Centre of Excellence – International Centre for Geohazards (ICG)

Annual Report - 2010

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Partners in ICG

NGI

NTNU

NGU Norges geologiske undersøkelse

NORSAR

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For the Norwegian Geotechnical Institute

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Summary

The "International Centre for Geohazards" (ICG) is one the first 13 Centres of Excellence (Senter for Fremragende Forskning, SFF) established by The Research Council of Norway (RCN) in 2003. The Norwegian Geotechnical Institute (NGI) is the host organisation for ICG. Partners in the centre are the University of Oslo (UiO), the Norwegian University of Science and Technology (NTNU), NORSAR, and the Geological Survey of Norway (NGU).

Results and activities in 2010

- The research plan was followed and the goals set for the year were achieved. With respect to four major goals of ICG, a) in-kind contribution from the partners, b) complementary projects from the industry, c) number of PhD candidates, and d) international networking, the results have exceeded by far the goals and expectations.
- The focus of ICG's research in 2010 was on:
  - Assessment of the risks associated with geohazards to individuals and society, with special focus on the impacts of climate change and changes in demography on the risks.
  - Development and improvement of methods for modelling the mechanical processes underlying the physical phenomena of different geohazards and for evaluating the consequences of geohazards.
  - Geohazards prevention and risk mitigation strategies.
  - Collaborative research efforts with European partners in European Commission's 7^{th} Framework Programme (FP7).
  - Graduate university programmes on geohazards at UiO and NTNU.
- Joint workshops, seminars, and project meetings contributed to further enhance the good collaboration among the five partners.
- The ICG partners are involved in several FP7 projects related to natural hazards. The latest project is MATRIX: New Multi-HAzard and MulTi-RIsK Assessment MethodS for Europe, which started in October 2010.
- There is considerable interest and enthusiasm about the activities of ICG, both in Norway and abroad.

Challenges for 2011

The overall research plan remains essentially unchanged. The main challenges foreseen for 2011 include:

- Finding complementary funding sources to maintain the high activity level at ICG through the end of 2012.
- Research on complex issues such as vulnerability and risk assessment, tsunami run-up estimation, disintegration of material during sliding, rainfall-induced landslides, earthquake response, etc.
- Identification of the niches where the combined expertise of ICG partners could be put into practical use on the international arena.
- Networking with centres of expertise who work on the societal aspects of the risk associated with geohazards.

- Further work on identifying the most appropriate strategies for geohazards prevention and risk mitigation.
- Implementing the achievements made at ICG in practical use within the partner organisations.
- Attracting PhD candidates, post-docs and guest researchers to Norway.
- Active participation in the research programmes on natural hazards and risk management in the 7th Frame Programme.
- Running and planning new international conferences, seminars and workshops.
- Publication in highly respected scientific journals.

Contents

1 BACKGROUND

The "International Centre for Geohazards" (ICG) is a Centre of Excellence (Senter for Fremragende Forskning, SFF) established by the Research Council of Norway in 2003. The Norwegian Centres of Excellence scheme is designed to stimulate Norwegian research groups to set up centres devoted to long-term basic research. The intention is to raise the quality of Norwegian research and bring more researchers and research groups up to a high international standard.

ICG is a consortium of five partners. Norwegian Geotechnical Institute (NGI) is the host organisation for ICG. Other partners in the centre are University of Oslo (UiO), Norwegian University of Science and Technology (NTNU), NORSAR, and Geological Survey of Norway (NGU). The consortium may be expanded with "associated partners" subject to agreement by all five main partners.

ICG's objective is to be an international centre of expertise on basic and applied research on geo-related natural hazards (geohazards), such as landslides, earthquakes and tsunamis. However, the frameworks and methodologies developed for the assessment of hazard, vulnerability and risk may also be applied for other types of threats. The main aim of ICG is to develop knowledge that can help save lives and reduce damage to infrastructure and the environment. Another aim is to train graduate students and highly-qualified researchers from Norway and abroad.

ICG prioritised international networking, and its status of "Centre of Excellence" contributed to opening many doors. In 2008, ICG was awarded the status of "World Centre of Excellence" in Japan, by the International Consortium for Landslides.

2 ORGANISATION OF ICG

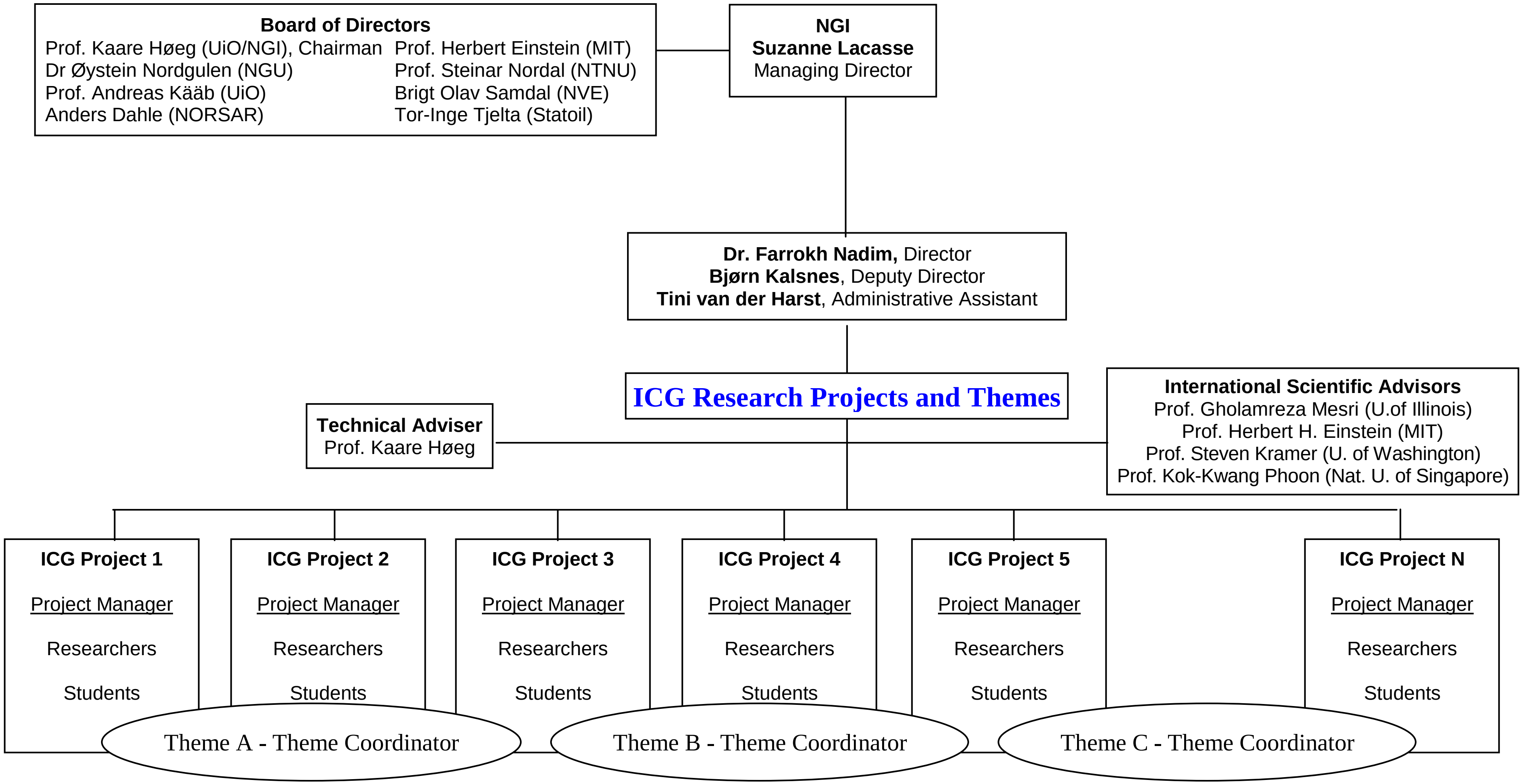
ICG has its own Board of Directors (Steering Committee). Each of the ICG partners, NGI, NTNU, UiO, NORSAR and NGU, has a representative on the Steering Committee. In addition, the Steering Committee has at least one external representative from Norway and one international representative. The Research Council of Norway may also appoint a member to the Steering Committee. ICG has associated partners, e.g. University of Tromsø, but they do not have a representative on the Steering Committee. As the host organisation, NGI appointed the director of ICG, and NGI's representative is the chairman of the Steering Committee.

