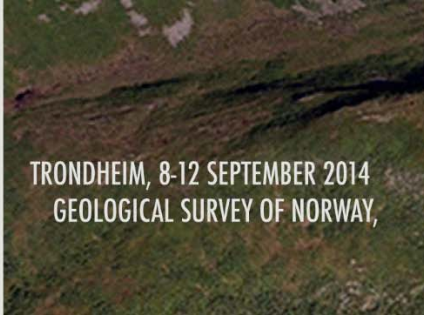
www.ngu.no/slopetectonics

THIRD SLOPE TECTONICS CONFERENCE



Organizers

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

UNIL | Université de Lausanne
Faculté des géosciences et de l'environnement

Åknes
Åknes/Tafjord Beredskap IKS

Supporters

Statens vegvesen

Nordnorsk Fjellovervåking

LiSALab
...a step ahead in monitoring structures and natural hazards
Powered by Ellegi srl

Norwegian Water Resources and Energy Directorate
NVE

Jernbaneverket

NIFS
NATURFARE
INFRASTRUKTUR - FLOM - SKRED

NavSys
navigation and systems

RIEGL

CSG
geotechnical monitoring

NGU Report 2014.030

3rd Slope Tectonics conference –
Program and abstract book

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

Geological Survey of Norway
Postboks 6315 Sluppen
NO-7491 Trondheim, Norway
Tel.: +4773904000
Telefax +4773921620

REPORT

Report no.: 2014.030	ISSN: 0800–3416	Grading: Open

Title:
3rd Slope Tectonics conference – Program and abstract book

Authors:
R.L. Hermanns, A. Liinamaa-Dehls, J.F. Dehls, T. Oppikofer

Client:
-

County:
-

Commune:
-

Map-sheet name (M=1:250.000)
-

Map-sheet no. and -name (M=1:50.000)
-

Deposit name and grid-reference:
-

Number of pages: 67 Price (NOK): 95
Map enclosures: 0

Fieldwork carried out:	Date of report:	Project no.:	Quality control:
-	01.09.2014	355400	

Summary:

The 3rd Slope Tectonic Conference arranged at the Geological Survey of Norway on September 8.-12. 2014, follows the 2nd Slope Tectonic Conference organized at the Geological Survey of Austria in 2011 and the 1st Slope Tectonic conference organized at the University of Lausanne, Switzerland in 2008. It stands in an international tradition and a total of 56 contributions will be given on rock slopes affected by slope tectonic processes from 20 counties including Argentina, Austria, Canada, Chile, China, Czech Republic, France, Iceland, Italy, Japan, Kazakhstan, Mongolia, Morocco, Nepal, Norway, Pakistan, Poland, Scotland (UK), Slovakia, and Switzerland.

Slope Tectonics is a young geo-scientific discipline dealing with mass-wasting controlled by structures and features from local to regional scale, their description, mapping, geotechnical analyses and modelling of evolution. The main aim of the conference is to bring together scientists dealing with slope failures from engineering-geological, structural-geological and geomorphic point of view to improve the understanding of the interplay of slope fabrics with mass movement. The contributions are arranged in six oral sessions covering the topics: Slow rock slope deformation, rockslides & active tectonics, geological and tectonic control on landslide distribution, rapid rock slope failures, monitoring & modelling of rock slopes, reactivation of pre-existing structures & formation of new structures in rock slopes, and a poster session. The conference includes a 3-day field trip to the glacially oversteepened fjordland of western Norway, where slope tectonic processes will be discussed in the field. The field trip includes sites related to the phenomena of catastrophic rock slope failures generating displacement waves, rock avalanching onto decaying Younger Dryas ice body and rock avalanche damming of valleys. The excursion guide is available as NGU report number: 2014.031.

The conference would not have been possible in its present form without the generous sponsorship of Åknes/Tafjord Beredskap IKS, University of Lausanne, Naturfare - Infrastruktur, Flom og Skred (NIFS, joint programme of NVE, Vegvesen and NSB), Nordnorsk Fjellovervåking, C.S.G. S.r.l, Lisalab, NavSys AS and RIEGL Laser Measurement Systems.

Keywords:	Rock slope failure	Rock avalanche
Slope stability monitoring	Rock slope monitoring	Faults
Tectonics	Earthquakes	

CONTENTS

Day 1: Monday September 8, 2014

8:15 – 8:45	Registration & coffee
8:45 – 9:00	Welcome & introduction
9:00 – 10:30	Oral session 1: Slow rock slope deformation
10:30 – 11:00	Coffee break
11:00 – 12:00	Oral session 2: Rockslides & active tectonics
12:00 – 13:00	Lunch break
13:00 – 15:15	Oral session 3: Geological and tectonic control on landslide distribution
15:15 -15:45	Coffee break
15:45 -17:15	Oral session 4: Rapid rock slope failures
19:00	Dinner at To Tårn

Day 2: Tuesday September 9, 2014

8:30 -10:45	Oral session 5: Monitoring & modelling of rock slopes
10:45 -11:15	Coffee break
11:15 -12:45	Oral session 5: Monitoring & modelling of rock slopes continued
12:45 -13:45	Lunch break
13:45 -15:00	Poster session
14:30 -15:00	Coffee break
15:00 -16:15	Oral session 6: Reactivation of pre-existing structures & formation of new structures in rock slopes
16:15	Discussion & conclusion

Day 3, 4, 5: Excursion (see separate programme)

COMMITTEES

Conference chair

Hermanns, Reginald (NGU)

Conference organizers

Hermanns, Reginald (NGU)
Jaboyedoff, Michel (University of Lausanne)
Blikra, Lars Harald (Åknes Tafjord Beredskap IKS)

Scientific committee

Agliardi, Federico (University of Milano – Bicocca)
Baron, Ivo (Museum of Natural History)
Blikra, Lars Harald (Åknes Tafjord Beredskap IKS)
Braathen, Alvar (UNIS)
Chigira, Masahiro (Kyoto University)
Clague, John J. (Simon Fraser University)
Crosta, Giovanni B. (University of Milano – Bicocca)
Dehls, John F. (NGU)
Derron, Marc-Henri (University of Lausanne)
Evans, Steve G. (Waterloo University)
Hermanns, Reginald (NGU)
Jaboyedoff, Michel (University of Lausanne)
Lauknes, Tom Rune (NORUT)
Loew, Simon (ETH, Zurich)
Lovisolo, Mario (C.S.G. S.r.l.)
Malet, Jean-Philippe (CNRS)
Nilsen, Bjørn (NTNU)
Oppikofer, Thierry (NGU)
Ostermann, Marc (University of Innsbruck)
Penna, Ivanna M. (University of Lausanne)
Rivolta, Carlo (Lisalab)
Rohn, Joachim (Univ. of Erlangen-Nuremberg)
Saintot, Aline (Bochum University)
Scarascia-Mugnozza, Gabriele (La Sapienza Univ.)
Sepulveda, Sergio (University of Chile)
Strom, Alexander (Geodynamics Research Center)
Wei Xiang (China University of Geosciences)
Yugsi Molina, Freddy Xavier (NGU)

Local organizing committee

Böhme, Martina
Dehls, John F.
Hermanns, Reginald
Oppikofer, Thierry
Sandøy, Gro
Yugsi Molina, Freddy Xavier

Secretary

Liinamaa-Dehls, Anne

Monday, September 08, 2014

9:00-10:30 **Oral session 1: Slow rock slope deformation**
(Chairs: Crosta, G. & Dehls, J.F.)

9:00	**F. Agliardi**, M. Barbarano, G.B. Crosta, F. Riva & A. Zanchi *Inherited and active tectonic controls on the Piz Dora sackung system (Val Mustair)*
9:15	**T. Oppikofer**, G. Majala Dreiås, A. Saintot, R.L. Hermanns & J. Gosse *Geological and structural control of the Ivasnasen and Vollan unstable rock slopes (western Norway)*
9:30	M. Della Seta, **C. Esposito,** S. Martino & G. Scarascia Mugnozza *Morpho-structural evolution of slope-to-valley systems and related implications on slope-scale gravitational processes: new results from the Mt. Genzana case history (central Apennines, Italy)*
9:45	**J. Lenart**, P. Tábořík, T. Pánek, V. Blecha, O. Turský & J. Vilhelm *Deep-seated slope deformations headscarps detection by a combination of geophysical techniques (Outer Western Carpathians)*
10:00	**J. Stemberk** *Recent tectonic activity influencing the development of deep seated slope deformations: examples from the Bohemian Massif and Western Carpathians*
10:15	**M. Chigira**, T. Sakashima, J. Minagawa, A. Funayama & K. Shibuya *Prediction and stability assessment of potential sites of catastrophic landslides*

Coffee break (10:30-11:00)

11:00-12:00 **Oral session 2: Rockslides & active tectonics**
(Chairs: Scarascia-Mugnozza, G. & Rohn, J.)

11:00 **A. Strom**

Caldera-like collapses in non-volcanic regions - evidence of neotectonic detachment folding

11:15 **I. Baroň**, L. Plan, B. Grasemann, I. Mitrović, J. Blahůt & J. Stemberk

Gravitational slope deformation triggered by neotectonic movement: first direct observations from the Emmerberg and Eisenstein Caves (Lower Austria)

11:30 **T. Redfield**, R.L. Hermanns, T. Oppikofer, F.X. Yugsi Molina, P. Osmundsen & S. Sepulveda

What can we learn for seismic hazard in Scandinavia from medium magnitude earthquakes in the Chilean fjord land?

11:45 **S.A. Sepúlveda**, V. Farías, V. Letelier & M. Farías

Megalandslides in the Tarapacá Region, northern Chile: A consequence of crustal fault active tectonics?

Lunch (12:00-13:00)

13:00-15:15 **Oral session 3: Geological and tectonic control on landslide distribution**
(Chairs: Malet, J. -P.& Penna, I.A.)

13:00 **S. Yamasaki** & Y. Yoshikawa

Searching for undiscovered tsunamigenic landslides, and the relationship between landslide morphology, process and tsunami

13:15 **F. Bucci**, M. Santangelo, M. Cardinali, F. Fiorucci & F. Guzzetti

Distribution of landslide volume in tectonically-controlled mountain landscapes

13:45 **K. K. Panthi**

Swalik formation and landslide hazard along Tinau valley, Nepal

14:00 **T. Saemundsson**, H. Norddahl & H.G. Petursson

Rock avalanches, rock slides and rock falls in the Quaternary bedrock in Iceland

14:15 **L. Xie**, E.Yan & L. Long

Research on Sensitivity of Reservoir Landslide Disaster-forming Factors in There-Gorge Based on Grey Correlation Method

14:30	**P. Migon** *Large-scale slope remodelling by mass movements – Kamienne Mts, Sudetes (SW Poland)*
14:45	**M. Rouai** & Y. El Kharim *On Self-Organized Criticality of landslides in Rif Mountains (Morocco)*
15:00	**M. Basharat**, J. Rohn, M. Rustam Khan & Y. Srafraz *The Jhelum Fault and its relations to active mass movements in the Northeast Himalayas of Pakistan*

Coffee break (15:15-15:45)

15:45-17:15 **Oral session 4: Rapid rock slope failures**
(Chairs: Strom, A. & Agliardi, F.)

15:45	D. Masera, M. Giardino, L. Perotti, A.V. Poschinger, N. Calhoun & **J. J. Clague** *Application of geomorphology and geomatics in the study of the Flims and Tamins landslides, Switzerland*
16:00	**A. Blais-Stevens**, M. Geertsema, J.W. Schwab & Th. W.J. van Asch *A complex landslide triggered in an Eocene volcanic-volcaniclastic succession along Sutherland River, British Columbia, Canada*
16:15	**I. Penna**, A. Abellán, A. Pedrazzini, S. Daicz, M.-H. Derron, L. Fauqué, & M. Jaboyedoff *The role of tectonics on the occurrence of the Potrero de Leyes rock avalanche (Pampeanas ranges)*
16:30	**D. Jarman**, S. McColl, S. Cook & S. Hoon *Can valley rebound after concentrated erosion of bedrock drive montane rock slope failure? The Glen Roy (Scotland) geodetic datum.*
16:45	**M. Ostermann** *The Brenner Pass Rockslide Cluster - Characterisation, Dating and Geomorphologic Impacts*
17:00	P. Frattini, **G.B. Crosta**, E. Valbuzzi & F. Agliardi *Inventory of large landslides and rock avalanches in the European Alps*

Tuesday September 9, 2014

8:30-10:45 **Oral session 5: Monitoring & modelling of rock slopes**
(Chairs: Blikra, L.H. & Yugsi Molina, F.X.)

8:30 **W. Xiang** & L. Lang

Comprehensive field test site in Huangtupo Landslides

8:45 **F. Dammeier**, C. Hammer, J.R. Moore, F. Haslinger & S. Loew

Automatic detection of rockslides in continuous seismic data

9:00 **L. Grämiger**, J.R. Moore, V. Gischig & S. Loew

Beyond debuttressing: Thermo-hydro-mechanical stresses and induced rock mass damage during repeat glacial cycles

9:15 **P. Tábořík**, J. Stemberk, F. Hartvich, J. Blahůt & T. Belov

Long-term monitoring of the active slope deformation Cerenište using a complex of geophysical and geotechnical techniques (Czech Republic)

10:00 **Q. Tan**

Stability analysis and prediction on Yanwanqiao west slope, Three Gorges Reservoir Region based on cut-through ratio study of the sliding surface

10:15 **P. Liščák** & M. Fraštia

Kraľovany Rockslide - its tectonical predisposition and kinematics

10:30 **B. Nilsen**

Challenges of rock slope stability analysis according to Eurocode 7, with particular emphasis on limit equilibrium analysis

Coffee break (10:40-11:15)

11:15-12:45 continued **Oral session 5: Monitoring & modelling of rock slopes,**
(Chairs: Loew, S. & Oppikofer, T.)

11:15 **J.-P. Malet**, J. Gance, C. Doubre, A. Stumpf, J. Travelletti, D. Raucoules & M. de Michelle

Estimation of landslide slip surface geometry and rheology from multiple optical and SAR sensors

11:30	**R. Schlögel**, C. Doubre, J-P. Malet & T. Lebourg *Kinematic of Deep-seated La Clapière Landslide (Tinée Valley, French Alps) monitored by DInSAR and ground-based measurements*
11:45	**T. R. Lauknes**, J. F. Dehls, L. H. Blikra, L. Rouyet, H. Ø. Eriksen, Y. Larsen & T. Grydeland *InSAR monitoring of the Jettan Rockslide in northern Norway using high-resolution Radarsat-2 and TerraSAR-X satellite data*
12:00	**L. Rouyet**, L. Kristensen, M.-H. Derron, C. Michoud, L. H. Blikra, M. Jaboyedoff & T. R. Lauknes *Monitoring and characterization of Mannen/Børa rock slope (western Norway) using GB-InSAR and satellite InSAR*
12:15	**A. Mathieu**, J.-P. Malet & J. Travelletti *Characterization of rockslide dynamics by the joint analysis of LiDAR and stereo-photogrammetric point clouds*
12:30	**R.L. Hermanns**, J. Gosse, T.F. Redfield, T. Oppikofer & T. Eiken *Understanding long-term gravitational rock slope deformation by means of terrestrial cosmogenic nuclide dating*

Lunch break (12:45-13:45)

13:45-15:00 Slope Tectonics Poster session

M. Bacenetti, P. Cadoppi, M. Morelli, M. Giardino, L. Perotti & G. Perrone

Recent tectonic activity vs. evolution of mountain relief in the Germanasca Valley (Cottian Alps, NW-Italy)

I. Baroň, M. Kernstocková & W. Gasper
Reconstruction of a paleostress field of a mudslide

J. Cai, R. Tang & L. Xie

Controlling Factors Analysis and Mechanism Research of Toppling Deformation for Homogeneous Equal Thickness Anti-dip Layered Rock Slopes

S. Cao, X. Wei, L. Lang & J. Wang

Structural features of No.1 adjacent to river sliding debris of Huangtupo Landslides

G.B. Crosta, P. Frattini, F. Pena Reyes & F. Riva

Control of large slope instability on surface and subsurface hydrology

G.B. Crosta & R.L. Hermanns

Third look at suspect mega rockslide called the Lluta collapse, N-Chile

D. Jarman & M. Ostermann

Koefels landslide complex, Oetztal, Austria - a twin-source interpretation

O. Krasny, H. Semíková & P. Kucera

Seismo-Acoustic monitoring of hydraulic fracturing laboratory tests of rock samples

C. Li, S. Liao & J. Wang

The sensibility analysis of the maximum value of PGA amplification factor

S. Lu, S. Liao & J. Wang

The research of effects of discontinuity plan factors on amplification coefficient of peak ground acceleration

G. Sandøy, T. Oppikofer & B. Nilsen

Back-analysis of the 1756 Tjellefonna rockslide (western Norway)

R. Tang, E. Yan & J. Cai

Formation mechanism of hydraulic driven bedding landslide - A case study in Xintang landslide

T. Wen, X. Yi & Q. Tan

Energy change law of sandstone under loading and unloading conditions in high stress area, and its damage analysis

X. Yi & R. Yong

Distribution of lateral force acting on landslide stabilizing piles under different morphological characteristics

Y. Zhang, H. Tang & C. Li

Second-order Dynamic System Model for Landslide Based on Physical Model Test

Coffee break (14:30-15:00)

15:00-16:15 Oral session 6: Reactivation of pre-existing structures & formation of new structures in rock slopes

(Chairs: Chigira, M. & Baron, I.)

