

**A seismological study of gravitational mass
movements based on lab-scale experiments**

Master's thesis
in the Department of Earth Sciences
at Freie Universität Berlin

by Zahra Amirzada

May 2015

assessed by
Prof. Dr. Onno Oncken & Prof. Dr. Niels Hovius
from Geoforschungszentrum Potsdam

I hereby certify that the work presented in this thesis has been composed independently without use of any sources or auxiliary means other than mentioned.

Zahra Amirzada

Berlin, 1st of May 2015

Abstract

Seismological monitoring of gravitational mass movements is considered an emerging field in earth and environmental sciences, allowing for the remote detection and quantification of slope processes by distant seismometers (Burtin et al. (2013); Petley (2013)). The method includes the possibility to invert seismic signals for a suite of aspects of event dynamics and for details of the fragmentation process. For a sound interpretation of these ground movement signals in nature, knowledge of the seismic source and of the energy transfer to the detector is paramount. Since most events however lack direct observations by other methods (e.g. cameras), the source–signal relationship often remains obscure. In order to shed light on the source–signal relationship in the context of monitoring gravitational rock movements, we started controlled laboratory experiments using analogue models. The idea of applying seismological monitoring techniques on a lab–scale opens for new and perhaps improved ways of characterizing natural events by their corresponding seismograms. Initial benchmark tests are carried out involving a controlled source i.e. a ballistic steel ball vertically impacting a horizontal glass base. These tests intend to calibrate and verify the monitoring method by relating a set of seismic metrics to the energy released during impact and deriving the respective scaling laws. Subsequently, the method is applied to models of dynamically fragmenting gravitational rock movements (Haug et al. (2014)). For this purpose a material was developed that fails in a brittle manner at lab–scale conditions. Experiments are performed by releasing the material down a slope and monitoring with a digital camera at a frequency of 50 and 250 Hz. The results from previous experiments illustrate the dynamic properties of samples as a function of shear strength or cohesion (Haug et al. (2014)). By application of the scaling law to the experimental data, we attempt to estimate the impact energy during analogue experiments, potentially allowing for qualitative and quantita-

tive information about the underlying mechanisms and the energy budget of the system. We find that the degree of fragmentation of a sample not only influences the mobility of experiments, but also their corresponding seismic signals and that the amount of energy consumed by fragmentation plays a more significant role in the energy budget of gravitational mass movements than has previously been assumed.

Acknowledgment

Many thanks to Dr. Matthias Rosenau and Oystein Thorden Haug for guidance and support along the way and for showing me how interesting the world of research can be. I left every meeting with many new ideas, motivation, helpful advice and good spirit. Thanks for always having an open door and a lot of patience. I thank Prof. Dr. Onno Oncken for giving me the opportunity to work on my thesis in the department of lithosphere dynamics at GFZ and for assessing my work together with Prof. Dr. Niels Hovius. Further gratitude is owed to Dr. Arnaud Burtin for Matlab support and for taking the time to answer any of my questions as well as to Prof. Dr. Frank Riedel for giving me the choice to decide on any field of work and for some inspiring talks.

Contents

1	Introduction	11
1.1	Motivation and Outline	14
1.2	Thesis Structure	16
2	Literature Overview	17
2.1	Dynamics of Gravitational Rock Movements	17
2.2	Seismic Monitoring in Nature	18
2.3	Experimental Approach	20
2.4	Wave Propagation	24
3	Monitoring techniques and setups	26
3.1	Seismological Monitoring	26
3.2	Optical Monitoring	27
3.3	Benchmark Setup	28
3.4	Experimental Setup	30
4	Methodology	32
4.1	Material Preparation	32
4.2	Sensor Calibration	33
4.3	Data Processing	33
4.3.1	Event Detection	34
4.3.2	Hilbert Transform and Analytic Signal	35
4.3.3	Seismic metrics	38
4.3.4	Spectral Analysis	38
5	Results	40
5.1	Bouncing ball benchmark	40

5.1.1	Observational results	41
5.1.2	Quantitative results	45
5.1.3	Physical Meaning	53
5.1.4	Scaling to Nature	54
5.2	Analogue Experiments	57
5.2.1	Observational Results	57
5.2.2	Quantitative Results	59
5.2.3	Application of the Scaling Law and Inferred Energy	65
5.2.4	Limitations of the Approach	68
6	Discussion	71
6.1	Signal Analysis	71
6.2	Validation of the Scaling Law	77
6.3	Possibilities and Limitations in the Lab	80
6.4	Application to Nature	81
7	Summary	83
	Bibliography	87