The activities of the ICG are grouped into three categories:

1. Research projects
2. Training and education
3. International networking and dissemination of information

The organisation chart and the project chart of ICG are shown on the following pages. The ICG projects and other ICG activities are elaborated further later in the report.

Organisation chart of ICG as of 31 December 2010



Project chart of ICG as of 31 December 2010

Dr. Farrokh Nadim, Director
Bjørn Kalsnes, Deputy Director
Tini van der Harst, Administrative Assistent

Technical Adviser
Prof. Kaare Høeg

International Scientific Advisors
Prof. Gholamreza Mesri (U.of Illinois)
Prof. Herbert H. Einstein (MIT)
Prof. Steven Kramer (U. of Washington)
Prof. Kok-Kwang Phoon (Nat. U. of Singapore

ICG Project	Project Managers	Post-docs & Guest Researchers
Risk and vulnerability analysis for geohazards	Mrs. Unni Eidsvig (NGI)	Juan Du, Prof. Kevin Simmons
Earthquakes – hazard, risk and loss estimation	Prof. Hilmar Bungum (NORSAR)	Filippo Marchi
Stability of rock slopes	Dr Reginald Hermanns (NGU)	
Geomechanical modelling	Prof. Steinar Nordal (NTNU)	Ariane Locat
Offshore geohazards	Dr Maarten Vanneste (NGI)	Cody Jones, Jean-Sébastien L'Heureux, Guillaume Sauvin
FP7 project SafeLand – Living with landslide risk in Europe	Mr. Bjørn Kalsnes (NGI)	Simone Colonnelli, Emanuele Intrieri
Tsunami modelling and prediction	Dr Carl Harbitz (NGI)	Dr Gunilla Kaiser, Dr Sara Bazin, R. Swarny, L. Gruenburg
Monitoring, remote sensing and early warning systems	Prof. Andreas Kääb (UiO)	

PhD-candidates at UiO & NTNU:
Maj Gøril Glåmen (NTNU)
Harald Iwe (UiO)
Bård Romsdal (UiO)
Samson Degago (NTNU)
Anders Gylland (NTNU)
Annika Bihs (NTNU)
Magnus Sparrevik (NTNU)
Håkon Heyerdahl (UiO)
Misganu Debella Gilo (UiO)
Hom Nath Gharti (UiO)
Rolv Bredesen (UiO)
David Unteregger (NTNU)
Martina Böhme (NTNU)
Nele Meyer (UiO)
Rafael Rodriguez (UiO)
Ana Priscilla Paniagua (NTNU)

Themes covering several projects	Theme Coordinator
Geophysics for geohazards	Dr Isabelle Lecomte (NORSAR)
Prevention and mitigation of geohazards	Dr Farrokh Nadim (NGI)

ICG-affiliated PhD-candidates in other universities than UiO and NTNU:
Chang Shin Gue (Cambridge Univ., UK)
Sook Ling Lee (Cambridge Univ., UK)
Tom Rune Lauknes (Univ. of Tromsø)

PhDs awarded in 2010:
Guro Grøneng (NTNU)
Trond Nordvik (NTNU)

Professors from Norway active in ICG:
Anders Elverhøi (UiO)
Bernd Etzelmüller (UiO)
Leiv-Jacob Gelius (UiO)
Lars Grande (NTNU)
Svein Hamran (UiO)
Kaare Høeg (UiO)
Andreas Kääb (UiO)
Hans Petter Langtangen (UiO)
Terje Midtbø (NTNU)
Farrokh Nadim (NTNU & UiO)
Bjørn Nilsen (NTNU)
Steinar Nordal (NTNU)
Geir Kleivstul Pedersen (UiO)
Hans Petter Jostad (NTNU)
Thomas Benz (NTNU)
Amir Masoud Kaynia (NTNU)

3 ACTIVITIES OF ICG's STEERING COMMITTEE

The main responsibility of ICG's Steering Committee is to set the priorities in the yearly research plans. The Steering Committee also acts as a technical advisor to the Director of ICG.

The Steering Committee shall also discuss and deal with

- annual budget
- annual technical report(s)
- annual financial report

The annual technical and financial report (this document) is prepared by the Director of the Centre and delivered to the Managing Director of NGI, who is responsible for reporting the activities of ICG to The Research Council of Norway.

The ICG Steering Committee is composed of:

Prof. Kaare Høeg (UiO/NGI), Chairman
Dr Øystein Nordgulen (NGU)
Prof. Andreas Kääb (UiO)
Mr Anders Dahle (NORSAR)
Prof. Steinar Nordal (NTNU)
Mr Brigt Olav Samdal (NVE)
Mr Tor-Inge Tjelta (Statoil)
Prof. Herbert Einstein (MIT, USA)

The Steering Committee held 2 meetings in 2010:

Meeting No. 1/10: 26 March 2010
Meeting No. 2/10: 3 December 2010

The following meetings in 2011 are planned:

Meeting No. 1/11: 25 March 2011
Meeting No. 2/11: 2 December 2011

One of the main topics of discussion for the ICG Steering Committee in 2011 is the evaluation of different models for ICG's future after 2012.

4 TECHNICAL ACTIVITIES OF ICG IN 2010

4.1 Core research activities

ICG divided its technical activities in 2010 into eight projects, and significant progress was done on each:

- Risk and vulnerability analysis for geohazards
- Earthquakes – hazard, risk and loss estimation
- Stability of rock slopes
- Geomechanical modelling
- Offshore geohazards
- FP7 project SafeLand – Living with landslide risk in Europe
- Tsunami modelling and prediction
- Monitoring, remote sensing and early warning systems

In addition to these projects, two "themes" that involve several projects were given high priority, and a Theme Coordinator was designated for streamlining the lateral cooperation among the technical projects in each theme:

- Applications of geophysics to geohazards
- Prevention and mitigation of geohazards

Detailed information about the ICG technical projects and themes is available on the ICG web site www.geohazards.no. The ICG web site was updated with a new outline in 2010.

In 2010 the partners in the ICG were involved in several high profile national and international projects. Three of these are presented below. The first two are activities within the ICG project on “Monitoring, remote sensing and early warning systems”, and the last one is related to the ICG project on “Geomechanical modelling”.

4.2 Rockslide Mapping by Satellite InSAR

Being a mountainous country, with long steep fjords and valley sides, Norway is particularly susceptible to large rock avalanches. With several thousand kilometres of inhabited coastline and valleys, it is a challenge to identify similar hazards in an efficient manner. Once we suspect an area to be sliding, it may take several years of measurements to confirm it and extensive ground instrumentation to characterize the type of motion.

Recently, the potentiality of differential synthetic aperture radar (InSAR) approach has been investigated to study landslides. The satellite based InSAR technique involves comparing the phase information from two SAR images to potentially detect millimeter to centimeter scale ground deformation patterns (Gabriel et al., 1989). Over the last decade, interferometry has become an important tool for mapping topography, studying surface deformation, observing glacial flows, and classification of terrains (Massonnet & Feigl, 1998).

InSAR analysis of the almost two decades long time series available in the ERS and Envisat archives enables rapid identification of landslides within a large region, allowing us to focus field mapping in areas with known hazards.

Since 2005, Norut and NGU have cooperated to establish a Norwegian facility for InSAR processing. More than 1100 ERS and Envisat SAR scenes covering three counties in northern and western Norway has been processed so far. This project has allowed us to identify numerous new landsides. Field investigations have also confirmed the accuracy of InSAR in quantifying differential movement within individual landslides. Figure 4.1 shows an orthophotomontage of the eastern part of Troms County showing the location of rockslide sites as black dots, the mapped structures and the overlain InSAR data. The sites that are moving the most (up to 10 mm/year over the last 10 years) are shown in red (Henderson et al., 2011). Figure 4.2 shows a detailed displacement map of a rockslide in Manndalen in Kåfjord municipality (Lauknes et al., 2010).

The first generation SAR satellites (ERS-1/2, Envisat, RADARSAT-1, JERS-1, ALOS) have proven well suited for InSAR studies to detect land deformation in many different areas. However, these satellites often fail to provide information in areas with low coherence and high displacement gradients.