15:00	**S. Loew**, M. Ziegler & S. Bucher *Exfoliation Fracturing in the Central Aar Granite (Switzerland)*
15:15	**M. Böhme**, H.S.S. Bunkholt, J.F. Dehls, T. Eiken, H.Ø. Eriksen, J. Gosse, R.L. Hermanns, L. Kristensen, F.X. Yugsi Molina & T. Oppikofer *Understanding the deformation mechanism of the unstable rock slope Gamanjunni 3, northern Norway, for hazard and risk assessment*
15:30	**F. Humair**, J.-L. Epard, M. Jaboyedoff, D. Pana, A. Pedrazzini *The role of tectonics as influencing factors to gravitational slope deformations in Foreland Fold and Thrust Belts (FFTB): examples from the Jura Mountain belt and the Livingstone Range anticlinorium*
16:45	**L.H. Blikra** & I. Skrede *Structural control of large rockslides: Does surface data give us the correct picture?*
16:00	**M. Jaboyedoff**, M.-H. Derron & I. Penna *Beyond Slope Tectonics*

Discussion and summary (16:15-)

ABSTRACTS

Inherited and active tectonic controls on the Piz Dora sackung system (Val Mustair)

F. Agliardi[1], M. Barbarano[1], G.B. Crosta[1], F. Riva[1] & A. Zanchi[1]

[1] University of Milano-Bicocca, Department of Earth and Environmental Sciences, Piazza della Scienza 4, Milano, Italy, federico.agliardi@unimib.it

Deep-Seated Gravitational Slope Deformations (DSGSD) are widespread in the European Alps, and affect valley slopes characterised by high relief, carved by glaciers and rivers in moderately strong rock masses with important structural controls. While the passive structural controls of brittle structures on DSGSD have been widely studied, the influences of inherited structures related to ductile tectonic deformation are less clear. Moreover, little is known about active tectonic controls on DSGSD in low-magnitude seismicity settings as the axial European Alps. We analysed the Piz Dora DSGSD by integrating field surveys, 3D structural analysis and numerical modelling. The DSGSD affects meta-sandstones, meta-conglomerates and phyllites of the Austroalpine S-Charl cover nappe, involved in a slope-scale WNW trending closed anticline fold. The area, actively uplifting at rate >1.4 mm/a, is characterised by seismic activity with maximum Mw>5 and experienced extensive glaciation during the LGM. The slope is affected by spectacular gravitational morpho-structures (double-crested ridges, scarps and counterscarps) associated to the deep-seated sliding of ca. 1.85 km^3 of rock mass along a basal shear zone up to 300 m deep. The DSGSD deformed recent periglacial features and partially collapsed. We set up a series of continuum-based (Finite-Element) and discontinuum (Distinct Element) numerical models, accounting for the geological structure of the slope and considering different conditions in terms of: a) rock mass constitutive models; b) active tectonic stress field (from structural and seismotectonic data); c) seismic loads. Model results suggest that the inherited folded structure prepared conditions favourable to instability, whereas earthquake shaking and related damage likely enhanced the triggering role of postglacial debuttressing, outlining the importance of active tectonic conditioning in relevant alpine sectors.

Recent tectonic activity vs. evolution of mountain relief in the Germanasca Valley (Cottian Alps, NW-Italy)

M. Bacenetti[1, 3], P. Cadoppi[1, 3], M. Morelli[2], M. Giardino[1, 3], L. Perotti[1, 3] & G. Perrone[1]
[1] Department of Earth Sciences, University of Torino, via Valperga Caluso 35, Torino Italy, marco.bacenetti@unito.it
[2] ARPA Piemonte, via Pio VII 9, 10135 Torino, Italy, michele.morelli@arpa.piemonte.it
[3] NatRisk Interdepartmental Research Centre, University of Torino

Possible interactions between recent tectonic activity and the evolution of mountain relief have been investigated at the regional (1:50,000) and local (1:5,000) scale in the Germanasca Valley (Cottian Alps, NW-Italy) through an integrated, multidisciplinary approach combining Structural analysis, Quaternary Geology, Geomorphology and PSInSAR data.

This area is affected by a diffuse low- to moderate- seismicity (Ml<5) characterized by shallow hypocenters (< 20 Km depth). Available apatite fission track data indicate that this sector reached shallow crustal levels, where brittle deformation mechanisms prevail since Late Oligocene times. Historical earthquakes (e.g. Prarostino's earthquakes, 1808 MS=5.5; Cumiana's earthquakes, 1980 Ml=4.8) caused both material and social damages in the area.

Geomorphology and morphotectonic analyses have been performed using field mapping activities, digital orthophotos (AGEA Orthophoto 2009), aerial stereo couples and DEMs (LiDAR5x5 meters, Regione Piemonte 2009). All collected data have been included in a GIS project, and then elaborated in a morphotectonic map. Preliminary interpretation shows strong geomorphological anomalies affecting hydrographic network, slope morphology and distribution of Quaternary deposits probable sign of a significant tectonic uplift of the area.

A lineament geometry analysis has been conducted by using TerraExplorer® Software. Statistical analysis of lineament trend individualized three sets of tectonic features: Ln1 (N0° - N30°E), Ln2 (N50° - N70°E), Ln3 (N80° - N100°E).

Application of Permanent Scatterers Synthetic Aperture Radar Interferometry (PSInSAR) provided high-resolution assessment of surface deformations over a wide region of weak uplift. We resolved vertical and horizontal motion in the area. Results have been compared with geological, geomorphological and morphotectonic field data offering interpretation keys to the present-day tectonic activity and the geomorphological evolution of the area.

Gravitational slope deformation triggered by a tectonic movement: first direct observations from the Emmerberg and Eisenstein Caves (Lower Austria)

I. Baroň[1], L. Plan[1], B. Grasemann[2], I. Mitrović[2], J. Blahůt[3] & J. Stemberk[3]

[1] Natural History Museum, Burgring 7, 1030 Vienna, Austria, ivo.baron@nhm-wien.ac.at, lukas.plan@nhm-wien.ac.at

[2] Department of Geodynamics and Sedimentology, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria, bernhard.grasemann@univie.ac.at, ivanka.mitrovic@univie.ac.at

[3] Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, V Holešovičkách 94/41, 182 09 Praha, Czech Republic, blahut@irsm.cas.cz, Stemberk@irsm.cas.cz

Studies on gravitational mass movements triggered by neotectonic activity mostly limit consideration to the effect of seismic waves; direct effect of tectonic displacements along individual faults has been undescribed in the literature so far. Here we present our first observation of displacement along neotectonic faults in the southern Vienna Basin – a Neogene pull-apart-structure at the junction with the left-lateral Salzach-Ennstal-Mariazell-Puchberg fault system (SEMP). The tectonic movements were measured by the TM71 crack gauge with automated data-reading frequency once per day. The crack gauge relies on the mechanical interference between two optical grids and it measures displacements of two blocks in 3D including rotations with sensitivity of 50 – 12.5 μm in all three space coordinates of displacement, and 3.2 10^{-4} rad in angular deviations of the two joint planes. The TM71 devices were installed in the Emmerberg and Eisenstein caves, about 15 and 30 m below the ground surface, respectively. The Emmerberg Cave is a 150-m-long karst cave which developed in Triassic Wetterstein limestone at a crest of the Fischauer Hills; its remotest gallery has been dissected by a sinistral strike-slip fault with an offset of 23 mm and can be associated to the SEMP. The Eisenstein Cave is situated at the opposite slope of the Fischauer Hills facing the tectonically active Vienna Basin near its marginal fault. The 2.3-km-long Eisenstein cave is developed in limestone, breccia and sandstone of Miocene age; it has a crevice character with N-S general trend and some hydrothermal alteration. The interpretation of the digital terrain models obtained by LIDAR shows that the cave is associated with the detachment zone of a deep-seated mass movement superimposed on the Vienna Basin marginal fault. On November 24th/25th 2013, the first event was recorded in the Emmerberg Cave. The SEMP-related fault accommodated 0.02 mm compression and 0.01 mm sinistral slip of tectonic origin. This tectonic impulse triggered a subsequent gravitational mass movement in the Emmerberg Cave, and probably in the Eisenstein Cave as well. We observed an activation of the monitored crack in the Eisenstein Cave from November 25th to 28th with total displacement of 0.05 mm. During this event, the eastern block subsided about 0.04 mm towards the Vienna Basin, rotated about 0.015° along the vertical plane and the crack opened about 0.03 mm with a minor dextral component. The fault in the Emmerberg cave experienced a subsequent gravitational relaxation on December, 2nd/3rd 2013, when the joint opened about 0.04 mm and the southern block subsided 0.01 mm towards the valley. However, the original sinistral tectonic displacement kept irreversible. These first tangible data approved high reasonability of such precise measurements for studying the active tectonic movements and their effect on triggering gravitational mass movements.

Reconstruction of a paleostress field of a mudslide

I. Baroň[1], .Kernstocková[2] & W. Gasperl[3]

[1] Museum of Natural History, Burgring 7, 1030 Vienna, Austria, ivo.baron@nhm-wien.ac.at

[2] Masaryk University, Kotlářská 2, Brno, Czech Republic, mujstock@email.cz

[3] Austrian Service for Torrent and Avalanche Control, Schmidtorstraße 2/II 4020 Linz, Austria, wolfgang.gasperl@die-wildbach.at

Paleostress analysis of fault slip data is a useful approach of structural geology for reconstructing regional tectonic processes. In order to understand changes in stress field of moving mass at slope, this method has also been applied for rockslides, DSGSDs and other large gravitational slope failures, which produced faults with kinematic markers in rock. But application of the method to landslides in soft material (such as mud) is limited due to short durability of slip surfaces and kinematic markers. Here we present paleostress analysis of a complex mudslide in Pechgraben (Lower Austria) activated in June 2013 after another event of smaller scale upslope in November 2012. The mudslide system has developed in Ultrahelvetic shale and clayey colluvium at the foot of the Northern Calcareous Alps, and slip surfaces with kinematic markers were shortly present. The moving area was 0.848 km² with an average depth of 8 m. Thanks to the field inspection exactly during the active motion we were able to measure totally 73 slip surfaces at 9 locations of the landslide body. We used a multiple inverse method in 9D space and the data were processed by a non-commercial code MARK2010. The results illustrate paleostress states and stress distribution within individual parts of the mudslide; we reconstructed compressional, extensional and strike-slip stress regimes, and also regimes with tilted axes of principal stress. The results are coherent with complex evolution of the sliding mass interpreted from differential LiDAR digital terrain models. This compatibility of results validates usability of the multiple inversion method for paleostress analysis of gravitational slope failures also in soft material.

The Jhelum Fault and its relations to active mass movements in the Northeast Himalayas of Pakistan

M. Basharat[1], J. Rohn[2], M. Rustam Khan[1]& Y. Srafraz[1]
[1]Institute of Geology, University of Azad Jammu and Kashmir, Muzaffarabad, Pakistan, basharatgeo@yahoo.com
[2] GeoZentrum Nordbayern, Friedrich-Alexander-University Erlangen-Nuremberg, Germany

Jhelum Fault truncates the structure along the western limb of the Hazara Kashmir Syntaxis from Balakot to Kohala, in the northeast Himalayas of Pakistan. Satellite imagery and field investigation reveals that the active mass movements in the area are associated along the Jhelum Fault. These mass movements were investigated according to the role of structural and tectonics relationship between the mass movements and the affected area. Therefore, mass movement inventory maps were prepared based on field investigation and satellite imagery. On the basis of detailed field work, the mass movements were classified into fall, slides and flow. The integration of topographic, lithological and structural information has been used to understand the geological, structural and tectonic relationship between the mass movements and the Jhelum Fault. The geological longitudinal profiles show the relation between the initiation, travel path and deposits of the active mass movements with respect to lithology, structure and faulting. The study suggests that the failure mode of these active mass movements were strongly controlled by the Jhelum Fault and lithological factors.

A complex landslide triggered in an Eocene volcanic volcaniclastic succession along Sutherland River, British Columbia, Canada

A. Blais-Stevens[1], M. Geertsema[2], J.W. Schwab[3] & Th. W.J. van Asch[4]

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8, Canada, ablais@nrcan.gc.ca

[2] BC Ministry of Forests, Lands, and Natural Resource Operations, 1044 5th Avenue, Prince George, British Columbia, V2L 5G4, Canada, marten.geertsema@gov.bc.ca

[3] PO Box 2525, Smithers, British Columbia, V0J 2N0, Canada, jwschwab51@gmail.com

[4] Department of Physical Geography, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, The Netherlands, T.W.J.vanAsch@uu.nl

On July 13, 2005 a complex rock slide-debris avalanche was initiated in a succession of sub-horizontal competent mafic basalts (Endako Formation) capping weaker felsic volcanic and volcaniclastic rocks (Ootsa Lake Formation) of Eocene age. This large landslide occurred within subdued topography of the Nechako Plateau in north central British Columbia near Sutherland River, 40 km west of Fort St. James. With a travel angle of 11°, the rock slide portion of the landslide measured about 550 m and the debris avalanche portion, which bifurcated into two lobes, measured another 900 m giving a total distance of roughly 1.5 km. The volume of the landslide was estimated at approximately 3 Mm^3. Above normal precipitation in the months preceding the event may have been a contributing factor in triggering the landslide. Several landslides have been observed in similar volcanic successions worldwide including southern British Columbia. Some common characteristics of these landslides are: structurally undisturbed with minor warping; horizontal to sub-horizontal bedding; arcuate head scarp; steep joints; debris consisting of intact blocks; basaltic lavas associated with intravolcanic and basal volcaniclastic sediments; volcaniclastics containing smectite (expandable clay mineral); and fossils and lignite within the volcaniclastics. The Sutherland landslide is one of many large landslides that have occurred in recent years in northern British Columbia. At least eight other large landslides have been triggered in volcanic rocks within the Nechako plateau.

Structural control of large rockslides: Does surface data give us the correct picture?

