of water. The landslide dam (arrowed) is 567 m high and is formed of approximately 2 km³ of rock debris emplaced during an earthquake on February 18, 1911. Usoi Dam is the tallest dam in the world, either natural or engineered. Geologists are concerned that the dam might fail during future large earthquakes or might be overtopped by a displacement wave produced by a landslide into the lake. In either case, a catastrophic flood would devastate the heavily populated Murghab River valley below the dam. (Google Earth image.)

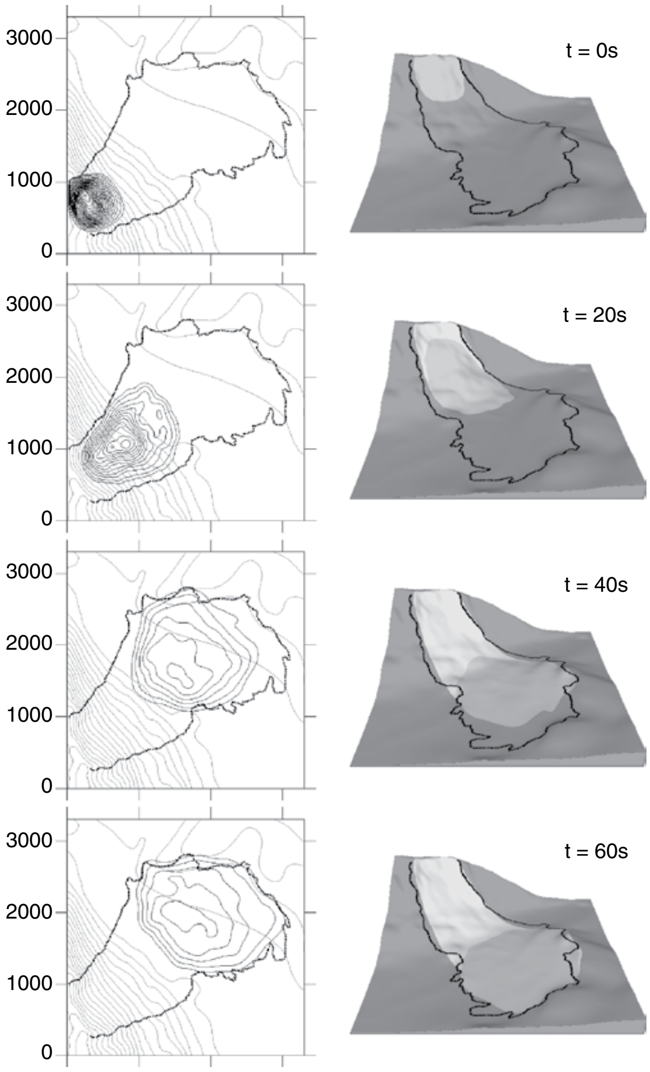

Fig. 4. Three-dimensional analysis of the Frank Slide. Plan (left) and oblique (right) views of the simulated moving mass at 20-s intervals. The flow-depth contours are 5 m, and the sliding surface contours are 50 m. The thick solid line demarcates the real extent of the landslide. (After McDougall and Hungr, 2004.)

Reginald Hermanns and Oddvar Longva continue the discussion of large rock-slope failures, drawing upon their considerable experience in the Andes. The next two chapters deal with more fluidized mass movements. Matthias Jakob and Kris Holm turn our attention to debris flows, focusing specifically on methods for assessing the risk from this type of mass movement. Kenneth Torrance describes different types of quick clay failures and the factors responsible for their sudden onset and retrogressive behavior. David Piper and colleagues discuss controls on different types of submarine landslides on the Canadian Atlantic continental margin. Brian Bornhold and Richard Thomson examine tsunami hazards related to landslides in coastal waters. Christian Huggel and colleagues review current understanding of the effects of climate change on the occurrence of landslides and debris flows in cold, temperate, and tropical mountains. The final chapter in the first part of the book, by Robin Fell and colleagues, deals with the geologic environments of landslides. They demonstrate that the geologic environment has a major influence on the likelihood and mechanisms of landsliding, the hydrogeology as it affects landsliding, and the strength of potential rupture surfaces in rock and soil.

The second part of the book consists of 10 chapters with a focus on numerical modeling of slope failure and new engineering measures aimed at reducing or eliminating landslide risk. Doug Stead and John Coggan introduce this section of the book with a summary of the state of the art in the numerical modeling of rock-slope instability. The next chapter, authored by David Petley, reviews remote sensing techniques applicable to landslides, including new technologies such as InSAR, LIDAR, and digital photogrammetry that are finding widespread use in characterizing slope instabilities. James Griffith and Malcolm Whitworth illustrate the importance of engineering geomorphology in the study of landslides, providing a review of mapping techniques and the engineering geomorphological aspects of landslide classification. Scott McDougall and colleagues discuss developments in runout prediction and the numerical methods used in current practice (Fig. 4). Randall Jibson then reviews methods of assessing the stability of slopes during earthquakes. Federico Agliardi and colleagues focus on slow, deep-seated rock-slope movements, commonly known by their German name, sackung. Although not as obvious as most other types of landslides, sackung are common around the world and can be very large. Numerical modeling is increasingly important in understanding this phenomenon. Erik Eberhardt then describes how landslide monitoring can be used, both as an early warning of failure and to improve our understanding of landslide failure mechanisms. Luciano Picarelli and colleagues use engineering case studies to illustrate the importance of groundwater in soil and rock slopes. The practical and theoretical concepts behind successful soil slope stabilization are then described by Edward Bromhead and colleagues. In the final chapter of this section of the book, Paolo Frattini and colleagues provide a state-of-the-art review of rockfall modeling.

The third part of the book comprises studies of specific landslides that integrate geologic, geotechnical, and remote sensing data. The case studies include: the 2006 Eiger rockslide, Switzerland (Michel Jaboyedoff and colleagues); the 2005 Randa landslides, Switzerland (Simon Loew and colleagues); instability on Turtle Mountain, Alberta (Corey Froese and colleagues); the Åknes rockslide, Norway (Lars Harald Blikra); a rockfall on Corno Grande in the Italian Apennines in 2006 (Gianluca Bianchi Fasani and colleagues); the Downie landslide, British Columbia (Katherine Kalenchuk and colleagues); the 1963 Vaiont Slide, Italy (Monica Ghirotti); landslides in Hong Kong (Steve Hencher and Andrew Malone); and landslides triggered by the 2008 Wenchuan earthquake, China (Masahiro Chigira and colleagues). The final chapter in the book, by Marko Bulmer, provides examples of landslides on other bodies in the solar system, including Mars, Venus, and Io, a moon of Jupiter. The presence of landslides on other planets, moons, and large asteroids illustrates the range of atmospheric and gravitational conditions in which mass movements can occur.

REFERENCES

Centre for Research on the Epidemiology of Disasters (2011). *EM-DAT: The OFDA/CRED International Disaster Database*. Université Catholique de Louvin, Centre for Research on the Epidemiology of Disasters, Brussels [available at www.emdat.be/database, accessed December 13, 2011].

McDougall, S. and Hungr, O. (2004). A model for the analysis of rapid landslide motion across three-dimensional terrain. *Canadian Geotechnical Journal*, 41, 1084–1097.

US Geological Survey (2011). *Landslides Hazards Program*. US Department of the Interior [available at http://landslides.usgs.gov, accessed November 16, 2011].