The new generation X- and C-band sensors (RADARSAT-2 Ultra-fine mode, Terra- SAR-X stripmap and spotlight modes, and COSMO-SkyMed) have higher spatial resolution and shorter revisit times, allowing for detection of deformation at both a finer spatial scale, but also making it possible to detect faster varying deformation phenomena. The high spatial resolution allows for a finer sampling of the deformation phenomena, thereby increasing the potential to discern coherent areas within vegetated regions. The shorter repeat intervals allow detection of larger magnitude displacements between two scenes, reducing the risk of undersampling. In effect, these improvements reduce the complexity of phase unwrapping. Furthermore, TerraSAR-X and COSMO-SkyMed operate at X-band, which gives higher sensitivity than C-band sensors to discern fine scale displacements.

An understanding of the 3D kinematics of the rockslope is essential for hazard analysis (Braathen et al., 2004, Henderson and Saintot, 2009), and it is expected that the new generation SAR sensors can further improve the knowledge of both spatial and temporal rockslide movement patterns. For fast moving landslides, it can be expected that many more objects will be detected. These objects may have been discarded previously due to signal decorrelation, or they have been classified as slow-moving due to temporal undersampling.

Figure 4.3 (right panel) presents preliminary displacement results from an ongoing research project where we record high-resolution RADARSAT-2 Ultra-fine mode data over the Åknes rockslide. We have performed a preliminary SBAS InSAR analysis of the Åknes rockslide using only eight

RADARSAT-2 Ultra-fine mode SAR scenes (Lauknes et al., 2009). In order to better understand the complex movement pattern at Åknes,the LISALab ground based interferometric SAR (GB-InSAR) system was installed and operated between July 17 and October 13, 2008, see the left panel in Figure 4.3. The preliminary results using the RADARSAT-2 Ultra-fine mode data show a good match with the LISALab GB-InSAR results. It should be noted that the radar line-of-sight (LOS) directions are quite different, so an exact comparison is yet to be done. More RADARSAT-2 Ultra-fine scenes are continuously being added to this time series.

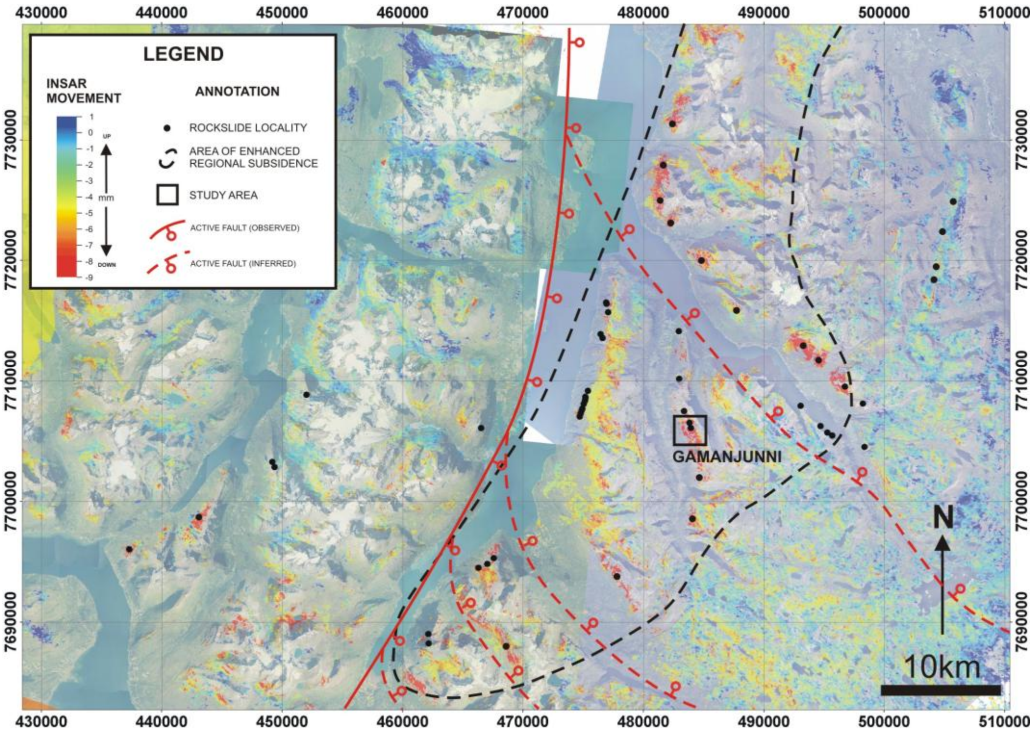


Figure 4.1 Detected displacements in Troms county using InSAR. From Henderson et al., 2011.

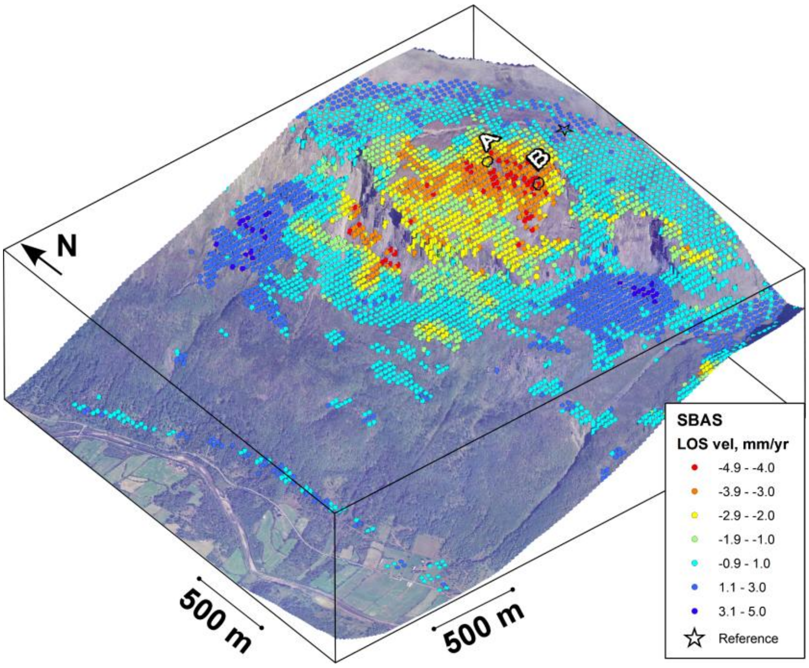


Figure 4.2. Detailed SBAS InSAR displacement results from the Gámanjunni slide in Manndalen i Kåfjord municipality. The red areas are subsiding with velocity rates up to ca. 5 mm/year. From Lauknes et al., 2010.

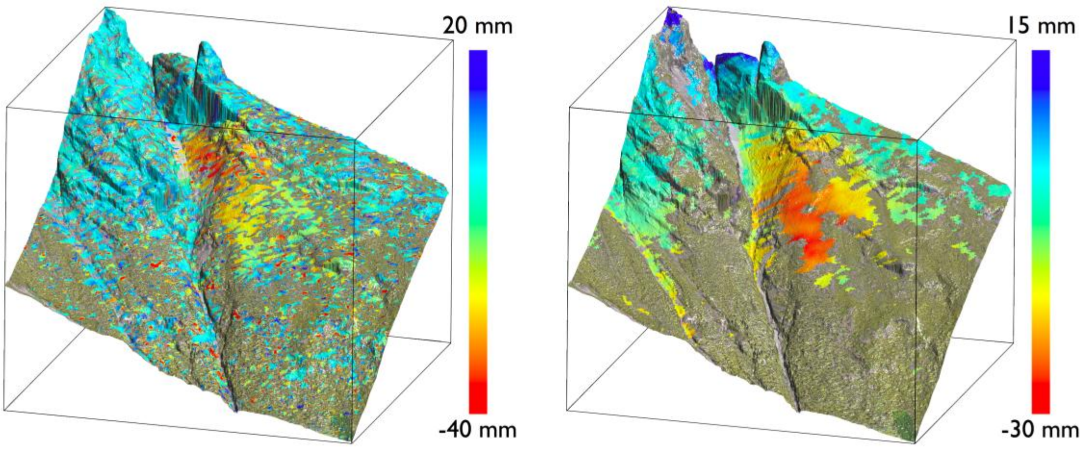


Figure 4.3. Surface displacement at the Åknes rockslide measured the LISALab ground-based interferometric SAR system (left panel), and RADARSAT-2 Ultra-Fine mode satellite InSAR (right panel). From Lauknes et al., 2009.