L.H. Blikra[1,2,3] & I. Skrede[1]
[1] Åknes/Tafjord Beredskap, Ødegårdsveien 93, N-6200 Stranda, lhb@aknes.no
[2] Norwegian Water and Energy Directorate, Vestre Rosten 81, N-7075 Tiller, Norway
[3] UiT The Arctic University of Norway, Dramsveien 201, N-9037 Tromsø, Norway

Rockslides are well-known to be controlled by the orientation and dip of fractures, foliation and faults. The detailed understanding of the structural control is the basis for the interpreted location of sliding planes and release fractures, which again are critical for analysis regarding stability, geometry, volume, run-out distance and related secondary effects like landslide dams and tsunamis.

Many rockslides are studied solely by surface geological mapping and remote sensing (LIDAR, photogrammetry), or at least with limited subsurface data. The structural control of the sliding surface and other release structures is thus frequently interpreted on the basis of surface structures.

Experience from detailed surface and subsurface investigations of several large rockslides in Norway are here used as example to evaluate if surface data gives sufficient knowledge to interpret the structural control. The discussion is based on surface and sub-surface data from the Åknes and Mannen rockslide in western Norway, and the Jettan rockslide in northern Norway. The surface data used include structural analyses, geomorphological analyses and kinematic data while the sub-surface data used is from boreholes including drill cores, structural data from televiewer and kinematics from displacement sensors. Stability modelling will also be used for the discussion.

Understanding the deformation mechanism of the unstable rock slope Gamanjunni 3, northern Norway, for hazard and risk assessment

M. Böhme[1], H.S.S. Bunkholt[2], J. Dehls[1], T. Eiken[3], H.Ø. Eriksen[4], J. Gosse[5], R.L. Hermanns[1], L. Kristensen[6], F.X. Yugsi Molina[1] & T. Oppikofer[1]

[1] Geological Survey of Norway, P.O.Box 6315 Sluppen, 7491 Trondheim, Norway, martina.bohme@ngu.no

[2] Statoil ASA, Strandvegen 4, 7500 Stjørdal, Norway

[3] University of Oslo, Department of Geosciences, P.O.Box 107 Blindern, 0316 Oslo, Norway

[4] Norut, P.O.Box 6434, Forskningsparken, 9294 Tromsø, Norway

[5] Dalhousie University, Halifax, Canada

[6] Åknes/Tafjord Beredskap IKS, Ødegårdsvegen 176, 6200 Stranda, Norway

Gamanjunni 3 is an unstable rock slope in Manndal Valley, northern Norway, that shows active deformation. It extends from the top of the slope at ~1200 m asl down to ~600 m asl and its maximum volume is estimated with 15 million m³. Until present a vertical downward displacement of ~100 m is observable. The unstable rock slope displays a high degree of internal fracturing and a high rockfall activity at its front and the southern lateral limit.

Field observations indicate that this unstable rock slope consists of different compartments. Structural mapping and analyses of terrestrial laser scans identified many discontinuities. However, none of those may act as a basal failure surface based on kinematical analysis. Also geophysical investigations (ground-based resistivity) do not indicate any clear structure that may form a basal limit. Different displacement measurement systems (differential GNSS, terrestrial laser scanning, ground- and satellite-based InSAR) show yearly average displacement of up to 4-5 cm. However, the displacement rate is not distributed equally over the entire unstable rock slope, but decreasing towards its toe. Furthermore, preliminary terrestrial cosmogenic nuclide dates, sampled on a profile along the head scarp, indicate that displacement commenced 6000 years ago. The average displacement rate during these 6000 years was with 1.3-2.5 cm/yr slower than measured by displacement measurement systems.

All available data and results from different analysis are integrated in order to understand the failure mechanism of Gamanjunni 3. We finally propose a compound biplanar rock slope deformation based on the observed displacement pattern, morphology and structures. Different scenarios are defined based on morphology and displacement pattern. Volumes and potential run-out areas are estimated for each scenario in order to define the risk that is posed to the local inhabitants.

Distribution of landslide volume in tectonically-controlled mountain landscapes

F. Bucci[1], M. Santangelo, M. Cardinali, F. Fiorucci & F. Guzzetti
[1] CNR-IRPI, Via Madonna Alta 126, 06128, Perugia, Italy, francesco.bucci@irpi.cnr.it

Despite faults are known to influence rock slope stability, the interactions between fault zones and slope deformations are poorly documented in regional scale studies, and their relationships remain poorly understood. In this work, we define the possible role of Quaternary faults in favouring slope instability in a tectonically-controlled landscape. We analyse the distribution of landslides in the Peloritani Mountains, NE Sicily, Southern Italy, a tectonically active region where landslides are abundant. For the purpose, we analyse a set of thematic layers, including (i) a detailed landslide inventory map prepared through the visual inspection of aerial photographs of different vintages, (ii) a map of recent faults and associated triangular facets, also identified through the visual interpretation of aerial photographs, (iii) geological and geomorphological data, and (iv) maps showing morphometric indices obtained from a 2 m × 2 m DEM. Geomorphological and photo-geological mapping revealed a spatial association between the gravitational displacements and the tectonically-controlled landscape modifications conditioned by the presence of faults crossing the mountain slopes. We find that the total landslide volume is dominated by a few large landslides clustered where high local relief and main recent fault segments coexist. Based on our findings, we hypothesize that the distribution of landslide volume is a proxy for the mid- to long-term activity of the faults. Our results highlight the role of the large-scale slope failures on the geomorphological evolution of a tectonically active area, and suggest a positive feedback between tectonic and gravitational deformations in active mountain belts.

Controlling Factors Analysis and Mechanism Research of Toppling Deformation for Homogeneous Equal Thickness Anti-dip Layered Rock Slopes

J. Cai [1], R. Tang[1] & L. Xie[1]
[1] College of Engineering China University of Geosciences, No.388 Lumo Road, Wuhan, China, 619242601@qq.com

Toppling deformation mechanism of anti-dip rock slopes is a difficulty in research of rock slope deformation mechanism, and it is a feasible method to study the toppling deformation of anti-dip layered rock slopes by using “limit equilibrium method” based on “cantilever beam theory”, which not only pay attention to deformation process but also focus on the mechanics analysis. Based on the research status at home and abroad, taking an anti-dip bank slope of Zhongliang Reservoir at Chongqing as an example, the size of the area of anti-dip slope deformation and failure, the distribution and area size of the rock layer which deform in the form of toppling, the amount of deformation (the bending deformation amount that relative to the original location), as well as the difficulty degree of deformation are selected as the evaluation indicators for the extent of the toppling deformation. Taking the of the anti-dip slope mechanics analysis model (cantilever beam limit equilibrium model) as the main model, supplemented by the corresponding numerical model, the nature role and interaction of the master factors(strata dip angle, slope dip angle, slope height, thickness, interlaminar mechanical parameters, strata mechanical parameters) of anti-dip slope are revealed through factor analysis and mechanical mechanism analysis. Results showed that: toppling deformation depends on the component force on the rock which is to produce bending deformation, the length of the possible bending rock and resistance to bending effects or flexural capacity. The master factors affect the toppling deformation by means of affecting the three variables above. The research achievements have theoretical significance and application value to the stability evaluation and prevention of anti-dip layered rock slopes.

Structural features of No.1 adjacent to river sliding debris of Huangtupo Landslides

S. Cao[1], X. Wei [1,2], L. Lang[1] & J. Wang[2]

[1] Department of Geotechnical Engineering and Geological Engineering, Faculty of Engineering, China University of Geosciences, No. 388 Lumo Road 430074, Wuhan, China, caoshen0108@gmail.com, xiangwei@cug.edu.cn, qqllz2008@126.com,

[2] Three Gorges Research Center of Geo-hazards, Ministry of Education, No. 388 Lumo Road 430074, Wuhan, China, 250824225@qq.com

Due to bulky volume, complicated geological structure and great potential hazard, Huangtupo Landslides in Three Gorges Reservoir area has been being the study focus of landslides. Many researchers did a lot of investigations on its geological conditions and formation. However, the geological structural features and formation mechanism of Huangtupo Landslide have not been completely exposed because of the limited geological exploration data. To in depth understand its internal geological structural characteristic and formation, we study No.1 adjacent to river sliding debris considered as one of the main parts of Huangtupo Landslides, based on geological information gained from underground tunnels excavated and geological boreholes. The main tunnel consisting of five branch tunnels goes through No.1 adjacent to river sliding debris, whereas the five branch tunnels go along sliding zones. They totally uncover four sliding zones at different locations. Besides, 8 addition boreholes go along the probable sliding zones. According to the geological data gained from underground caves and boreholes, we found that weak intercalated layers developed widely in the slide bed of No.1 adjacent to river sliding debris. There are multilayers sliding zones in No.1 adjacent to river sliding debris and the sliding zone is not a complete and continuous surface area. Besides, the current study results would exam and modify the previous theoretical investigations on formation mechanism of Huangtupo Landslides.

Prediction and stability assessment of potential sites of catastrophic landslides

M. Chigira[1], T. Sakashima[2], J. Minagawa[2], A. Funayama[2] and K. Shibuya[3]

[1] Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji 611-0011, chigira@slope.dpri.kyoto-u.ac.jp

[2] Pacific Consultants Co., Ltd., Nishishinjuku Sumitomo Fudousan Shinjuku Oak Tower (22F) Shinjuku-ku, Tokyo 163-6027 Japan, toshihiko.sakashima@tk.pacific.co.jp, jun.minagawa@tk.pacific.co.jp, atsushi.funayama@tk.pacific.co.jp

[3] Aero Asahi Corporation, Minamidai 3-1-1, Kawagoe 350-1165, kenichi-shibuya@aeroasahi.co.jp

Recently occurred deep-seated catastrophic landslides, including 39 rock avalanches induced by 2011 typhoon Talas in Japan, revealed that most of catastrophic landslides are preceded by deep-seated gravitational slope deformation that can be identified using LiDAR DEMs. We examine geomorphic features of gravitational slope deformations and summarizes the methodology of predicting potential sites of catastrophic landslides.

Irregularly shaped bumpy slope is typically made when incipient sliding zones are being made in a rock body with complex discontinuities like broken beds or mixed rocks. Only this topography does not suggest the high probability of catastrophic failure, but additional small scarps upslope and failures downslope may suggest high probability.

Symmetric alignment of linear depressions on both sides of a ridge suggests lateral spreading with the settlement of the ridge top, which does not likely develop to catastrophic failure. Linear depressions and wrinkles developed on one side of a ridge are generally made by flexural toppling. This type is self-stabilizing deformation, but when downslope-facing eyebrow scarps are made upslope and lower part of the slope is failed, catastrophic failure likely occur. Ridge-top depressions, when connected to hollows on both sides of a deformed area, catastrophic failure are also likely occur.

Large head scarps or ridge top depressions on an under-dip cataclinal slope suggest buckling deformation, which may be stable when a competent rock layer exists or deformation extent is less, but when the deformation progresses further and lower slope is failed, the probability of catastrophic failure becomes high.

Large head scarps or ridge top depressions on an over-dip cataclinal slope suggest sliding in a strict sense with a mature and continuous sliding zone. Such a landslide may continue slow movement without catastrophic failure, but when the foot is cut by failure, it may develop to catastrophic failure.

Control of large slope instability on surface and subsurface hydrology

G.B. Crosta[1], P. Frattini[1], F. Pena Reyes[1] & F. Riva[1]

[1] Dept. Earth and Environmental Sciences, University of Milano-Bicocca, p.zza della Scienza 4, 20126 Milano, Italy

Large slope instabilities, such as DSGSD and rockslides, can significantly control the surface and subsurface hydrology at the slope scale. In fact, morphostructures (scarps, counter-scarps and trenches) parallel to the slope direction affect the surface water runoff, directing it transversal to the slope dip, and favour its percolation within the slope through the more conductive materials aligned with the trench. These processes control the spatial distribution of springs, the development of the drainage network, and the slope hydrochemistry, locally controlling the solute transport and circulation.

In this contribution, we study the control of DSGSD phenomena in the upper Valtellina (Central European Alps, Northern Italy), where 29 DSGSDs have been mapped on an area of about 900 km^2 (Crosta et al, 2013). By studying the spatial distribution of springs and river channels within and outside the DSGSDs, we observe a decrease of drainage density inside the large instabilities, and an increase in springs with a relatively high flow rate inside the DSGSD and at the lateral border. This suggests that DSGSDs favour the infiltration of superficial water and its concentration along preferential flow paths mainly controlled by morphostructures. Then, we collected historical chemical data (4070 samples from springs, wells, lakes, rivers and public fountains), and we performed four sampling campaigns, from summer 2012 to spring 2013, to complete a hydrologic year. During these campaigns, we measured the spring discharge, and we collected samples for chemical (anions and cations) and isotopic (tritium, deuterium and O18) analyses in almost 40 selected spring located throughout the study area. The analysis of these chemical data suggests that DSGSDs that favour a deeper circulation can increase the residential time, thus affecting the water hydrochemistry along the slope.

Third look at suspect mega rockslide called the Lluta collapse, N-Chile

G.B. Crosta[1] & R.L. Hermanns[2]

[1] Università degli Studi di Milano Bicocca, Dept. Of Earth and Environmental Sciences, Milano, Italy, Giovannibattista.crosta@unimib.it

[2] Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway, reginald.hermanns@ngu.no

Science is often driven by the desire to document the superlatives. A suspicious niche in the Andean escarpment between Arica and the western Cordillera visible on a 3-D Landsat image with 30-m resolution was mapped as a gravitational collapse with a size of 600 km^2 surface area and a magnitude of 50 km^3 volume (Wörner et al., 2002), that represented in the early 21st century one of earth´s largest rock slope failures. Strasser and Schlunegger (2005) remapped the suspicious niche and identified that the collapse, mainly characterized by a very thin deposit, had a maximum volume of 26 km^3 that was stored in the "run-out area" while the remaining volume was mobilized by secondary failures along a proposed but eroded away head scarp. Based on stratigraphic relations the authors determine a minimum age of 2.5 Ma for the main event. We remapped the area on high-resolution (1 m) satellite imagery and by field mapping focussing on the "run-out area" of the landslide. Our observations indicate that mapable units in the "run-out" area are continuous for several kilometres without deformation, however strongly obscured by multiple landslides 0.01 to 7.5 km^2 in size. The largest of those landslides overlies in direct contact a volcanic ash with a preliminary $^{40}Ar/^{39}Ar$ age of 19.5 Ma. This is younger than an $^{40}Ar/^{39}Ar$ age of a tephra layer sampled close to surface in the depocentre of what was mapped the "run-out" area providing a preliminary age of 20.7 Ma. The Lluta valley has the largest catchment of northernmost Chile and is thus the most mature valley in the region. The valleys to the south are smaller and valley flanks are covered by multiple landslides however individual landslides can more easily be mapped out. Thus we interpret the Lluta collapse as a landslide cluster made up of multiple landslides of various size overlying each other partially that has repeatedly undergone gravitational processes for the past 20 Ma at the intersection of the Andean escarpment and the incising Lluta valley. Their evolution and relationships are still open research subjects and require a careful analysis.

Automatic detection of rockslides in continuous seismic data

F. Dammeier[1], C. Hammer[2], J.R. Moore[3], F. Haslinger[4] & S. Loew[1]

[1] Department of Earth Sciences, ETH Zurich, Switzerland (dammeier@erdw.ethz.ch)

[2] Institute of Earth and Environmental Science, University of Potsdam, Germany (Conny.Hammer@geo.uni-potsdam.de)

[3] Department of Geology and Geophysics, University of Utah, USA (jeff.moore@utah.edu)

[4] Swiss Seismological Service, Switzerland (florian.haslinger@sed.ethz.ch)

Increasing settlement of alpine regions presents greater exposure to rock slope hazards, but a thorough investigation of these hazards in both time and space requires a complete catalogue of events. Due to the number and remoteness of rockslide events, however, comprehensive field assessment is not feasible. Seismic networks are often already in place in the relevant regions, and the seismic record may be used to remotely analyze rockslide signals. We employ a hidden Markov model (HMM) approach to automatically detect and classify seismic signals caused by rockslides. The seismic signals are first parameterized into a number of features describing different time-series, frequency and polarization attributes. The resulting feature vectors are then used to build HMMs for background seismicity as well as for rockslide events. Finally, we calculate the relative probability that an unknown seismic signal is best modelled by a rockslide HMM rather than a background noise HMM. In this way we can detect rockslide seismic signals embedded in continuous data for a variety of different rockslide types and volumes. Using two seismic stations in the Swiss Alps we created an event catalogue spanning several years, allowing us to draw first conclusions about rockslide distribution and timing. This may enable us to further investigate rockslide preconditions and triggers. Apart from basic research, this method may also be included in automatic earthquake processing routines. If rockslides are detectable within a few minutes of occurrence, it can enable timely mitigation of secondary hazards such as lake formation behind large new deposits.