4.3 Precise analysis of mass movements by matching repeat optical images

Slow movements of rocks, debris and ice are important processes in high mountain regions that modify landscape and occasionally trigger geohazards. Detecting, monitoring and understanding the kinematics behind these movements is a crucial step in early recognition of associated threats. Two and three dimensional surface displacement fields on instable slopes and have been successfully studied using repeat remotely sensed images (Delacourt et al., 2004; Kääb, 2005; Kääb et al., 1997; Kääb and Vollmer, 2000). The vertical change in elevation is measured using a relatively well-established technique of differencing digital elevation models measured at different times. However, techniques of horizontal (lateral) displacement measurement have yet to be standardized. Image correlation and interferometric techniques have so far been utilized. The first involves digital tracking of corresponding features in repeat images, while the second involves computation of object displacements from microwave phase shifts that are caused by changes in the distance between sensor and object within the temporal baseline. It is the first approach, which is introduced here, is the theme of PhD research work by Debella-Gilo at UiO.

Although photogrammetric methods are successfully used to monitor mass movements, rapid advances in technologies of data acquisition are not complemented with similar advances in data analysis. There is large room for improvements in precision and reliability of the image matching methods used for monitoring displacements of Earth surface masses. Improvements in precision and reliability enable the utilization of the (sometimes waste) available collections of air-borne and space-borne multi-temporal images for this purpose. A couple of research works aimed at this goal have been done in the past years.

Bi-temporal aerial images over rock slides around the Aletsch glacier and other areas of the European alps were used as case study to investigate the effects of sensor resolution and to evaluate the performances of different sub-pixel matching approaches for estimating horizontal displacement of the slow-moving masses (Debella-Gilo and Kääb, 2011). The mass loss and associated retreat of Aletsch glacier triggered the sliding of rock masses through debutressing of the valley flanks (Figure 4.4). This slide is measured by correlation-based image matching using bi-temporal aerial images acquired in 1976 and 2006. The rocks sections crept downslope with a maximum of about 4.5 meters at surface over the 30 years period. Additionally, the study indicated that matching (displacement estimation) errors increased linearly with ground pixel size. Besides, interpolating the images prior to matching improved the precision of the matching (hence displacement estimation) most compared to the other sub-pixel approaches.

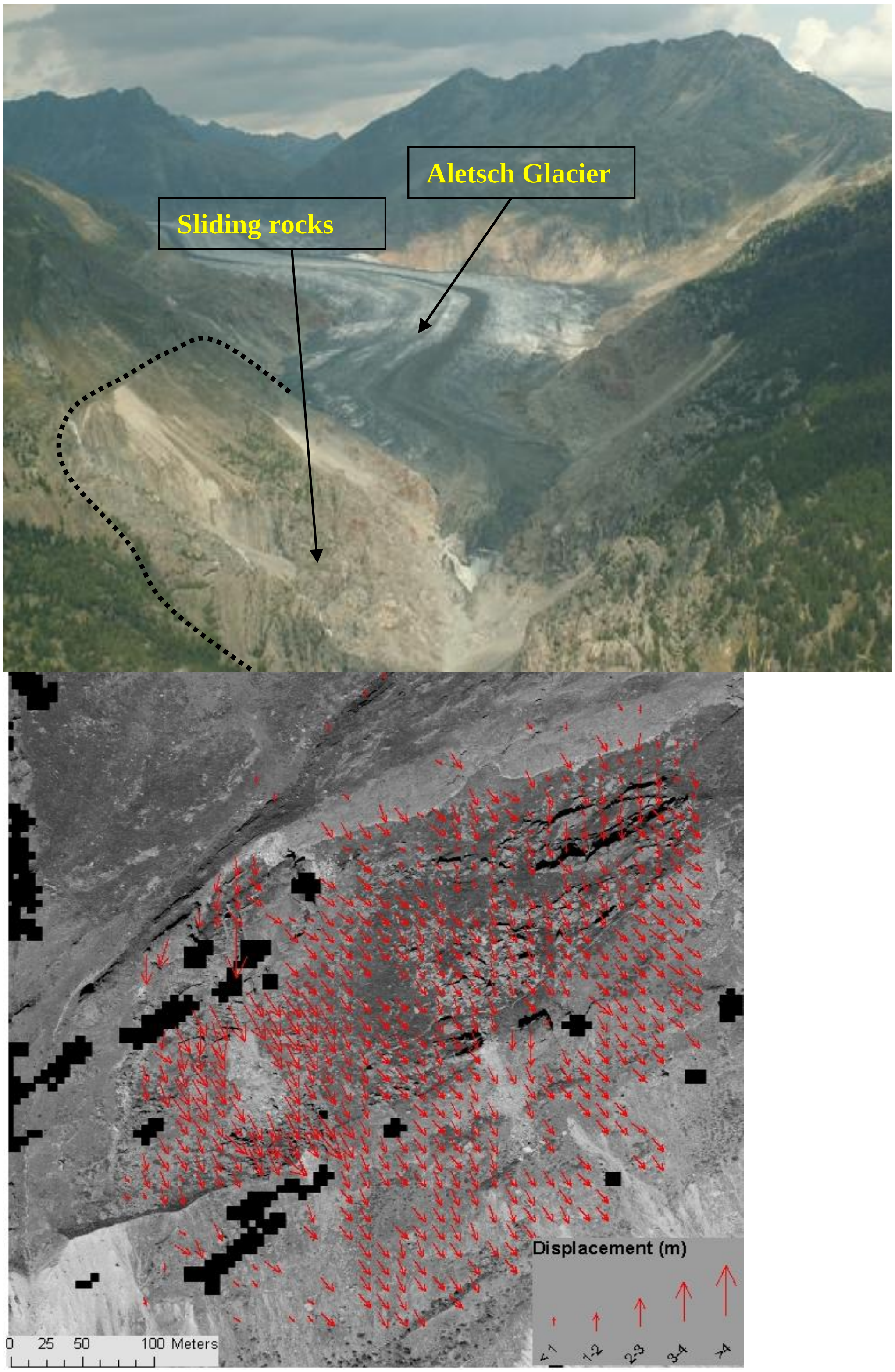


Figure 4.4 Displacement vectors on the Aletsch rockslides of the Swiss alps (1976 – 2006) as estimated by matching aerial orthoimages. The image displayed is from 2006. Aletsch Glacier is to the lower right of the displacement field shown.

Catastrophic landslides are often preceded by initial slow movements that are hardly detected. Precise matching of repeat images can reveal the magnitude and direction of the slow movement. High spatial resolution images taken by the QuickBird satellite was used to measure the surface displacements of the La Clapiere landslide in the southern French Alps (Figures 4.5 and 4.6). The landslide is threatening infrastructure around the town of Saint Etienne de Tinee. The images analyzed were taken on 6 September 2003 and 27 September 2010. Surface displacements on the landslide within the seven-year period were computed using the least squares image matching method. The method is tested on a landslide for its capability to both model deformation and match displacements with very high precision. The results showed about 15 m maximum displacement over the seven years investigated with a mean displacement of 4.5 m.

Figure 4.5 The La Clapiere landslide near the town of Saint Etienne de Tinee, France.

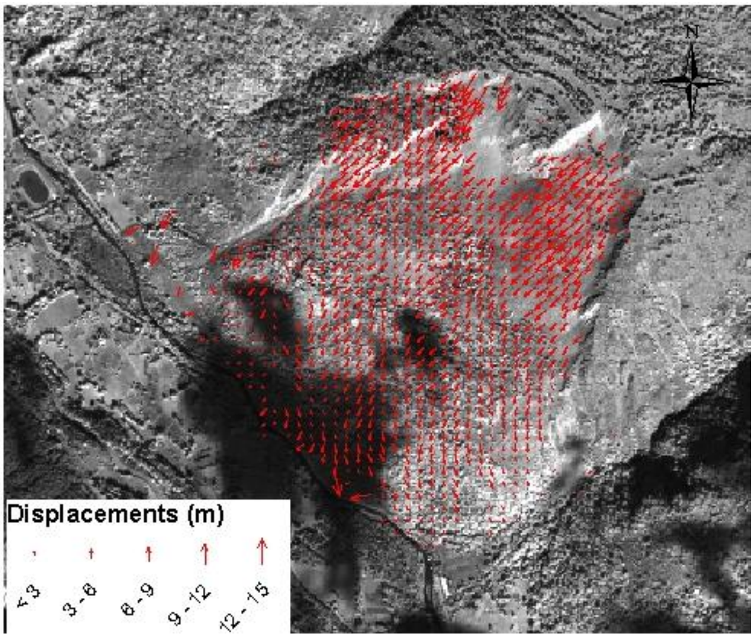


Figure 4.6 Displacement vectors of the La Clapiere landslide

A long temporal baseline in bi-temporal images of Earth surface mass movements leads to a reduced signal-to-noise ratio (SNR) in the matching images. Besides, there is no standard rule as to how to select the size of image patches to be matched. An algorithm that automatically excludes areas lacking adequate SNR and that spatially adapts to the patch size has been developed here. Figure 4.7 shows displacement vectors on the Baltoro glacier, Karakoram, computed using the algorithm that automatically excludes low SNR areas and locally adapts the window sizes. The image pair used was 15-m resolution Landsat7 ETM+ panchromatic images captured on June 16, 2000 and July 27, 2001. Ice flux, as inferred from surface displacements, is an important component in the development of supraglacial and glacier-frontal lakes, in particular on the long, flat and debris-covered glacier tongues found in the Himalaya. Related lakes in the Himalaya contain up to 100 Mio m^3 and more water volume, sometimes dammed just by fragile moraine ridges, and thus pose a high potential disaster magnitude.

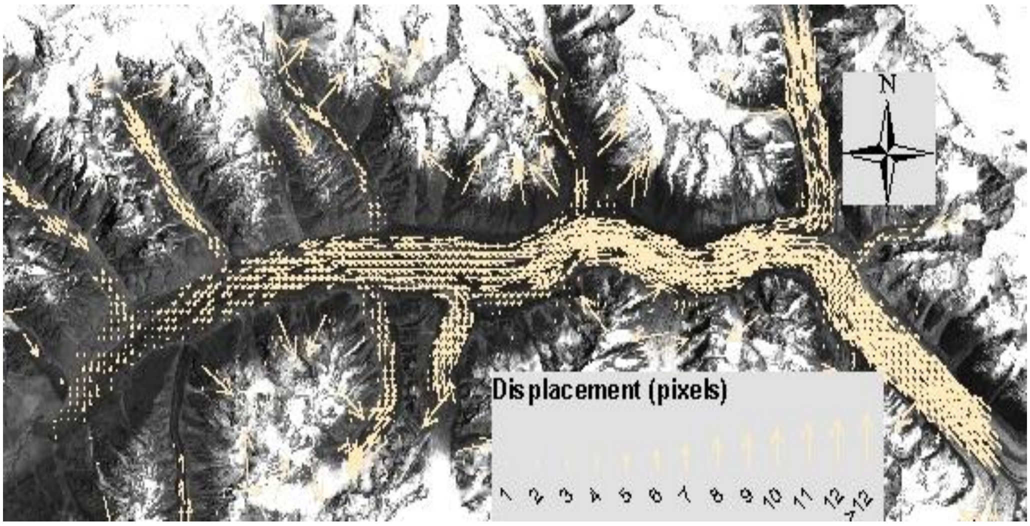


Figure 4.7 Displacement vectors over the Baltoro glacier computed using automated matching of Landsat7 ETM+ panchromatic images captured on June 16, 2000 and July 27, 2001 over a part of the Karakoram Mountains of Pakistan with the spatially adaptive algorithm. Notice that low contrast areas and stable ground are automatically excluded

In conclusion, matching repeat air-borne and space-borne optical images can be used to monitor and analyze the displacement and deformation on Earth surface masses such as slow-moving landslides, rockglacier creep and glacier flow with ever improving precision and reliability. The implication of this development is that the existing collections of remote sensing data, sometimes reaching back several decades, can be used increasingly to detect, reconstruct, monitor and analyze different types of Earth surface mass movements including those related to geohazards.

4.4 Progressive failure in soft, sensitive clay – The process of falling dominos

Quick clay has the fascinating and scary characteristic that it may turn liquid when overloaded. Still, many people in Scandinavia and Canada live in areas with quick clay. As long as the clay is not overloaded the areas will remain stable and safe. But if the toe of a quick clay slope is eroded by a river, or a too heavy road is built on the top of the slope, a retrogressive or progressive failure may develop. In order to build in such areas we need thorough insight into material behavior and numerical simulation tools that enable us to make safe designs. This is one of the reasons for the research within ICG project 5.
As an example consider a modest slope loaded by a fill. The load is assumed large enough to locally overload the quick clay just beneath it. The overloaded soil volume will lose most of it strength; it cannot even carry its own weight and adds to the load on the neighboring soil volume downhill. This downhill neighbor must then carry both the load from the embankment (fill) and the already overloaded soil. This may in turn cause the downhill quick clay to collapses and the process repeats itself in a progressive developing manner. A falling domino effect may be seen. Looking at historical landslides in quick

clay a typical feature is that they all initiate from a relatively small disturbances, before spreading out to cover vast areas. Simulating this process has until recently been impossible, but new numerical simulations at ICG capture most of the mechanisms observed, Figure 4.8.

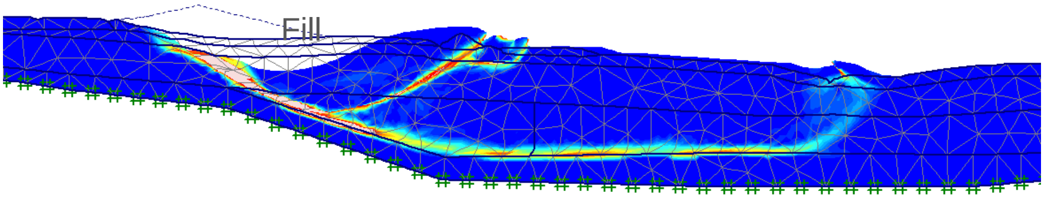


Figure 4.8 Numerical simulations of a slide showing how failure first develops under the fill and then gradually progresses down the slope along the light blue to red coloured shear bands.

4.4.1 Understanding quick clay

Current research within ICG relates in particular to the mechanisms in the clay structure when loaded beyond its maximum capacity with special focus on the zones of failure; the shear bands. This involves activities listed below and is illustrated by Figure 4.9:

- Lab and field experiments
  - Controlled development of simple and composite failure zones in quick clay
  - Small scale model tests
  - Analyses of external and internal response
- Numerical computer analysis
  - Simulation of the processes acting in the failure zone

4.4.2 Lessons learned from the Kattmarka quick clay slide, 13 March 2009

The Kattmarkvegen quick clay slide took place on 13 March 2009 close to the city of Namsos in the middle of Norway. The slide involved between 300,000 and 500,000 m^3 clayey, sensitive soils and destroyed several homes, fortunately without serious injuries to persons. The slide started in an area with ongoing construction for widening a local road. Figure 4.10 shows an overview of the slide from the air, while Figure 4.11 illustrates the progress of the slide following the initial slide marked as number 1. After the event a committee was appointed by the Ministry of Transportation in Norway to study the cause of the slide and see if procedures, rules or regulations should be changed to avoid similar events in the future. The committee was headed by the ICG project 5 manager Steinar Nordal, NTNU with Claes Alén, Chalmers, Leif Jendeby Vägvärket, Einar Lyche, Rambøll, Arnfinn Emdal, NGI, and Christian Madshus, NGI, as members. The work drew upon ICG knowledge and provided measurements and soil data of considerable value to current ICG research.