Morpho-structural evolution of slope-to-valley systems and related implications on slope-scale gravitational processes: new results from the Mt. Genzana case history (central Apennines, Italy)

M. Della Seta[1], C. Esposito[1], S. Martino[1] & G. Scarascia Mugnozza[1]

[1] "Sapienza" University of Rome – Department of Earth Sciences, P.le A. Moro 5, Rome, Italy, marta.dellaseta@uniroma1.it, carlo.esposito@uniroma1.it, salvatore.martino@uniroma1.it gabriele.scarascia mugnozza@uniroma1.it

This abstract is intended to point out the advances in the research project aimed at constraining and framing in the Quaternary morpho-structural evolution a slope-scale gravitational process featured by DSGSD-related landforms and a major rockslide scar affecting the western slope of Mt. Genzana ridge (central Apennines). For this case history we previously proposed a preliminary conceptual evolutionary model that, also based on the experiences from other case histories in the central Apennines, was aimed at highlighting the relationships between inherited geological-structural setting and Quaternary morpho-evolutionary dynamics in the onset of DSGSD processes until to paroxysmal phases (i.e. occurrence of massive rock slope failures).

The previous conceptual evolutionary model has been strengthened and detailed by means of morphometric analyses that allowed us to recognize at least 7 relict surfaces suspended at different elevations above the present base level. Such surfaces have been indirectly dated according to available bibliographic data. The morphometric analysis allowed us to reconstruct the main morpho-evolutionary stages of the slope-to-valley system in terms of relief energy variations and related uplift rates. These results were the basis to design and perform a sequential numerical analysis that took into account:

- a detailed engineering-geology model that benefited of detailed geomechanical surveys and laboratory tests on rock matrix samples. According to an equivalent continuum approach, different litho-technical units were identified along the slope section, also on the basis of the position with respect to main tectonic elements;
- the geometrical and related energy relief variations over time which affected the slope-to-valley system during the Quaternary, as revealed by the constrained morpho-evolutionary model;
- the geodynamic stress regime variations connected with the Quaternary tectonic activity;
- the time-dependent behaviour of the rock mass.

As a result, it was possible to back-analyse the observed DSGSD process from its onset up to the occurrence of localized massive rock slope failures. The results of modelling:

- highlighted the relevant role of the inherited structural pattern in identifying the preferential strain concentration zones and failure surfaces;
- pointed out the importance of rock mass creep during the steady states of the morpho-evolution;
- confirmed the hypothesis that the Scanno rock-avalanche scar is the result of two separate failure events, as a first landslide involved the lower part of the slope and favoured a subsequent failure in the upper part of the slope;
- allowed us to assess the residual risk in terms of stress-strain conditions affecting the analysed slope section at present.

Inventory of large landslides and rock avalanches in the European Alps

P. Frattini[1], G.B. Crosta[1], , E. Valbuzzi[1] & F. Agliardi[1]

[1] Dept. Earth and Environmental Sciences, University of Milano-Bicocca, p.zza della Scienza 4, 20126 Milano, Italy

We present an orogen scale inventory of large landslides (mainly rockslides) and rock avalanches a in the European Alps, which complement the orogen-scale inventory of DSGSD that has been recently presented for the Crosta et al (2013). The inventory includes over 1700 large landslides ranging in area between 0.1 and 17 km^2, and about 100 rock avalanches ranging between 0.09 and 15.5 km^2. The inventory covers an area of about 110,000 km^2 extending over the alpine territories of Italy, France, Switzerland, and Austria, and was prepared by using available satellite imagery (multi-temporal, Google Earth, Google, Inc.) and topographic data at different resolutions (DEMs from 1 m x 1m up to 20 m x 20 m for different areas). The inventory was validated against local or regional landslide inventories already available at different scales. Geometrical features and geomorphological parameters have been collected and related to the different phenomena and local settings in order to assess the control of local slope morphology on the occurrence and the geometry of these large instabilities. The frequency-area relationship for the mapped features is presented. The inventory shows that large landslides are widespread in the Alps with clustering in sectors of the orogen. Their spatial distribution has been analysed though bivariate and multivariate analysis (mainly Principal Component Analysis and Discriminant Analysis) against a variety of factors, including: lithology, proximity to tectonic structures, seismicity, uplift and exhumation rates, position within the mountain belt and along main and tributary valleys, slope morphometry (e.g. relief, elevation, gradient, etc.), ice thickness of glaciers during LGM, and mean annual rainfall. The analysis allowed a preliminary assessment of conditions favourable to the onset and development of large landslides. Finally, the distribution of large landslides and rock avalanches is compared with the distribution of DSGSD in the Alps.

Beyond debuttressing: Thermo-hydro-mechanical stresses and induced rock mass damage during repeat glacial cycles

L. Grämiger[1], J.R. Moore[2], V. Gischig[3] & S. Loew[4]

[1] *ETH Zurich, Geological Institute, Sonneggstrasse 5, Zurich, Switzerland, lorenz.graemiger@erdw.ethz.ch*

[2] *University of Utah, Geology & Geophysics, 115 South 1460 East, Salt Lake City, Utah, jeff.moore@utah.edu*

[3] *UBC Vancouver, Department of Earth, Ocean, & Atmospheric sciences, 2207 Main Mall, Canada, gischig@sed.ethz.ch*

[4] *ETH Zurich, Geological Institute, Sonneggstrasse 5, Zurich, Switzerland, simon.loew@erdw.ethz.ch*

Stress redistribution during successive glacial cycles generates elastic and inelastic deformations in alpine valley rock walls; creation of new fractures, propagation of slip along existing joints, as well as failure of intact rock bridges constitutes rock mass damage and conditions future slope instability. Here we explore the role of coupled thermo-hydro-mechanical (THM) stress changes in driving long-term progressive damage and conditioning paraglacial rock slope failure in a conceptualized glacier valley. We develop a 2D numerical model of THM stress changes, where each response mechanism is tied to the changing glacier ice extent and thickness, i.e. not only glacier loading, but also changes in bedrock temperatures and water pressure related to the glacier are considered. Thus, THM stress changes and resulting rock mass damage can be explored in both space and time. We use the distinct element code UDEC, creating a simplified fractured rock slope loosely based on the Aletsch glacier valley, Switzerland. We analyse cyclic THM damage processes and the resulting spatial and temporal damage distribution, along with their relation to Holocene glacier fluctuations. Furthermore, we compare thermal, hydraulic, and purely-mechanical driving forces of rock mass damage and evaluate their impact as preparatory factors of paraglacial rock slope instability. Our results lead to improved understanding of the rock mass response to glacial cycles and clarify coupled interactions driving rock mass damage.

Understanding long-term gravitational rock slope deformation by means of terrestrial cosmogenic nuclide dating

R.L. Hermanns[1], J. Gosse[2], T.F. Redfield[1], T. Oppikofer[1] & T. Eiken[3]
[1] Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway, reginald.hermanns@ngu.no
[2] Dalhousie University, Halifax, Canada
[3] University of Oslo, Oslo, Norway

Development of earth observation techniques such as differential Global Navigation Satellite Systems (dGNSS), terrestrial laser scanning (TLS) or radar interferometry (InSAR) made it possible in the past decades to measure yearly displacement rates in the range of centimetres and sub centimetres. Gravitationally driven slope deformation are measured in Norway and around the world on critical slopes with those techniques. However as the measurement period is so far short (up to a maximum of ca. a decade or two) the displacement rates determined are difficult to interpret as the long-term displacement rates since displacement initiation are unknown.

We apply terrestrial cosmogenic nuclide (TCN) dating on sliding surfaces exposed by rockslides in order to determine long-term displacement rates to compare them to present day velocities. We sampled sliding surfaces of currently active rockslides that have either failed at least once in prehistoric times or not yet undergone catastrophic failure. At two localities Oppstadhornet (a rockslide on an island in western Norway) and Skjeringahaugane (a rockslide within the inner fjord land in western Norway) sliding started right after deglaciation, 14 kyr and 10 kyr ago, respectively. The long-term displacement rates match short-term displacement rates measured with dGNSS, thus indicating constant conditions. At the Gamanjunni 3 site in northern Norway, TCN dating indicates that sliding has started 6 kyr ago with displacement rates ranging from 1.3 to 2.5 cm/yr until ca. 2 kyr ago (youngest sample). These velocities are significantly slower than present-day displacement rates of 4 to 5 cm/yr measured today by dGNSS, TLS and InSAR, indicating thus acceleration of displacements after ca. 2 kyr.

The role of tectonics as influencing factors to Gravitational Slope Deformation in Foreland Fold and Thrust Belts (FFTB): examples from the Jura Mountain belt (Switzerland) and the Livingstone Range anticlinorium (AB, Canada).

F. Humair[1], J.-L. Epard[1], M. Jaboyedoff[1], D. Pana[2], A. Pedrazzini[3]

[1] Institute of Earth Sciences (ISTE), Faculty of Geosciences and Environment, University of Lausanne, Switzerland.

[2] Alberta Geological Survey (AGS), Canada.

[3] Office of Environment, Republic and Canton of Jura, Switzerland.

Tectonic conditions are commonly ascribed as keys parameters controlling Gravitational Slope Deformations (GSD)' predisposing factors in many mountain belts worldwide.

With this contribution, we investigate the role played by tectonic settings on to the development of large GSD in FFTB, and specifically in two areas located in the Jura Mountains and the Alberta Foothills. Both are characterized by thin-skinned tectonic affecting carbonate rocks, by low metamorphism when present, by low neotectonic activity and by relatively low local relief.

We first focus on the specific analysis of two GSDs at each field site (field mapping, remote sensing, geomechanical modelling) to assess the effective impact of anticlines and related structures on the GSDs failure mechanism. In particular the predisposing factors are compared to the following indicators: structural settings (fold hinges, faults, thrusts, bedding attitude, persistent fracturing), rheological parameters (mechanical stratigraphy, weak vs. resistant lithologies), topographic and hydrometeorogical conditions (local relief, slope, drainage pattern, precipitations).

The predisposing factors are then expanded to regional scale and compared to GSDs inventories (75 in the Jura, 160 in the Livingstone Range) in order to interpret if GSDs spatial distribution can be generalizable and if it is restricted to these specific structural conditions, or if other causes must be taken into account to explain the GSD's development.

Preliminary results highlight a spatial clustering of GSD which are primarily affected by 1) the presence/absence of basal thrusts, 2) the geometry of folds (i.e. the bedding attitude), 3) their lithological properties and 4) the local relief.

The results are finally compared to existing results from other mountain belts (Alps, Andes) to discuss whether the tectonic context impacts similarly on GSD development in FFTB than in different tectonic settings.

Beyond slope tectonics

M. Jaboyedoff[1], M.-H. Derron[1] & I. Penna[1]

[1] Group of Risk Analysis – ISTE, University of Lausanne, Geopolis, Lausanne, Switzerland, michel.jaboyedoff@unil.ch

Slope mass movements produce structures, which were described in several cases, but only few have been interpreted in terms of deformation markers. In fact there exist similarities among classical tectonics structures and structures induced by slope processes. That is why slope tectonics has been defined; it is a way to point out the potentiality to interpret deformations induced by gravity at the slope level.

This work attempts to summarize all the structures that can be observed in landslides, involving from soft materials to hard rocks. For instance in earthflows the cracks show an “en echelon” pattern, while hard rock can present similar behaviour but also solid rotations (like garnets). Sensitive clays spreads display a style of deformation very similar to basin deformations. Such spreads also exist in some weak bedrock at the mountain scale.

As a final remark, it is clear from analogue models that depending on materials and the scale of observation, it is possible to reproduce similar geometries which validate the use of the term slope tectonics. In addition, such approach leads to the idea that strain controls failure and thus the amount of movements must be related to the size of the instability.

Can valley rebound after concentrated erosion of bedrock drive montane rock slope failure? The Glen Roy (Scotland) geodetic datum.

D. Jarman[1], S. McColl[2], S. Cook[3] & S. Hoon[3]
[1] Mountain Landform Research, Scotland. david.jarman914@virgin.net
[2] Massey University, New Zealand. s.t.mccoll@massey.ac.nz
[3] Manchester Metroplitan University. s.j.cook@mmu.ac.uk

Large-scale rock slope failure is a widespread phenomenon in many mountain ranges. While modelling and back analysis of specific RSF events can explain why and how they have occurred, the underlying drivers of montane RSF especially in glaciated contexts remain poorly understood. In particular there is no integrated model of all the stresses acting on a mountain ridge-slope-valley system. The concept of 'rebound' as an RSF driver has been mooted in landslide classifications, but has not been closely considered. The spatial incidence of RSF in the British mountains and elsewhere suggests an association with geomorphic contexts where rebound effects might be magnified by concentrated erosion of bedrock, for example in glacial breaches. One of the densest RSF clusters in Britain is in Glen Roy, Scotland, around a glacial breach some 500 m deep. Here a unique geodetic datum, the world-famous Parallel Roads (a sequence of ice-dammed lake shorelines) exceptionally permits calibration of the rebound effect. Precise levelling of these shorelines by J.B. Sissons identified a series of abrupt steps and tilts. This dataset has been reanalysed to show that all the dislocated segments are displaced upwards, and nearly all coincide with rock slope failures of slope deformation and landslip character. This result provides an input into a comprehensive slope stress model.

Koefels landslide complex, Oetztal, Austria - a twin-source interpretation

D. Jarman[1], M. Ostermann[2]
[1] Mountain Landform Research, Scotland. david.jarman914@virgin.net
[2] University of Innsbruck, Austria. marc.ostermann@uibk.ac.at

The Koefels/Niederthai landslide complex is one of the largest in the Alps, and has dammed Oetztal with a barrier some 3-400 m deep, cut by the Maurach gorge. Previous estimates of its total volume range between 2500 and 3200 M m^3. However a geomorphologically-reasonable reconstruction of the Fundus 'lost ridge', constrained by 'clonestamping' relief forms and gradients from adjacent terrain, only generates a source volume of 1700 M m^3 (including 30% bulking-up). A more extreme landform eminence could have been supported by the orthogneiss geology, but the available footprint limits scope for magnification. Anomalous terrain on the opposite (east) side of the valley at Niederthai suggests a 'lost mountain' source of up to 1300 M m^3 which would match the shortfall. Although the upper slopes this side are paragneiss, and the visible debris is orthogneiss, this can be reconciled. The current interpretation of one or more high-energy rock avalanches capable of crossing the deep glacial trough to terminate midway up the far side has no comparators in the European mountains, and is more typical of Himalayan relief. A twin-source account is more conservative, but clearly requires dynamic modelling and groundtruthing to establish a sequence of events, whether synchronous interdigitation or sequential.