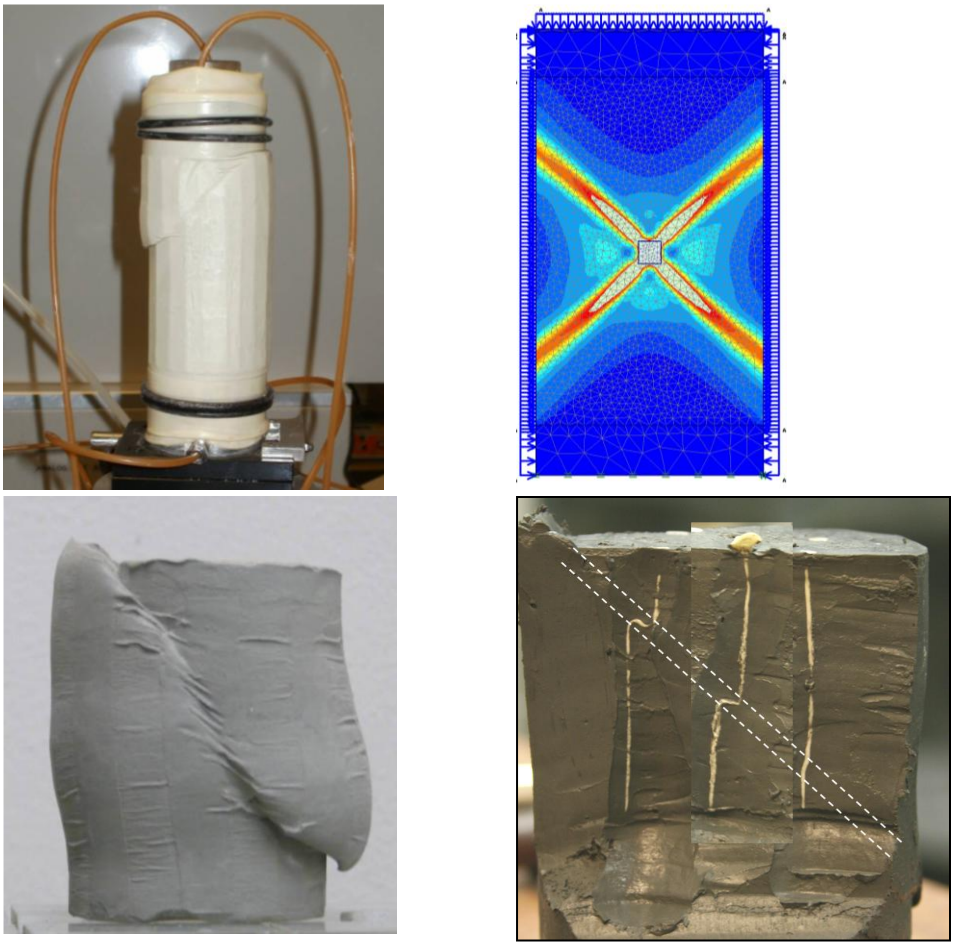


Figure 4.9 Laboratory tests and simulations of narrow failure zones in loaded quick clay samples reveal a complex reaction involving local generation and dissipation of excess pore water pressure.

The investigation confirmed that the slide was initiated by rock blasting under construction work for upgrading the local road. This was concluded after thorough geotechnical and geological investigations, including excavations of slide debris to identify what was left of boreholes for the explosives etc.
Due to most unfortunate geological conditions with weak joints and fault zones, the explosives in blast number 19 actually pushed a vertical face of rock against sensitive clay with such force that the quick clay liquefied and an initial failure took place, Figures 4.12 and 4.13. The initial slide left a 5 meter high steep back scarp in the quick clay terrain from where the slide developed retrogressively across the entire bay area.

A comprehensive laboratory field and laboratory investigation by NTNU, Chalmers and NGI after the slide, revealed highly sensitive materials with partly quick clays in between coarser layers with loose silt and fine sand. Both traditional and more advanced studies of the stability of the bay showed low safety margins already before construction. The road widening project was originally not found extensive enough to require detailed geotechnical investigations and stability evaluations before the slide. Thus the contractor did not know about the vertical rock face against the clay, Figure 5, and that he was blasting about 2 meters from the sensitive clay. Further, he was not sufficiently aware that he operated in a region with low safety. New rules actually proposed before the slide and now implemented, require slope stability evaluations for construction work like in Kattmarka. Additional rules are not found to be needed, but the importance of mapping the subsurface rock/clay interface is stressed.

The energy release in the blasting and numerical simulations of the expected dynamic shock wave supports that the amount of explosives used were quite sufficient to liquefy a considerable volume of soil. Numerical simulations of the stability of the area with this clay region liquefied, predicted failure as observed. The first slide started about half a minute after the blasting, delayed by higher strength of the intact clay for rapid loading.

The Kattmarka slide illustrates the importance of soil investigations, risk mapping and stability evaluations before construction work is initiated The event illustrates the danger of progressive or retrogressive spreading of an instability if an initial slide is triggered in areas with sensitive clays. The key is to fully prevent any initial slide. The Kattmarka slide has pushed us towards a more careful and stricter practice even for small scale construction projects. There is no excuse in the small size of a construction project if the consequences of a slide could be large.

Figure 4.10 Arial view of the Kattmarka slide (Foto: Leif Arne Holme – gjengitt med tillatelse)

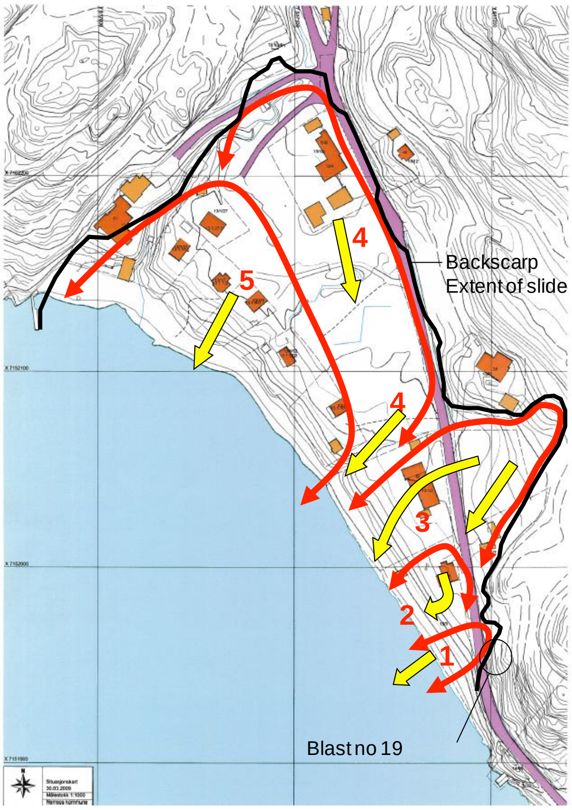


Figure 4.11 The progress of the slide over time based on eye witness reports and observations in the terrain.

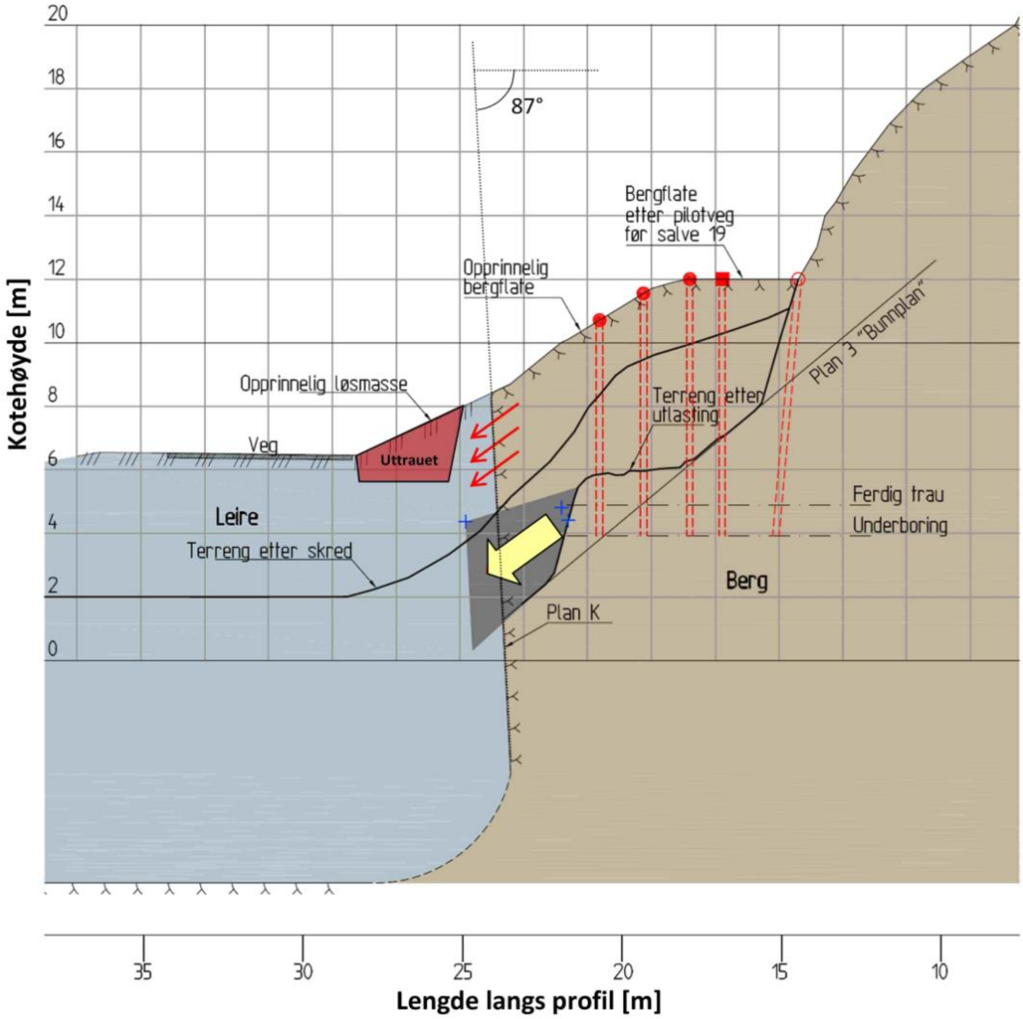


Figure 4.12 A cross section in the south-east north-westerly direction at the site of rock (berg) blasting showing the unknown and highly unfavourable position of the clay (leire) relative to the holes with explosives. The vertical rock face in the centre of the figure (Plan K) was pushed between 0.5 to 1.0 metre out into the clay and caused large volumes of the clay to liquefy. The shaded block marked with the arrow was identified after the slide and revealed that the slide actually was initiated by blasting.

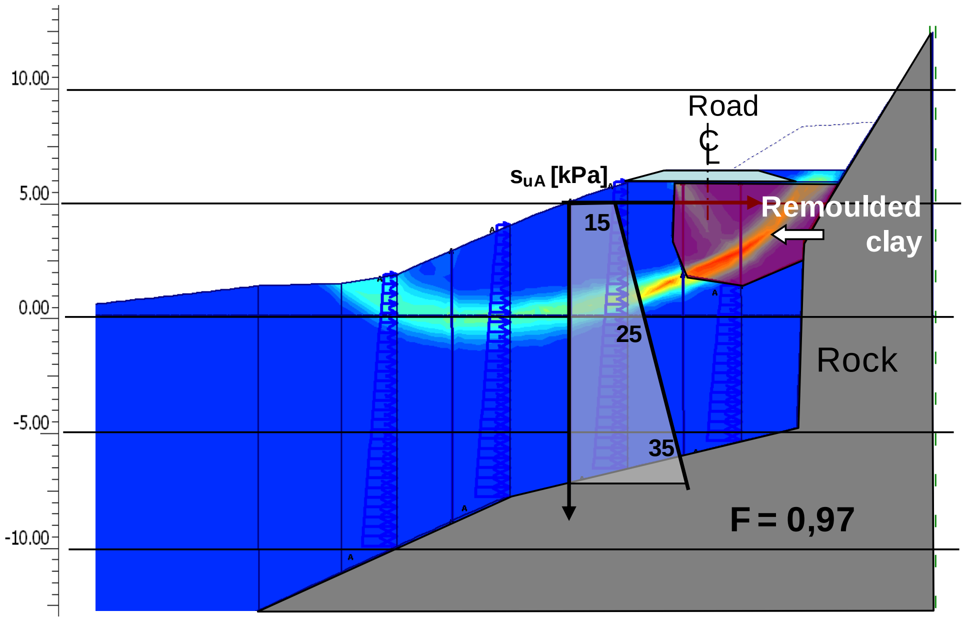


Figure 4.13 Stability simulations using the finite element program with the NGI – ADP soil model shows that remoulding of the clay in the red shaded zone leads to a factor of safety F = 0.97. The profile shown runs towards the sea through zone 1 in Figure 4.11.

5 NATIONAL AND INTERNATIONAL COOPERATION, AND OTHER ICG ACTIVITIES IN 2010

5.1 ICG Publications in 2010

The ICG Publication List for 2010 is given in Appendix A.

5.2 International contacts

Regarding international activities, NGI/ICG continued work on its regional network programme in Asia, which aims to increase the local competence in managing risks associated with different types of landslides.

Several projects in Asia aiming at increasing the local competence in managing risks associated with tsunamis continued in 2010. These projects involved the ICG partners NGI, NORSAR and UiO. These projects have also involved a stronger research related focus on vulnerability issues on a local scale.

The ICG partners NORSAR and NGI are involved in several institutional co-operation projects in India, Pakistan, Bangladesh, Vietnam and Bhutan with focus on problems related to earthquakes, landslides and tsunamis.

Under the leadership of NGU, the ICG project on rockslides started collaboration with several organisations in South American countries where rockslides represent a major geohazard.

In 2010, ICG partners were quite active in research projects sponsored by the European Commission's 7th Framework Programme. An overview of these projects is provided in Section 8.3 of the report.

5.3 Website

The website of ICG is www.geohazards.no. The website was redesigned in 2010 and it is the main channel for disseminating information about ICG to the general public, as well as the specialists.

6 DOCTORAL CANDIDATES AND GUEST RESEARCHERS IN 2010

So far 14 candidates have completed their PhD studies with support of ICG (3 in 2007, 4 in 2008, 5 in 2009, and 2 in 2010). The first table below presents the list of PhD candidates with studies underway or completed in 2010. ICG counted 22 candidates at the end of 2010, and two among them completed their PhD in 2010.

The second table lists the post-doctoral researchers and other guest who spent extended research period at ICG in 2010: two post-docs, two visiting professors and nine visiting researchers, most of whom are completing their PhD's.

ICG's PhD-candidates in 2010

Name	Nationality	University	Financial source	ICG Project
Maj Gøril Glåmen	Norway	NTNU	NTNU	Risk & vulnerability
Guro Grøneng*	**Norway**	**NTNU**	**ICG**	**Rockslides**
Harald Iwe	Norway	UiO	NGI/ICG	Monitoring, RS & GIT
Bård Romstad	Norway	UiO	UiO/ICG	Monitoring, RS & GIT
Trond Nordvik*	**Norway**	**NTNU**	**NTNU**	**Monitoring, RS & GIT**
Samson Degago	Ethiopia	NTNU	NTNU	Geomechanics
Anders Gylland	Norway	NTNU	ICG/NTNU	Geomechanics
Annika Bihs	Germany	NTNU	NTNU	Geomechanics
Magnus Sparrevik	Sweden	NTNU	NGI	Risk & vulnerability
Håkon Heyerdahl	Norway	UiO	NGI	Slope instability
Misganu Debella Gilo	Ethiopia	UiO	UiO	Monitoring, RS & GIT
Hom Nath Gharti	Nepal	UiO	UiO	Earthquake risk
Tom Rune Lauknes	Norway	UiT	ICG/NORUT/NRS	Monitoring, RS & GIT
Chang Shin Gue	Malaysia	Cambridge Univ., UK	NGI/ICG	Offshore geohazards
Sook Ling Lee	Malaysia	Cambridge Univ., UK	NGI/ICG	Offshore geohazards
Rolv Bredesen	Norway	UiO	UiO / Simula	Tsunamis
Håkon Heyerdahl	Norway	UiO	NGI	Slope instability
David Unteregger	Austria	NTNU	NTNU	Geomechanics
Martina Böhme	Germany	NTNU	NGU / NTNU	Rockslides
Ana Priscilla Paniagua	Costa Rica	NTNU	NTNU	Geomechanics
Nele Meyer	Germany	UiO	ICG /RCN	Risk & Vulnerability
Rafael Rodriguez	Mexico	UiO	PEMEX	Offshore geohazards

* *PhD thesis successfully defended and doctoral degree awarded in 2010.*

Post-doctoral and guest researchers at ICG in 2010

Position	Name	Nationality	Academic degree	Financial source
Post-doc.	Dr Jean-Sébastien L'Heureux	Canada	Ph.D.	ICG/NGU
Post-doc.	Dr Sara Bazin	France	Ph.D.	IPGP / ICG
Visiting professor	Dr Gunilla Kaiser	Germany	Ph.D.	Univ. of Kiel
Guest researcher	Ariane Locat	Canada	MSc	ICG
Guest researcher	Filippo Marchi	Italy	MSc	ICG
Guest researcher	Simone Colonnelli	Italy	MSc	ICG / U. Bologna
Guest researcher	Emanuele Intrieri	Italy	MSc	ICG /U. Firenze
Guest researcher	Juan Du	China	MSc	China / ICG
Guest researcher	Cody Jones	USA	MSc	NSF
Guest researcher	Guillaume Sauvin	France	MSc	ICG
Visiting professor	Prof. Kevin Simmons	USA	PhD	Fulbright scholar
Guest researcher	Rowan Swarny	USA	BSc	NSF
Guest researcher	Laura Gruenburg	USA	BSc	NSF

7 ACCOUNTING 2010

7.1 Cash funding (kNOK)

The numbers below are minimum estimates. The actual cash funding from ICG partners and other industrial sources are greater.