Seismo-Acoustic monitoring of hydraulic fracturing laboratory tests of rock samples

O. Krasny[1], H. Semíková[2] & P. Kucera[1]
[1] ARCADIS CZ a.s., Geologická 4, Prague, Czech Republic, otakar.krasny@arcadis.cz , petr.kucera@arcadis.cz,
[2] ISATech s.r.o., Osadní 26, Prague, Czech Republic, hsemikova@isatech.cz

The paper describes the results of the acoustic monitoring of hydraulic fracturing tests of cubic rock samples which were realized within the 4-year research project STIROMAS which was carried out in the underground laboratory site of the research facility UEF Josef in the Czech Republic. Research was focused on different ways of stimulating the potential geothermal rock structures of HDR type using the technique of hydraulic fracturing. During the 3rd stage of the research project which was called the „macro-sample testing" several cubic rock samples of selected rock types were tested. Volumes of the samples were chosen to be in an interval 0.2 to 1.0 m^3.

The tests consisted of hydraulic fracturing of these monolithic blocks by pressurized working fluid which was lead to the core of each sample by prepared axial drill-hole. The tests main goal was to determine the hydraulic fracture strength (HFS) of each of the rock type depending on the various options of selected hydraulic pressure curve. The main parameter was usage of linear or pulse type of hydraulic pressure. Tests were also being monitored by a set of seismo-acoustic sensors of different frequency working intervals (main frequencies 0.5 Hz; 4.5 Hz and 1,2 kHz). Recorded seismo-acoustic impulses arising during the process of creating of new cracks in the rock samples were analyzed in relation to the geo-mechanical parameters of the different rock types. Geo-mechanical parameters of the individual rock types were assessed on the basis of an extensive file of rock mechanics laboratory tests.

Research project was supported by the Ministry of Industry and Trade of the Czech Republic during the project "Stimulation of rock massif to establish a fracture reservoir for capture of geothermal energy in the hot-dry-rock system" (Grant Number: FR-TI3/523).

InSAR monitoring of the Jettan Rockslide in northern Norway using high-resolution Radarsat-2 and TerraSAR-X satellite data

T. R. Lauknes[1], J. F. Dehls[2], L. H. Blikra[3], L. Rouyet[1], H. Ø. Eriksen[1], Y. Larsen[1] & T. Grydeland[1]
[1] Norut Northern Research Institute, Tromsø, Norway, tom.rune.lauknes@norut.no
[2] Geological Survey of Norway, Trondheim, Norway
[3] Åknes Tafjord Beredskap IKS, Stranda, Norway

Many rockslides are clustered east of the Lyngen fjord in Troms county, northern Norway. Among these, the Jettan rockslide at Nordnes is of particular interest due to the severe consequences should catastrophic failure occur.

In order to fully understand the kinematics and geometric configurations susceptible for sliding, it is imperative to obtain precise deformation measurements of potential unstable rock slopes. At the Jettan rockslide, an extensive in-situ deformation monitoring system has been installed, including extensometers and crack meters, tilt meters, lasers, permanent GPS stations and a weather station.

Extensive InSAR studies have been carried out in the area using ERS, Envisat ASAR, Radarsat-2 Fine and Ultrafine and TerraSAR-X stripmap images. Time series InSAR processing has been carried out using the short baselines subset (SBAS) and persistent scatterer (PSI) algorithms. Due to the long season of snow cover in Norway, the processing has only used summer/autumn scenes, leaving long gaps in the deformation time series. In order to partially offset this problem, a network of 8 corner reflectors has been installed, allowing us to measure deformation throughout the year.

Here, we present the results of the SBAS and PSI processing of the Radarsat-2 and TerraSAR-X datasets. These high-resolution datasets give us an improved understanding of the spatial deformation variability in the rockslide. We compare InSAR corner reflector results with in-situ measurements. Furthermore, we combine observations from both ascending and descending geometries, to decompose the total deformation into vertical and east/west directions. This allows us to extract more information about the true displacement vector, thereby increasing the interpretability of the displacement patterns.

Deep-seated slope deformations headscarps detection by a combination of geophysical techniques (Outer Western Carpathians)

J. Lenart[1], P. Táboříkˇ[2,3], T. Pánek[1], V. Blecha[2], O. Turský[1] & J. Vilhelm[2]

[1] Department of Physical Geography and Geoecology, Faculty of Science, University of Ostrava, Chittussiho 10, CZ 710 00, Ostrava – Slezská Ostrava, Czech Republic, jan.lenart@osu.cz

[2] Institute of Hydrogeology, Engineering Geology and Applied Geophysics, Faculty of Science, Charles University in Prague, Albertov 6, CZ 128 43 Praha 2, Czech Republic, petr.taborik@post.cz

[3] Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, V Holešovičkách 41, CZ 182 09, Praha 8, Czech Republic, petr.taborik@post.cz

Deep-seated gravitational slope deformations are among the widespread phenomena recorded in the area of the Outer Western Carpathians (Moravian-Silesian Beskydy Mts.). The presence of this phenomenon is expressed by the evolution of the typical processes (such as sackung, sliding) and landforms (crevice-type caves, headscarps, counter-slope scarps, slope-scarps depressions, double ridges). One of the most pronounced and well detectable landforms are just the headscarps. However, many of the headscarps are evolving within their initial stadium and their existence is hardly distinguishable – only as small slope steps, tension cracks or opened ridges in the terrain. These initial forms can originate also inside the previously gravitationally relocated rock blocks (during ancient slope movements), which are gradually affected by the consequential slow slope movement. This paper is concerned with the detection of the initial landslides headscarps arising in the incoherent flysch rocks (formed by the thick-bedded sandstones and thin-bedded shales) by using the combination of these geophysical techniques: electrical resistivity tomography (ERT), ground penetrating radar (GPR), seismic tomography (SRS) and microgravimetry (MVG). The accent is put on the applicability of the particular techniques with regard to their depth range, accuracy and potentiality to discern the subsurface structures. The results are demonstrated on the examples of two different areas: (1) The initial headscarp developing above the foregone ancient landslide, and (2) the initial headscarp developing on the top of the previously slided rock block.

The survey was supported by the University of Ostrava Foundation project SGS19/PřF/2014 and by the Charles University in Prague Foundation project GAUK no. 862213.

The sensibility analysis of the maximum value of PGA amplification factor

C. Li[1], S. Liao[1] & J. Wang[1]
[1] *Faculty of Engineering, China University of Geosciences (Wuhan), 388 Lumo Rd., Hongshan District, 430074 Wuhan, Hubei, China, hyi2010@sina.com*

Abstract: The study of dynamic response rules of block rock slop under seismic loading is quite important to slope dynamic stability analysis. Earthquake dynamic response of slope includes acceleration, velocity, displacement, dynamic stress, strain response, etc. All the standard parameters can be built connection with acceleration, in other words, the dynamic responses in slope are all induced by acceleration of seismic. Therefore, the study of dynamic response rules in time and space of acceleration is becoming the basic problem in this field. In this article, 3DEC simulation model is built to discuss the acceleration dynamic response. Orthogonal experiment design method is applied and the sensibility of the maximum value of PGA amplification factor in rock mass slope is evaluated through numerical calculation and statistics. The changing rule of maximum PGA amplification factor is analyzed under structure effect. Based on this, taken into consideration the correlations and random linkage in structure factors, range analysis and variance analysis are used to put the sensibility of maximum PGA amplification factors in order. The sensibilities of dip angle starting position, shear stiffness, normal stiffness and distance of discontinuities are in descending orders. Therefore, when there is structure with big dip angle and develops shallowly, the dynamic response will be stronger. Under the effect of seismic loading, this type of dynamic stability problem in rock slope will be more prominent.

Keywords: Rock slope; Dynamic response; PGA amplification factor; Sensibility analysis

Kraľovany Rockslide - its tectonical predisposition and kinematics

P. Liščák [1] & M. Fraštia[2]

1 Department of Engineering Geology, State Geological Institute of Dionýz Štúr, Mlynská dolina 1, 817 04 Bratislava, Slovakia, pavel.liscak@geology.sk

2 Slovak University of Technology, Faculty of Civil Engineering, Radlinského 11, 81368 Bratislava, Slovakia

Rockslide Kraľovany in northern Slovakia, which has been activated in the active limestone and dolomite quarry in spring 2013, has become one of the most spectacular slope failures in the modern history of Slovakia, both in terms of the dimensions as well as the risk to society. The essential condition for sliding has created a tectonic failure in the form of overthrust line with accompanying mylonitization and subsequent alterations. The main triggering factors were excessive effective precipitation in winter season 2012/2013 in combination with snow cap melting in spring, and inadequate quarrying of the raw material – limestone and dolomite – in the frontal part of the slide extending for more than five decades. The slide masses reaching a volume of more than 2 million m3 pose a risk for recent infrastructure and lives and property of inhabitants and visitors to the site. Moreover, a route of the most important transportation artery – motorway D1 – has been designed in the very place of the accumulation zone of the rockslide. In May 2013 an Emergency State has been declared here. This situation has asked for immediate action of engineering geologists from the State Geological Institute of Dionýz Štúr and Slovak University of Technology and supplementary engineering geological survey realized by the National Motorway Company. The investigation of the slide has comprised engineering geological mapping, exploration drilling with subsequent installation of inclinometers and piezometers and geodetic monitoring based on terrestrial and GNSS methods, land-based and aerial photogrammetry and laser scanning. The set of applied methods has provided relevant data, which have contributed to analysis of the mechanism and factual activity of complex rockslide consisting of several blocks, covering a period of May 2013 - July 2014.

Exfoliation Fracturing in the Central Aar Granite

S. Loew[1], M. Ziegler[1] & S. Bucher[1,2]
[1] ETH Zurich, Engineering Geology, Sonneggstrasse 5, 8092 Zurich, Switzerland, simon.loew@erdw.ethz.ch
[2] now at: BTG Büro für Technische Geologie AG, Breitenstrasse, 50, 8832 Wilen SZ, Switzerland, info@btgeo.ch

Exfoliation joints are well-known natural fractures limited to near the ground surface. Relatively few details, however, are known about their distribution and age in the Swiss Alps. Exfoliation joints follow the landscape surface at the time of their formation; the age of the associated landscape feature then provides a maximum age of exfoliation joints. While landscape forms can change through time, exfoliation joints preserve elements of former landscape morphologies by their undisturbed orientations. Mapping above and below ground in the Aar and Reuss Valleys of the Central Alps revealed that exfoliation joints are widespread and occur between valley bottoms and mountain crests within glacial and predominantly fluvial landforms. Exfoliation joints mainly occur in massive granitic rocks with minor brittle tectonic overprint within the first 200 meters below ground surface. Based on detailed geomorphological and fractographic investigations we could relate the impact of erosional episodes, and accompanying stress changes, on exfoliation joint formation in granitic rocks. We find that exfoliation joints formed during up to four periods between the lower Pleistocene and the Holocene. Borehole-based investigation of the *in-situ* stress state at four sites and observations of localized fracturing (spalling) around shallow tunnels within our study area indicate high compressive principal stresses, σ_1 and σ_2, subparallel to the ground surface and supports the notion that the bulk of investigated exfoliation joints formed as extensional fractures in an overall compressive stress field.

The research of effects of discontinuity plan factors on amplification coefficient of peak ground acceleration

S. Lu[1], S. Liao[1] & J. Wang[1]

[1] Faculty of Engineering, China University of Geosciences (Wuhan), 388 Lumo Rd., Hongshan District, 430074 Wuhan, Hubei, China, lushahaha@hotmail.com

Abstract: Through much numerical simulation calculation, the influence rules of discontinuities on rock mass slope dynamic response are studied. The results indicate that change of structure occurrence will lead to the different directions of reflection and refraction of seismic wave. The distribution of field energy of seismic wave will be changed. It finally reflects on the spatial variation of slope amplification factor PFA contours. As for dip layered slope, when dip angle of structure is relatively small, structures have a reduction effect on seismic propagation. When the angle is relatively big, it has the opposite effect. The dynamic stability of slope decreases with the increase of dip angle. The existing of anti-dip layered slope will make the propagation of seismic of rock slope decay. As structure dip angle increases, the strength of discontinuity decreases. The dynamic stability of anti-dip layered structure is better than that of dip layered structure. In addition to this, the starting position of structure is a big factor on seismic dynamic response of rock slope. The higher the position is, the stronger the response is. With the increasing of structure stiffness, the strength of seismic dynamic response has the tendency increase. The effect of structure stiffness on reflected and transmitted waves is mainly on the relationship of energy distribution, but not impact can be seen at the propagation path of them in rock slope. When the incident wave is shear wave, the seismic dynamic response to structure shear stiffness is more sensitive than that to normal stiffness. Finally, more intense the discontinuities are, worse the integrity of rock slope is and stronger the seismic dynamic response is while the dynamic stability of slope turns poorer.

Estimation of landslide slip surface geometry and rheology from multiple optical and SAR sensors

J.-P. Malet[1], J. Gance[1], C. Doubre[1], A. Stumpf[1,2], J. Travelletti[3], D. Raucoules[4] & M. de Michelle[4]

[1] Institut de Physique du Globe de Strasbourg, CNRS UMR 7516, Université de Strasbourg, 5 rue R. Descartes, F-67084 Strasbourg, France.

[2] Domaines Océaniques, CNRS UMR , Institut Universitaire Européen de la Mer, Université de Brest, Place Copernic, F-29000 Plouzane, France

[3] BEG – Bureau d'Etudes Géologiques, Rue de la Printse 4, CH-1994 Aproz, Swizerland.

[4] BRGM – Bureau de Recherches Géologiques et Minières, Avenue C. Guillemin, F-45000 Orléans, France.

The objective of this work is to present a methodology to inverse the displacement measurements obtained from a series of SAR and optical satellite and airborne sensors in order to estimate the geometry (shape, depth) and the rheology of the shear band of active large landslides. The method is applied to deformation maps obtained from the interferometric processing of C-band, X-band and L-band SAR sensors, from the correlation of optical Pléiades images, and from airborne laser scanning point clouds. The method is tested on three large landslides of South East France (La Valette, Super-Sauze and La Clapière).

The estimated geometries at the three sites are in agreement with ground-based geophysical seismic and resistivity tomographies. Further, different rheological behaviours (frictionnal, viscous) are inferred from the time-lapse analysis of the deformation pattern. The method can be applicable to any type of movement where 3D remote-sensed information on a at least three dates is available.

Application of geomorphology and geomatics in the study of the Flims and Tamins landslides, Switzerland

D. Masera[1], M. Giardino[1], L. Perotti[1], A.V. Poschinger[2], N. Calhoun[3] & J. J. Clague[3]
[1] Department of Earth Sciences, University of Torino, I-10125 Torino, Italy
[2] Bavarian Environment Agency, D-86179 Augsburg, Germany
[3] Department of Earth Sciences, Simon Fraser University, Burnaby, BC V5A 1S6 Canada

We used an integrated geomorphologic-geomatics approach to analyze landforms and sediments produced by the Flims and Tamins landslides in the Rhine Valley, Switzerland. The Tamins landslide (estimated volume = 1.6 km^3) occurred early at the beginning of the Holocene Epoch and was followed, about 9000 years ago and just upvalley, by the huge Flims landslide (ca. 9.3 km^3). The focus of our study is the "Toma hills", which are peculiar, isolated hills located on the floor of Vorderrhein valley between the Flims and Tamins landslides, and also downvalley of the Tamins landslide. The Toma hills consist of intact rootless masses of Flims and Tamins landslide debris that were rafted downvalley on a thick layer of liquefied valley fill ("Bonaduz gravel") during the Flims landslide. We performed a geomatic analysis of LiDAR-derived digital elevation models and also mapped the Toma hills in a GIS using pocket PC and GPS instruments. We also performed a close-range photogrammetric analysis of exposures of landslide debris that forms the hills. A digital map of the Toma hills and the Tamins and Flims landslides provides new insights into the extents of the two landslides, the sources of the hills, and their relation to the Bonaduz gravel. More generally, we demonstrate the power of our photogrammetric technique in building precise 3D models for sedimentological and morpho-structural analyses of outcrops.

Characterization of rockslide dynamics by the joint analysis of LiDAR and stereo-photogrammetric point clouds

A. Mathieu [1], J.-P. Malet[1] & J. Travelletti[2]

[1] Institut de Physique du Globe de Strasbourg, CNRS UMR 7516, Université de Strasbourg, 5 rue R. Descartes, Strasbourg, France.

[2] BEG – Bureau d'Etudes Géologiques, Aproz, Swizerland.

The objective of this work is to analyze the dynamics of a rockslide developed at the contact between sandstones and black marls in the Sanières catchment (South-East France) through the joint analysis of laser scanning and stereo-photogrammetric point clouds. The rockslide, occurred in August 2013, has a volume estimated at ca. 1M m3 and has created a large main scarp of 475 m in length. Further, the rockslide deposits have reached and filled the torrential channel downslope. A large volume of unstable debris is still available on the slope. The formation of a debris-dam in the channel is expected and could trigger a debris flow in case of failure. Since the rockslide cannot be stabilized, it is necessary to develop a monitoring strategy for the slope. The monitoring dataset includes ground-based and aerial optical images (continuous and campaign measurements) and ALS/TLS surveys. Information on the spatial and temporal distribution of the displacements is retrieved from the processing of the data using DEM differencing techniques and image correlation techniques.

The multi-date deformation maps indicate that the rockslide movement is composed of:

I. A global subsidence of the rockslide body controlled by the geometry of a slip surface located close to the lithological contact between allochtoneous flyschs and autochoneous black marls;
II. Surficial movement of large boulders and weathered marly panels downslope.

The time-serie analysis of the optical images indicates an acceleration of the superficial movement during the winter in relation to several snowmelt episodes. The kinematic regime of the global subsidence is controlled by structural features, and displacement rates of a few centimeters per month are measured. The opening of large cracks uphill of the main scarp suggest a further retrogression of the unstable slope. The influence of the geometry of the slip surface is investigated in order to better constrain the morpho-structure of the rockslide and forecast the evolution of the deformation.

Large-scale slope remodelling by mass movements – Kamienne Mts, Sudetes (SW Poland)

P. Migoń[1]

[1] *Institute of Geography and Regional Development, University of Wrocław, pl. Uniwersytecki 1, 50-137 Wrocław, Poland, piotr.migon@uni.wroc.pl*

The present-day topography of the Kamienne Mountains (936 m asl) in SW Poland bears a strong signature of large-scale mass movements and is therefore unique within the Sudetes range, generally regarded as lacking large deep-seated gravitational slope deformations. Recent examination of digital elevation models built from high-resolution LiDAR data has revealed ubiquitous occurrence of slope failures affecting entire hillslopes, combining into complex deformation zones, of a total extent much larger than previous geological mapping suggested. Using geomorphic features as markers of deformation, different types of mass movements can be recognized, from lateral spreading through multiple rotational slides, collapses of undercut rock slopes, to subsequent toe failures and flowslides.

Reasons for the large extent of slope deformation are complex, but geological structure and the pre-existing morphology seem to play the key roles. The Kamienne Mountains are built of volcanic rocks of Permian age, mainly rhyolites, rhyolitic tuffs, and trachyandesites, overlying or sandwiched between weaker sedimentary formations of the same age, among which mudstones and claystones are important. The volcanic rocks are heavily jointed and although their intact strength is high, the rock mass strength is moderate. Nevertheless, the slopes in volcanic rocks are very steep, often in excess of 40°, apparently in the consequence of efficient downwearing in sedimentary formations at the mid- and footslope. Oversteepening and removal of basal support seem to be the primary drivers of slope instability, while rock mass discontinuities in the volcanics provide the ready zones of weakness along which disintegration of rock slopes takes place. An evident asymmetry in the deep-seated slope deformation pattern, with north-facing slopes preferentially affected, is linked to regional geological factors and the general dip of volcanic bodies and sedimentary strata to the south, further reflected in N–S geomorphological asymmetry.

Challenges of rock slope stability analysis according to Eurocode 7, with particular emphasis on limit equilibrium analysis

B. Nilsen[1]

[1] *Norwegian University of Science and Technology (NTNU), Dept. of Geology and Mineral Resources Engineering, Trondheim, Norway, e-mail: bjorn.nilsen@ntnu.no*

Calculation of rock slope stability may be based on several alternative approaches, with empirical, limit equilibrium, numerical and probabilistic as the most common. Eurocode 7, which over the last 10 years has become the basic standard for geotechnical design in most European countries, allows for using all these principles provided that the guidelines described in the Eurocode are followed. In Norway, Eurocode 7 replaced the National Standard NS3480 in 2010 as the only standard to be used for geotechnical design. The introduction of Eurocode 7 represented some important changes of the way slope stability analysis and calculation is to be carried out. Most importantly, the previously very commonly used principle of calculating one single Factor of Safety (FS) is no longer to be used, and in Norway it will be in conflict with the national law for Planning and Construction to use this principle. The "new" approach to be used is the so-called Partial Factor (PF) principle, involving partial factors to be placed on all acting forces/loads (i.e. gravitational forces, water pressure, seismic forces) and on material strength (i.e. cohesion, friction angle and support elements). The values to be used for the various factors are defined in the Eurocode system. However, several dilemmas and questions arise when using the partial factors for rock slopes. In this contribution the basic differences between the traditional FS-method, which is still the most commonly used for limit equilibrium analysis outside Europe, and the PF-principle will be discussed, as well as some important aspects of defining partial factors, particularly connected to geological parameters.

Geological and structural control of the Ivasnasen and Vollan unstable rock slopes (western Norway)

T. Oppikofer[1], G. Majala Dreiås[2,3], A. Saintot[4], R.L. Hermanns[1] & J. Gosse[5]
[1] *Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway, thierry.oppikofer@ngu.no*
[2] *Norwegian Water Resources and Energy Directorate, Trondheim, Norway*
[3] *Norwegian University of Science and Technology, Trondheim, Norway*
[4] *Department of Endogenous Geology, Ruhr University Bochum, Bochum, Germany*
[5] *Dalhousie Geochronology Centre, Dalhousie University, Halifax, Canada*

The Ivasnasen and Vollan unstable rock slopes are located on opposite slopes in the upper part of the U-shaped Sunndal Valley (western Norway). Vollan lies on a SE-facing slope compose of quartzite in the upper part and calcareous phyllite and garnet micaschist in the lower part while Ivasnasen faces NW and exposes competent augengneiss. These different lithological units belong to different nappes or nappe complexes, which were thrusted over the gneissic basement during the Caledonian orogeny and folded into a large syncline forming the initial valley.

The rock slope deformation at Vollan is characterized by a steep back-scarp along the subvertical valley-parallel SW-NE metamorphic foliation in the quartzites and a series of parallel counterscarps in the phyllites. Field observations and a kinematic analysis indicate toppling as possible failure mechanism along the back-scarp, while the counterscarps are most likely formed by compression in the relatively incompetent phyllites induced by the toppling movement of the quartzites. Extremely slow to no displacements have been detected by periodic differential global navigation satellite system measurements over the past five years.

A post-glacial rock avalanche occurred at Ivasnasen with a reconstructed volume of 1.2 million m^3. Failure occurred along a single planar sliding surface formed by the 45°-55° NW-dipping metamorphic foliation in the augengneiss. The same structure forms the back-scarp and sliding surface of the present unstable rock slope only a few tens of metres to the west. No displacements are currently recorded by periodic terrestrial laser scanning and extensometer measurements at that site. Yet the site is considered as unstable rock slope owing to the offset of the mass along the sliding surface. The current unstable area is estimated to have a volume of 2.1 million m^3. Both sliding surfaces, as well as the rock avalanche deposits, were sampled for cosmogenic nuclide exposure dating. The objective of the chronology is to determine 1) if sliding occurred to catastrophic failure, 2) when the catastrophic failure occurred, and 3) if the unstable rock mass has moved since catastrophic failure.

Brenner Pass Rockslide Cluster - characterisation, dating and geomorphologic impacts of fife early Holocene rockslides

M. Ostermann[1]

[1] *Institute for Geology, University Innsbruck, Innrain 52, A-6020 Innsbruck, Austria, marc.ostermann@uibk.ac.at*

The post-glacial development of mountain valleys near Brenner Pass (Austria, Italy) was profoundly influenced by instantaneous local base-level rise caused by large dimensional rockslides (RS). Within an area of about 20x20km the remnants of five early Holocene rockslides/rock avalanches are preserved. Each catastrophic rock slope failure had blocked the valley it descended into and caused a backwater lake. The former surface extent of these lakes varies between a few thousand m² (Brennersee RS) and more than 15km² (Stilfes RS). Nowadays the lake basins are fully filled up with successions of lacustrine and fluviatile sediments (Stilfes RS, Pfitsch RS, Ridnaun RS) or still impound a lake (Obernberg RS, Brennersee RS). In any case the geomorphological impacts of the slope failures have been dramatically.
To evaluate the principal geometrical parameters and to allow characterisations and classifications extensive fieldwork has been combined with LIDAR-interpretation and numerous drill-core data. The involved rock volumes range from about 0.013 km³ (Brennersee RS) up to 0.6 km³ (Ridnaun RS). Lithologically three failures comprised calcareous phyllites whereas at Obernberg calcitic marbles and at Ridnaun paragneisses and phyllithic mica schists have failed.

To determine the chronology of the events four different age-dating methods (^{14}C, ^{36}Cl, $^{234}U/^{230}Th$, OSL) have been applied. Two events (Pfitsch RS, Stilfes RS) have been age-dated to the beginning of Holocene at about 11.5 ka. The three other catastrophic events (Ridnaun RS, Obernberg RS, Brennersee RS) occurred around 8.5 ka. It seems that the rock slope failures do not only cluster in space but also in time. This findings favour earthquakes as the main triggering factor of the catastrophic rockslides in the Brenner Pass area, where several slopes show features of different evolutionary stages of DSGSDs and where ongoing seismicity has been reported.

Swalik formation and landslide hazard along Tinau valley, Nepal

K. K. Panthi[1]

[1] *Norwegian University of Science and Technology (NTNU), Sem Saelands vei 1, NO-7491 Trondheim, Norway, e-mail address: Krishna.panthi@ntnu.no*

Swalik rock formation is one of the youngest geologic formations in the Himalayan region. This is a young sedimentary formation with an age varying between very recent and 14 million years. Swalik is the southernmost mountain series of the Himalaya where altitude varies from 150 meters to 1500 meters. The Swalik formation is more than 2500 km long and trends northwest southeast direction and dips towards north. The formation is cross-cut by many rivers and ribver systems originated from the Lesser and Higher Himalayan Mountains. Main rock types in this formation are sandstone, salestone, mudstone, limestone and dolomites. Due to dynamic monsoon, varying weather pattern, young and fragile geologic formation and dynamic tectonic activity extensive valley slope erosion, rock fall evants and large scale landslides are very common.

This presentation aims to discusses and explain one of the most critical valleys of the Swalik formation located in the central Himalaya i.e. the Tinau valley, where many landslides, rockslides and rock fall hazards are occurring every monsoon period and during medium to large seismic events. Geological and geomorphological settings and hazard pose to the civil society will be described and presented with illustrations, figures and photographs.

The role of tectonics on the occurrence of the Potrero de Leyes rock avalanche (Pampeanas ranges)

I. Penna[1], A. Abellán[1], A. Pedrazzini[2], S. Daicz[1], M.-H. Derron[1], L. Fauqué[3], & M. Jaboyedoff[1]
[1] Group of Risk Analysis – ISTE, University of Lausanne, Geopolis, Lausanne, Switzerland, ivanna.penna@unil.ch
[2] Office de l'Environnement du Canton du Jura, Chemin du Bel Oiseau 2, 2806 Saint Ursanne, Switzerland
[3] Argentinean Geological Survey, Av. General Paz 5445 - San Martín, Buenos Aires, Argentina

Tectonic activity has a direct impact on slope stability by reducing rock mass strength through increasing fracturing network during deformation and exhumation, by driving slopes into threshold angles, and in form of energy release during earthquakes. Slope deformation processes resulting from relief construction, especially where landscape dynamics are not competent enough to degrade the relief, have also been documented as key factor on slope instability. The aim of this study is to explore the role of tectonic uplift on the occurrence of the Potrero de Leyes rock avalanche, one of the largest slope failures in the Pampeanas ranges (Argentina). These ranges constitute the eastern mountains developed because of the horizontal subduction of the Nazca plate. Here, subduction-derived shortening is accommodated by reverse faults with vergence to the west which in the study area has created a vertical offset of ~1000 m in an ancient peneplain. The features leading to the Potrero de Leyes rock avalanche were analysed by field survey, terrestrial LIDAR and Gigapan acquisitions, 3D topographic reconstructions, and numerical modelling. The rock avalanche involved 240 millions m3 of highly fractured granitoide rocks, and the rock mass run-out was ~4 km long, with a 10° Farböschung angle. Linear depressions parallel to the mountain front developed in the granitoide rocks located immediately north of the rock avalanche may indicate a process of gravitational deformation affecting the mountain front. Our analyses show that the unstable conditions on the slope may result from low rock mass strength derived from fracturing, combined with slope deformation on the mountain front.

What can we learn for seismic hazard in Scandinavia from medium magnitude earthquakes in the Chilean fjord land?

T. Redfield[1], R.L. Hermanns[1], T. Oppikofer[1], F.X. Yugsi Molina[1], P. Osmundsen[1] & S. Sepulveda[2]

[1] Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway, tim.refield@ngu.no

[2] Departamento de Geología , Universidad de Chile, Santiago, Chile

For conceptual purposes Redfield & Osmundsen (2009) proposed a two-end-member rock-slide categorization scheme that reflects Norway's extended margin architecture. Type 1 slides are comprised by compartments that incorporate extensively-developed fault-rock fabrics whose origins can be directly traced to regional-scale, through-going, brittle-phase deformation. These slides occur in tectonically 'mature' settings such as Chile's Puerto Aysén and Norway's Møre Trøndelag Fault Complex (MTFC). Type 2 slides, whose compartments incorporate pervasive and exposed fractures or foliation planes but are unrelated to regional brittle fault zones, occupy the opposite end of the spectrum. While Type 2 events can occur within a fault zone such as the MTFC, Type 1 events are much less likely to occur outside it.

The (Type 1) Punta Cola rockslide is one of many slope failures triggered by the M_w 6.2 earthquake on 21st of April 2007 near Puerto Aysén. The slide occurred in gneissic to tonalitic bedrock and was sited along the Punta Cola strand of the regional Liquiñe Ofqui Fault Zone, within 1 or 2 km of the 2007 epicenter. Field mapping revealed 11 normal and 9 reverse brittle faults in the main lateral release surface, indicative of strong structural preconditioning of the slide due to tectonic breakdown of the rock mass along an extra-regional intra-plate fault system. The main failure plane is characterized by abundant slickenlines carried in epidote and chlorite and a handful of poor-quality normal-sense kinematic indicators. A brittle-regime thrust fault with a breccia- and gouge-rich damage zone, also mineralized with epidote and chlorite surfaces and on the order of 2 to 5 meters thick, crops out near the toe of the failure. The thrust fault was tectonically reactivated in a normal sense, evidenced by good quality kinematic indicators in its core. A zone of intensely-fractured rock near the head scarp completed the pre-failure structural compartment.

As in 2007 in Puerto Aysén, the ground acceleration that accompanies a large earthquake may be sufficient to collapse large parts of fault-infused, unstable mountain slopes in Norway. The incomplete record of Norwegian seismicity makes it difficult to quantitatively assess earthquake repeat intervals for a discrete region in Norway. However, four convergent vectors (proximity to stress-generating Plio-Pleistocene depocenters, high levels of recent onshore erosion, yet-incomplete post-glacial uplift, and topographically-elevated, un-buttressed escarpments adjacent to excised fjords and deep, sediment-filled basins and mega-basins) offer qualitative hints that the more uplifted sectors of the Norwegian mainland are characterized by excess, seaward-directed stress. Potential exists for both Type 1 and Type 2 rockslope instabilities to be triggered by an onshore or a very near-shore Norwegian M_w 6+ earthquake. In concept, lesser seismic events occurring very close to sites already greatly destabilized by the slow, steady fault-rock forming processes that accompany the inexorable decay of an upthrown escarpment may also trigger sufficient horizontal ground acceleration to release single or multiple rockfalls or rockslides.

On Self-Organized Criticality of landslides in Rif Mountains (Morocco)

M. Rouai[1] & Y. El Kharim[2]
[1]Earth Sciences Department, Faculty of Sciences, My Ismail University, Meknes, Morocco, mohamed.rouai@gmail.com
[2] Earth Sciences Department, Faculty of Sciences, A. Essaadi University, Tetouan, Morocco, ykharim@yahoo.fr

Landslides exhibit fractal (power-law) frequency-size distributions in different geological conditions, and are generally modelled as self-organized critical (SOC) phenomena. We have studied the frequency-area statistics of landslides in the Tetouan region (Rif mountains, northern Morocco), considering an inventory of 2009 landslides. The data set contains different types: rock falls, flows, slow movements (creeps), simple and complex landslides.
The cumulative frequency-area distribution of all landslides, without consideration of their types, does not show a simple power-law relation but can be fitted by two linear segments with two exponents (β_1=0.89 and β_2=1.87).

The sorting of landslides, with regard to the type shows that they correlate well with a power-law for simple slides, flows, and creeps with an exponent β ranging from 1.44 to 1.57. Complex landslides distribution can be fitted either by a power-law (β=1.30) or by a "bifractal" fit with two exponents (β_1=0.68 and β_2=1.72). Rock falls show a low value β=0.77.

Regarding the geology and lithology of landslides, the cumulative frequency-area distributions show different behaviours. Marls correlate very well with a simple power-law (β=1.42), flyschs show often a “bifractal” regime. Limestones (falls in general) can be fitted either by a simple power-law (β=0.82) or by a "bifractal" fit with low exponents (β_1=0.47 and β_2=1).

The mean result of this work is that the exponents of observed power-law distributions are subject to considerable variability. Fractal exponents seem not to be a unique and universal value, but should depend on the type of landslides, lithology, and geological settings. The difference the exponents and the subjective choice of the fit seem to be critical for landslide risk assessment.

Monitoring and characterization of Mannen/Børa rock slope (western Norway) using GB-InSAR and satellite InSAR

L. Rouyet[1], L. Kristensen[2], M.-H. Derron[3], C. Michoud[3], L. H. Blikra[2], M. Jaboyedoff[3] & T. R. Lauknes[1]

[1] Norut Northern Research Institute, Postbox 6434 Forskningsparken, 9294 Tromsø, Norway, line.rouyet@norut.no, tom.rune.lauknes@norut.no

[2] Åknes/Tafjord Beredskap, Ødegårdsvegen 176, 6200 Stranda, Norway, lk@aknes.no, lhb@aknes.no

[3] Institute of Earth Sciences, Bâtiment Géopolis, Quartier UNIL-Mouline, 1015 Lausanne, Switzerland, Marc-Henri.Derron@unil.ch, Clement.Michoud@unil.ch, Michel.Jaboyedoff@unil.ch

The Mannen/Børa rock slope is located in Møre of Romsdal County (western Norway). Mannen is a complex rockslide of 15-25 mill. m3 of volume, affecting the left side of the Romsdalen valley. Børa is a large plateau directly located on its south-eastern side and showing signs of activity.

The wide continuous monitoring network developed since 2009 in Mannen includes various in situ devices: DGPS, lasers-reflectors, extensometers, tiltmeters and meteorological station. In addition, a GB-InSAR is installed in the valley to continuously monitor the rockslide since 2010 and a support for intermittent GB-InSAR measurements on Børa area was built in summer 2011. The availability of two GB-InSAR systems in a 2 km2 area allows having a very large coverage of the rock slope and gives information about the reliability of results in the overlap part.

GB-InSAR data in Børa were analysed for 3 campaigns in 2011 and 2012, and compared with permanent GB-InSAR and in situ data. In addition, TerraSAR-X/TanDEM-X images from 2010 were processed. The combined results of GB-InSAR, in situ and satellite data provide a good overview of the Mannen rockslide behaviour. Overall the results are consistent and complementary.

The main interest of GB-InSAR campaigns in Børa is to highlight the presence of an unusual, but coherent, pattern in the overlap area with Mannen data. Significant positive displacements, i.e. upslope along-the-LOS, are recorded in August 2011. 2012 Børa campaign combined with the analysis of Mannen GB-InSAR data shows that the pattern is not homogenous in time and that inversions of movement have a seasonal occurrence.

Rock avalanches, rock slides and rock fall activity in the Quternary bedrock in Iceland

T. Saemundsson[1], H. Norddahl[1] & H.G. Petursson[2]

[1] Institute of Earth Science, University of Iceland, Askja, Sturlugata 7, Reykjavík, Iceland, steinis@hi.is / hreggi@hi.is

[2] Icelandic Institute of Natural History, Borgum við Norðurslóð, Akureyri, Iceland, hgp@ni.is

Rock avalanches, rock slide and rock fall activity is high in Iceland, both in the Tertiary and Quaternary bedrock. Mass movements in those types of bedrock are though somewhat different, both in size, origin and triggering factors. The Móberg formation characterize the Late Quaternary and partly the Holocene bedrock in Iceland. Móberg or hyaloclastite is a hydrated tuff-like breccia rich in black volcanic glass, formed during volcanic eruptions under water, under ice or where subaerial lava flows reach the sea or other bodies of water. The volcanic landforms produced by eruptions can either be móberg ridges or móberg cones, often capped by lava formed in subaerial flows. The móberg can also be inter bedded by lava beds erupted subaerially during interstadial stages. The Quaternary bedrock is distributed along the volcanic zones and in the southern part of the island.

The Móberg formation is highly variable both in texture, structure and hardness of individual beds. It is very easily eroded, both by precipitation, wind erosion and frost and thaw processes. Both coastal and glacial erosion have been, and are, active sculpturing the móberg formation, often resulting in steep or even overhanging cliffs and mountain slopes.

In the southern part of the island, in the vicinity of the active, glacier covered central volcanoes, quite a few rock slides and rock avalanches have occurred during the last decades. Being tectonically active the bedrock in those areas is cut by numerous faults and fissures. These rock slides and rock avalanches have fallen from steep valley slopes, which have been undercut by advancing outlet glaciers, followed by rapid retreat of the glaciers during the last century. More rockslide and rock avalanche activity is expected in these areas following the retreating glaciers.

Back-analysis of the 1756 Tjellefonna rockslide (western Norway)

G. Sandøy[1], T. Oppikofer[1] & B. Nilsen[2]
[1] Geological Survey of Norway (NGU), Trondheim, Norway, gro.sandoy@ngu.no
[2] Norwegian University of Science and Technology (NTNU), Trondheim, Norway

In 1756 the largest historically recorded rockslide in Norway took place at Tjelle in the Langfjord (Møre & Romsdal). Three displacement waves of up to 50 meters were created by the impact of the failed rock mass constituting the Tjellefonna rockslide. A total of 32 people were killed and houses and boats around the fjord were destroyed.

This study presents a back-analysis of the Tjellefonna rockslide by (1) reconstructing the topography before the rockslide, (2) assessing the volumes of the initial rockslide mass, the onshore and offshore deposits, (3) assessing the major discontinuities involved in the rockslide, and (4) 2D numerical slope stability modelling for evaluating parameters and trigger factors.

The topography is reconstructed using the Sloping Local Base Level technique and a manual ART reconstruction in the PolyWorks software. Both topographic reconstructions yield an initial rockslide volume between 9.2 and 10.4 million m^3, which is lower than previous estimates (12-15 million m^3). Only 3.9 million m^3 was deposited in the fjord, which is important for assessing the generation of rockslide-triggered displacement waves. This highlights the necessity of precise volume estimations prior to back-analyses of landslide-triggered displacement waves.

The granitic to granodioritic gneissic rock mass at Tjellefonna have high to very high mechanical strength. Field mapping reveals that the intact rock strength is compromised by a combination of a variably developed foliation, extensive faulting and four persistent joint sets. However, kinematic feasibility study reveals no clear failure mechanism.

The numerical slope stability model Phase2 analyses include shear strength reduction (SSR) investigations and parameter sensitive tests. These tests demonstrate that the failure of the Tjellefonna slope must have required strain softening in combination with triggering factors, where high groundwater level is an essential feature. Additionally, the analyses show that a sub-horizontal structure is critical in order to induce slope instability. It is assumed that the Tjellefonna rockslide was not composed of a uniform plane, but of a complex surface consisting of joints, faults, foliation surface and intact rock bridges.

Kinematic of Deep-seated La Clapière Landslide (Tinée Valley, French Alps) monitored by DInSAR and ground-based measurements

R. Schlögel [1], C. Doubre[1], J-P. Malet[1] & T. Lebourg[2]

[1] Institut de Physique du Globe de Strasbourg, CNRS UMR 7516, Université de Strasbourg, 5 rue R. Descartes, Strasbourg, France, schlogel@unistra.fr

[2] Géosciences Azur, CNRS UMR 6526, Université de Nice-Sophia Antipolis, 250 Avenue A. Einstein, Valbonne, France

Located in the Argentera-Mercantour Massif in South-Eastern France, the La Clapière landslide is one of the largest mass movement in Europe with a volume of ca. 65 million m^3. Although the landslide was initiated in 1951, it still represents an important threat because a massive failure could potentially block the Tinée river and create a landslide dam.

The surface displacement rates recorded since 1982 reach an average of about 1 $cm.day^{-1}$. In 1987 and 1997, accelerations with displacement rates up to 5 $cm.day^{-1}$ have been observed. In the last years, the measured displacement rates are less than 1 $cm.day^{-1}$. Spatially, those velocities are heterogeneous, with larger displacements observed in the upper North-East slope. The lithology consists of different metamorphic units (granodiorite and weathered mica gneisses) highly affected by normal faults and a single over-thrusting fault. Three fault orientations can be distinguished (N010°E-N030°E, N080°E-N090°E and N110°E-N140°E) with a dip angle close to 90° near the scarp and decreasing downslope. Rotational movements are observed in the upper slope with a depth of the failure surface comprised between 100 and 200 m.

In this work, a set of L-band ALOS/PALSAR interferograms combined to field survey (EDM measurements) covering the period 2007-2010 is analysed to understand the landslide kinematics. Decorrelation due to the mountainous topography, vegetation coverage, changing meteorological conditions and high sliding velocity induces difficulties to interpret the DInSAR results. After a selection of the InSAR deformation maps (small temporal and perpendicular baselines), the method considers InSAR coherence maps and slope gradient maps to filter the interpretable results. Phase unwrapping is realized by integrating daily displacement measurements on a series of 50 benchmarks located on both stable and unstable slopes. The results highlight several sliding compartments closely linked to the inherited tectonic features. Morpho-structural features such as ridges, depressions, scarps, counterscarps and gullies delimit several kinematic compartments in line with the InSAR deformation maps.

Megalandslides in the Tarapacá Region, northern Chile: A consequence of crustal fault active tectonics?

S.A. Sepúlveda[1], V. Farías[1] , V. Letelier[1] & M. Farías[1]
[1] Departamento de Geología, Universidad de Chile. Plaza Ercilla 803, Santiago, Chile. sesepulv@ing.uchile.cl

The northern Chile Tarapacá Region has a distinctive morphology characterized by a series of deeply incised ravines (*quebradas*) between 19º-20ºS, which continues further north into the Arica-Parinacota Region. At the foothills of the Altiplano plateau, these large *quebradas* carve the hilly Precordillera and the Central Depresion, forming an abrupt relief with depths of several hundreds of metres. These geomorphologic features are well preserved in the extremely arid environment of the Atacama Desert and present key sites to understand the tectonic and climatic evolution of the region during the last ten million years. Inside such ravines, the steep and high slopes, mainly composed of thick clastic and ignimbritic rocks present conspicuous landslide deposits including large rock avalanches, slumps and block slides, with volumes that can reach up to about six cubic kilometres.

The megalandslides have been mapped and their morphometric parameters, including estimated volume, travel angle and runout were measured in the main *quebradas* of the region, including Camarones, Camiña, Moquella, Aroma and Tarapacá ravines, among others. The location of the main landslides coincide with main tectonic features such as regional scale flexures and reverse faults, suggesting a potential seismic trigger in order to generate the large slope failures, more likely in combination with higher groundwater levels at least between the Miocene and early Pliocene. However, geomorphologic observations in Aroma ravine suggest maximum ages of late Pliocene in this area, while lacustrine deposits in Camiña valley interpreted as the product of more recent rock avalanches have been dated as Holocene, indicating that such landside processes may still pose a real hazard at present. In addition, some of these flexures have presented seismic activity in the last decades. The geographic distribution of the largest failures and comparison with worldwide databases suggest that local seismicity from active faults is a likely trigger of megalandslides in the region, in opposition to large magnitude, offshore megathrust earthquakes that have no evidence so far of producing large rock slope failures, including observations from the 1st April 2014 earthquake (Mw 8.2).

This work is co-funded by FONDEF D10I-1027 and FONDECYT 1140317 projects and the Department of Geology, University of Chile.

Recent tectonic activity influencing the development of deep seated slope deformations: examples from the Bohemian Massif and Western Carpathians

J. Stemberk[1]

[1] *Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, V Holešovičkách 41, 182 09, Prague 8, Czech Republic;* stemberk@irsm.cas.cz

More than ten years of systematic three-dimensional displacement monitoring across faults has resulted in evidence for the influence of recent tectonic movements on deep seated slope deformations situated in different geological regions within the Czech Republic. Since 2000 these fault movements have been recorded by the monitoring network TecNet, managed by the Institute of Rock Structure and Mechanics (www.tecnet.cz), using the sensitive 3-D dilatometer TM-71 (Klimeš et al. 2012). The sites of this extensive monitoring network are preferably situated underground within caves, galleries, or tunnels. Those is caves include sites in the Bohemian Massif and Outer Western Carpathians that are known to have developed in association with deep seated slope deformations, such as Mužský Hill in Bohemian Paradise (Rybář et al. 2006) and Kněhyně Cave in the Moravskoslezské Beskydy Mts. (Baroň et al. 2014). The recorded data have been able to identify periods of increased tectonic activity which interrupt periods of relative tectonic stability. Indeed one of the most fundamental achievements of this systematic monitoring has been the detection of aseismic pulses which have been shown to affect large parts of Europe (Stemberk et al. 2010). These pulses were later verified through comparison with data recorded by other geophysical methods (Košťák et al. 2011). The recorded displacements are thought represent significant changes in the recent configuration of the tectonic stress field due to underlying processes operating within the lithosphere/asthenosphere. By comparing the displacements recorded those caves whose development is associated with slope deformations to those whose development is not, it can be seen that aseismic tectonic pulses exert a considerable influence on slope deformation processes - this influence appears to be greater than hitherto appreciated. In this presentation it will be demonstrated that the slope movement magnitude during a tectonic pulse is able to exceed the slope movement magnitude caused by extreme rainfall.

References:

Baroň I., Bečkovský D., Míča L. 2014. Application of infrared thermography for mapping open fractures in deep-seated rockslides and unstable cliffs. *Landslides* 11, 15-27.

Klimeš J., Rowberry M.D., Blahůt J., Briestenský M., Hartvich F., Košťák B., Rybář J., Stemberk J. & Štěpančíková P. 2012. The monitoring of slow-moving landslides and assessment of stabilisation measures using an optical-mechanical crack gauge. *Landslides* 9, 407-415.

Košťák B., Mrlina J., Stemberk J. & Chán B. 2011. Tectonic movements monitored in the Bohemian Massif. *Journal of Geodynamics* 52, 34-44.

Rybář J., Stemberk J., Hartvich F. 2006. Slope failures around the rock castle Drábské světničky, Czech Republic. *Acta Geodynamica et Geomaterialia* 3, 51-65.

Stemberk J., Košťák B. & Cacoń S. 2010. A tectonic pressure pulse and increased geodynamic activity recorded from the long-term monitoring of faults in Europe. *Tectonophysics* 487, 1-12.

Caldera-like collapses in non-volcanic regions - evidence of neotectonic detachment folding

A. Strom[1]

[1] *Geodynamics research centre – branch of JSC "Hydroproject Institute", Volokolamskoe Shosse, 2, Moscow, Russia. strom.alexandr@yandex.ru*

Landslides of any type, regardless of the triggering phenomena, represent motion of earth materials into free space under gravity force. Volume that had disappeared from the head-scarp must be balanced with the deposited volume. However, there are unusual cases when large amount of rocks (up to 3 km^3) had really "disappeared" in the ranges' interiors. The most impressive is the Kyzylkiol cavity located in the Central Tien Shan at the watershed area of the Santash Ridge. The latter represents the asymmetric neotectonic anticline 30 km long and about 10 km wide bounded by neotectonic reverse fault. It is the caldera-like rhomboid-shape depression 3×2 km in size and up to 800 m deep (mean depth is about 500 m) with steep walls. According to geomorphic expressiveness it can be dated as early Holocene. Well developed relief on top of the Santash Range disrupted by the Kyzylkiol cavity walls indicate that the collapse had occurred catastrophically when the anticline formation had been completed. One more similar, though much smaller and, likely, older feature is located about 30 km west from the Kyzylkiol one, on top of another neotectonic anticline. The only one historical analogue is the so called Bitut structure that originated in 1957 in the central part of the Ihe-Bogdo Range in the epicentral zone of the M8.1 Gobi-Altai earthquake. To explain origin of such features one should find "free space" in the ranges' interiors large enough to accommodate the amount of rocks that had "disappeared" from above. Evidence of neither volcanism nor karst processes, nor pull-apart formation were found in the study areas. It is hypothesized that the required "free space" could appear in the core zones of neotectonic anticlines that have been formed during the detachment folding of the tectonically stratified upper crust.

Long-term monitoring of the active slope deformation Čeřeniště using a complex of geophysical and geotechnical techniques (Czech Republic)

P. Tábořík[1,2], J. Stemberk[2], F. Hartvich[1, 2] , J. Blahůt[2] & T. Belov[1]

[1] Institute of Hydrogeology, Engineering Geology and Applied Geophysics, Faculty of Science, Charles University in Prague, Albertov 6, CZ 128 43 Praha 2, Czech Republic, petr.taborik@post.cz
[2] Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, V Holešovičkách 41, CZ 182 09, Praha 8, Czech Republic, petr.taborik@post.cz

Presented contribution is aimed to show a progress in application of complex geophysical and geotechnical monitoring of the active slope deformation Čeřeniště (České Středohoří Mts.). The main scarp as well as toppled ridges, forming the upper part of the complex slope deformation, are according to geophysical survey predisposed by tectonic structures and further affected by deep-seated gravitational processes (spreading, toppling). Central part is formed by a large platform which is followed by active flow-like landslide composed of weathered colluvium. Main goals of the long term research are i) to describe dynamics of the complex slope deformation, and ii) to reveal a connection among predispositions (tectonics, lithology), triggering factors (extreme precipitations, soil humidity changes, long-term climatic oscillations) and landslide activity. For description of a long-term landslide activity the measurements of displacements have been performed by means of i) 3-D spatial dilatometers, ii) extensometric tape, iii) geodetic measurements and repeated laser scanning. In order to identify relations between triggering factors and landslide activity, time-lapse geophysical measurements, besides the hydroclimatic monitoring, were established on the landslide. Variations in resistivity distribution are measured by means of electrical resistivity tomography (ERT). The time-lapse resistivity survey would serve as an effective tool which can yield information on subsurface water saturation and its changes and, also, it could help to reveal relations within the system "precipitation – subsurface saturation – mass movement activation". Furthermore, using the monitoring of movement velocity based on repeated geodetic measurements we shall be able to determine the causal connection between precipitation, soil saturation and (re)activation of mass movements. Last but not least, the studied locality serves also as a testing site for the repeated resistivity measurements in terms of i) measuring parameters optimization, ii) different electrode configurations testing, iii) data processing optimization.

Research is supported by grant projects: CzechGeo LM2010008 and GAUK 862213.

Stability analysis and prediction on Yanwanqiao west slope, Three Gorges Reservoir Region based on cut-through ratio study of the sliding surface

Q. Tan[1]

[1] *China University of Geosciences, No. 388 Lumo Road, Wuhan, P.R. China, email: tanqw0531@126.com*

The instability of the high cutting slopes threatens the life and property security of local citizens due to the reconstruction projects occurring in the Three Gorges Reservoir Region. On the basis of the stability investigation of Yanwanqiao west slope, this paper presents the stability and prediction analysis by utilizing the surface displacement by GPS data and deep displacement by borehole clinometer data. The monitoring results show that the displacement of the slope has a slight increase year by year. In order to make a further and accurate stabiliTy study on the slope, an analysis of failure mechanism—the cut-through ratio of the sliding surface is investigated using the GPS and borehole clinometer data. And based on the cut-through ratio, monitoring data and other geological data, the stability of Yanwanqiao west slope was calculated by SIGMA/W. The result shows that the potential sliding surface with a tension fracture cut area occurred near the slope crest and a shear sliding cut area occurred near the slope toe; however, the whole sliding zone from crest to toe had not formed yet. Therefore, the Yanwanqiao west slope requires a further reinforcement measurement urgently.

Formation mechanism of hydraulic driven bedding landslide —A case study in Xintang landslide

R. Tang[1], E. Yan[1] & J. Cai[1]

[1] College of Engineering China University of Geosciences, NO.388 Lumo Road, Hongshan District, Wuhan, P. R. China, arzkama23@126.com

Hydraulic driven bedding rock landslide is one of the most typical types of landslide and widely existed in nature. The formation mechanism of hydraulic driven bedding landslide is the hot spot in landslide research area. The geological evolutionary history of landslide has important guiding significance for investigating landslide formation mechanism, thus for the large and complex landslide which was developed in rivers bank, its formation mechanism is closely related with valley landscape evolution and bank slope stress field evolution. This article takes Xintang ancient landslide as a typical representation case of Qingjiang river basin, based on the theories of engineering geology, geomorphology, structural geology, analyzing the engineering geological conditions of Xintang landslide and geological evolutionary history of valley; inferring the geological evolutionary history of landslide according to geological evolutionary history of valley; looking for evidence from the geological prospecting data and summarizing the formation mechanism of landslide; finally, a mechanical analysis of landslide has been done and the corresponding critical parameters of landslide instability failure has been given. The results show that, the large scale hydraulic driven bedding rock landslide such as Xintang landslide can be formed and damaged only by the combined effect of unloading stress in front of the rivers bank slope and hydrophobic interaction. The research results have theoretical significance and applied value of hydraulic driven bedding rock landslide.

Energy change law of sandstone under loading and unloading conditions in high stress area , and its damage analysis

T. Wen [1], X. Yi[1] & Q. Tan[1]

[1] Faculty of Engineering, China University of Geosciences, Wuhan, No.388 LuMo Road, HongShan, Wuhan, China, wentao200840@sina.com

According to the results of triaxial compression tests and pre-peak unloading confining pressure tests in high stress area, sandstone's energy variation under the different stress paths was analyzed. The results showed that under the same confining pressure, the energy consumption indexs of pre-peak unloading confining pressure tests were less than the triaxial compression tests, such as, the total absorbed energy, elastic energy, dissipation energy. The energy variation characteristics and initial stress paths were closely related, and increased with confining pressure. The elastic energy stored at the pre-peak was more than dissipation energy, and dissipation energy just increased rapidly near the peak point. The dissipation energy caused the rock damage, the lithology deterioration, and loss of strength. Damage variable was defined from the view of energy. At first damage variable under low confining pressure was greater than high confining pressure, and near the failure damage, the variable under high confining pressure was greater than low confining pressure. Unloading confining pressure reduced the rock's restraint, accelerated the damage development of rock, and the stress state was increasingly unbalanced. Therefore, the study of rock damage evolution in the view of energy was more practical.

Comprehensive field test site in Huangtupo Landslides

W. Xiang[1, 2] & L. Lang[1]

[1] Faculty of Engineering, China University of Geosciences, No. 388 Lumo Road 430074, Wuhan, China, xiangwei@cug.edu.cn, qqllz2008@126.com.

[2] Three Gorges Research Center of Geo-hazards, Ministry of Education, No. 388 Lumo Road 430074, Wuhan, China,

The Badong field test site built in Huangtupo Landslides in Three Gorges Reservoir area of Yangzi River consists of underground testing tunnels and a series of monitoring system. The underground testing tunnels are located in No.1 adjacent to river sliding debris of Huangtupo Landslides and are composed of one master tunnel, five branches of tunnels and two testing tunnels. The master tunnel is 907 meters long and its cross section is 5.0 meters wide and 3.5 meters high. It goes through the sliding mass, the sliding zone and the sliding bed of No.1 adjacent to river sliding debris. Five branches of tunnels are perpendicularly connected to the master tunnel and have the similar cross sectional size, 3.0 meters wide and 3.5 meters high. The third branch of tunnel is the longest one (145 meters in length) in the five of branches tunnels. The length of the fifth branch of tunnel is 40 meters and is second to the third one. Both these two branches of tunnels uncover sliding zones and two testing tunnels were respectively designed along these sliding zones. The second branch of tunnel is 10 meters long. The length of the first and the fourth branches of tunnels is the shortest (5 meters in length). Besides, the monitoring system of the Badong field test site includes a series of monitoring devices such as GPS stations, synthetic aperture radar, borehole clinometer, time domain reflectometer and the monitoring devices of moisture content and matrix suction and etc. This monitoring system could provide dynamic real-time information showing surface and deep displacement change, the fluctuation of water level and stress alteration of Huangtupo Landslides. In summary, the Badong field test site has been playing the comprehensive role of research of landslide geo-hazard, professional instruction and popularization of science.

Research on Sensitivity of Reservoir Landslide Disaster-forming Factors in There-Gorge Based on Grey Correlation Method

L. Xie[1], E. Yan[1] & L. Long[1]

[1] China University of Geosciences, No. 388 Lumo Road, Wuhan, P.R. China, xieliangfu@gmail.com

According to dynamic disaster-forming factors controlled by internal factors, reservoir landslide can be classified as rain-induced landslide, reservoir-water-rising landslide and reservoir-water-falling landslide. The paper performs a statistical analysis on 100 reservoir landslides in Three-Gorge from Fengdu to Badong region about the prone geological model of different types of reservoir landslide and the correlation degree between static background factors and dynamic disaster-forming factors. Firstly, the system of static factors is established. Secondly, the prone geological model of different types of reservoir landslide is sketched out through data statistics. Finally, the correlation degree between the static and dynamic factors is calculatted based on the Grey correlation method. The result shows: (1) Three prone geological models of reservoir landslide are different from each other greatly mainly because of the topography and the characteristics of sliding zone. (2) The Grey correlation degree are listed from big to small as follows: strata dip angle, internal friction angle of slip band, topographic slope, cohesive force of slip band, coefficient of submergence, slope height, thickness of landslide body, slope shape, slide face dip, style of slope, permeability characteristics and formation lithology.

Searching for undiscovered tsunamigenic landslides, and the relationship between landslide morphology, process and tsunami

S. Yamasaki[1] & Y. Yoshikawa[2]

[1] Kitami Institute of Technology, Koen-Cho 165, Kitami, Hokkaido, Japan*, yamasaki@mail.kitami-it.ac.jp*

[1] Kitami Institute of Technology, Koen-Cho 165, Kitami, Hokkaido, Japan*, yoshi@mail.kitami-it.ac.jp*

In tectonic active regions, such as Japan, there is high potential of tsunami hazard to coastal areas by earthquakes that make fault related ground surface deformations on water bottom. However not all tsunamis are attributed to such fault activities. Submerged landslides from coastal mountains and landslides on water bottom, often associated with earthquakes, have generated deadly tsunamis in history. Even if earthquakes which magnitude are around 6, fault activities on ground surface are small or invisible in this condition, induces a lot of landslides in mountain slope, but there were only a few reports about subaqueous landslides. To understand tsunamigenic processes and to know the hazard frequency of areas, we need to carry out the marine geologic survey. But, its difficulty regarding high cost and inaccessibility of research vessels, especially for shallows, has hindered scientific research from this viewpoint. Recently we are embarking searching for tsunamigenic subaqueous landslides using late leisure-use fish finders that are high performance, extremely low cost and mobile. This method provides high definition bathymetric maps and images of the bottom material by side-scan sonar that uses fan-shaped acoustic beam to recognize small subaqueous landslides and rough temporal information of them. Using this method and the computing tsunami simulation, we found some subaqueous landslides that likely correspond to the historical tsunamis. In this presentation, we also report morphological and geo-structural variety of subaqueous landslides in our investigated three water areas, Japan, and we discuss their evolving processes and tsunami generation processes. Then, we conclude that the variety of morphology and process of landslide are important for considering the genetic process and the wave height of the landslide induced tsunamis.

Distribution of lateral force acting on landslide stabilizing piles under different morphological characteristics

X. Yi [1] & R. Yong[2]

[1] Faculty of Engineering, China University of Geosciences, Wuhan, No.388 LuMo Road, HongShan, Wuhan, China, yxl1048931618@163.com

[2] Faculty of Engineering, China University of Geosciences, Wuhan, No.388 LuMo Road, HongShan, Wuhan, China, yongruicug@gmail.com

The safety of the landslide is always closely related to the mechanical parameters and the morphological characteristics. However, for the study of the lateral force acting on piles, the morphological characteristics were neglected in recent researches. The paper added the morphological characteristics to estimate the force of the piles, the model to describle the force behavior under different morphological characteristics was built for the numerical simulation, and the numerical code FLAC3D was used to monitor the force of the piles. The numerical simulation of the piles was desigened in terms of the univariate analysis and the Orthogonal experimental design, and four influential factors were employed to account for the efforts of the morphological characteristics including the inclined angle of the slip zone, the thickness of the slip zone, the volume of the accumulation body and the embedded depth of the piles. These four influential factors were analyzed based on the value of the force and the force concentration factor. The results show that among all these factors the thickness of the slip zone is the most important one , followed by the gradient of the slip zone, the volume of the accumulation body and the embedded depth of the piles.

Second-order Dynamic System Model for Landslide Based on Physical Model Test

Y. Zhang[1], H. Tang[1] & C. Li[1]
[1] College of engineering, China University of Geosciences, Wuhan, China, 430074, e-mail ZYQ20060910@126.com

From the viewpoint of dynamic system, a landslide can be considered as a classical second-order dynamic system. A second-order dynamic differential equation consists of inertia term, damping term, elastic item and input force term, while the factors affecting landslide dynamic characteristics are the density, cohesion, friction angle, Poisson's ratio and so on. Therefore, the key point of modelling is to establish the function between the landslide and second-order dynamic system. On the basis of the four compositions of second-order systems, all the influencing factors of landslide can be divided into inertia factor, damping factor, elastic factor and resolution of force factor. Physical model test method is used to match every influencing factors to the four coefficients of second-order differential equation, which are mass, damping coefficient, elastic coefficient and decomposition coefficient of force along the sliding direction, respectively, The four coefficients of the differential equation can be used to reflect the effect of all the influence factors acting on landslide, thus a integrated second-order dynamic system landside model can be established. The feasibility for the landslide model of second-order dynamic systems has been verified by the measurement for the step response of the physical model test.