Activity	Funding				SUM
	RCN	NGI	NGU/NORSAR/ UiO/NTNU	Other/ Industrial	
Technical Projects	9,210	5,000	5,000	5,500	24,710
Non-technical activities	1,390	500	500	-	2,390
Administration & Steering Committee meetings	1,400	500	-	-	1,900
Total	12,000	6,000	5,500	5,500	29,000

7.2 In kind (kNOK)

The numbers below are minimum estimates. The actual numbers are higher.

Contribution	NGI	NGU	NTNU	UiO	NORSAR	Sum "In kind"
Personnel	2,000	200	0*	0*	200	2,400
IT	500	500	100	100	500	1,700
Office spaces	2,000	600	500	500	300	3,900
Laboratory/Equipment	500	50	100	100	100	850
Project work / proposals/ etc.	1,000	200	500	500	700	2,900
Stipend to PhD-candidates	900	130	1,900	1,300	-	4,230
TOTAL	**6,900**	**1,680**	**3,100**	**2,500**	**1,800**	**15,980**

* Included in "Project work / proposals/ etc."

7.3 Total (kNOK)

The total funding in 2010 is therefore 44,980 kNOK, which is very close to the level of funding of ICG in earlier years.

8 PLANNED ACTIVITIES AND BUDGET FOR 2011

8.1 Research Projects and Education

The following projects were approved for 2011 by the Board of Directors:

- Vulnerability and risk analysis for geohazards
- Earthquake hazard, risk and loss
- Stability of rock slopes
- Geomechanical modelling
- Offshore geohazards
- SafeLand – Living with landslide risk in Europe
- Tsunami modelling and prediction
- Remote sensing, monitoring and early warning systems

In addition, 2 cross-expertise areas that involve several projects have assigned "theme coordinators":

- Applications of geophysics to geohazards
- Prevention and mitigation

The graduate (MSc and PhD) programmes initiated respectively in 2003 and 2005 at UiO and NTNU are continuing.

8.2 International networking

Travels to disaster prevention and natural hazard centres in USA, China, Japan, Canada and Cuba are planned. Active participation (lecturing) in 5-10 international conferences is planned for 2011. In most cases, ICG representatives are asked to give keynote or state-of-the-art lectures.

8.3 EU projects in the 7th Framework Programme

The ICG partners had an impressive success rate in the proposals submitted to the 7th Framework Programme (FP7) in topics related to geohazards. The following FP7 projects with strong ICG participation have already started:

- MOVE (Methods for the Improvement of Vulnerability Assessment in Europe) – Kick-off date: 1 October 2008.
- SafeLand (Living with landslide risk in Europe: Assessment, effects of global change and risk management strategies) – Kick-off date: 1 May 2009 (ICG is the coordinator for SafeLand).
- SHARE (Seismic Hazard Harmonization in Europe) – Kick-off date: 1 June 2009.
- SYNER-G (Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain) – Kick-off date: 11 November 2009.
- MATRIX (New ***M***ulti-H***A***zard and Mul***T***i-***RI***s***K*** Assessment Method***S*** for Europe) – Kick-off date: 18 October 2010.

8.4 IPCC work

ICG's Director Farrokh Nadim is one of the Lead Authors of the IPCC (Intergovernmental Panel on Climate Change) Special Report on "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" (SREX). Other Lead authors from Norway are Prof. Karen O'Brien (University of Oslo) and Dr Åsgeir Sorteberg (University of Bergen). The zero'th and first draft of SREX were completed in 2010. The final version of SREX is planned to be issued in January 2012.

8.5 Organising conferences and workshops in 2011 and 2012

ICG is co-sponsoring (together with NTNU) a seminar and PhD-level course on geodynamics and geotechnical earthquake engineering in October 2011 in Oslo.

2012 is the 10th anniversary of ICG, as well as the last year of the large, integrating FP7 project SafeLand (www.safeland-fp7.eu). To mark these two milestones, ICG is planning to organize a 2- or 3-day seminar on geohazards risk mitigation near the end of 2012.

8.6 ICG budget for 2011

The table below reflects funding from The Research Council of Norway only. Considerable cash and in-kind contributions from the ICG partners and other sources of funding come in addition to the amounts below (see Section 7).

ICG budget in 2011 based on funding from The Research Council of Norway

Activity	Funding from Research Council (kNOK)	Comments	SUM
8 technical projects	9,215	See Section 8.1.	Total for technical projects = kNOK 10,460
Graduate programmes on geohazards	700		
Coordination of 2 themes	545	See Section 8.1.	
IT solutions, EU Proposals, web site & information, conference participation, etc.	800		Total for other activities = kNOK 2,400
International networking	200		
Administration & Steering Committee meetings	1,300		
Contingency	100		
Total	**kNOK 12,860**		

The total expenditure charged to the funds provided by The Research Council of Norway is budgeted to be kNOK 12,860 in 2011. The annual funding from the RCN is 12 MNOK in 2011 and 8 MNOK in 2012. The accumulated unused funds from the RCN in 2010 were about NOK 2.5 mill., which have been transferred to the ICG budgets for 2011 and 2012.

9 REFERENCES

Braathen, A., L. H. Blikra, S. S. Berg and F. Karlsen 2004. "Rock-slope failures in Norway; type, geometry, deformation mechanisms and stability," Norwegian Journal of Geology, 84: 67–88.

Debella-Gilo, M., and Kääb, A., 2011. Sub-pixel precision image matching for measuring surface displacements on mass movements using normalized cross-correlation: Remote Sensing of Environment, v. 115, no. 1, p. 130-142.

Delacourt, C., Allemand, P., Casson, B., and Vadon, H., 2004. Velocity field of the "La Clapière" landslide measured by the correlation of aerial and QuickBird satellite images: Geophys. Res. Lett., v. 31, no. 15, p. 15-19.

Gabriel, A. K., R. M. Goldstein and H. A. Zebker 1989. "Mapping small elevation changes over large areas: Differential radar interferometry," Journal of Geophysical Research, vol. 94, no. B7, pp. 9183–9191, 1989. doi:10.1029/JB094iB07p09183.

Henderson, I. H. C., T. R. Lauknes, P. T. Osmundsen, J. Dehls, Y. Larsen, and T. F. Redfield 2011. "A structural, geomorphological and InSAR study of an active rock slope failure development," Slope Tectonics, Geological Society, London, Special Publications, 351, pp. 185–189, doi:10.1144/SP351.10,.

Henderson, I. H. C., and A. Saintot (in press). "Regional spatial variations in rockslide distribution from structural geology ranking: an example from Storfjorden, western Norway," Slope Tectonics, Geological Society, London, Special Publications.

Kääb, A., 2005. Remote sensing of mountain glaciers and permafrost creep, Zürich, Geographisches Institut der Universität Zürich, 264 p.

Kääb, A., Haeberli, W., and Gudmundsson, G. H., 1997. Analysing the creep of mountain permafrost using high precision aerial photogrammetry: 25 years of monitoring Gruben Rock Glacier, Swiss Alps: Permafrost and Periglacial Processes, v. 8, no. 4, p. 409-426.

Kääb, A., and Vollmer, M., 2000. Surface geometry, thickness changes and flow fields on creeping mountain permafrost: automatic extraction by digital image analysis: Permafrost and Periglacial Processes, v. 11, no. 4, pp. 315-326.

Lauknes, T. R., J. Dehls, Y. Larsen, and L. H. Blikra 2009. "Monitoring of the Åknes rockslide in Storfjorden, Western Norway using corner reflector InSAR," 6th International Workshop on SAR Interferometry: Advances in the Science and Applications of SAR Interferometry (FRINGE 2009), ESA ESRIN, Frascati, Italy, November 30–December 4.

Lauknes, T. R., A. Piyush Shanker, J. F. Dehls, H. A. Zebker, I. H. C. Henderson, and Y. Larsen 2010. “Detailed rockslide mapping in northern Norway with small baseline and persistent scatterer interferometric SAR time series methods,” Remote Sensing of Environment, vol. 114, no. 9, pp. 2097–2109, doi:10.1016/j.rse.2010.04.015.

Massonnet, D., and K. L. Feigl 1998. "Radar interferometry and its application to changes in the Earth’s surface," Reviews of Geophysics, vol. 36, no. 4, pp. 441–500, 1998. doi:10.1029/97RG03139.

Appendix A - ICG Publications in 2010

NOTE: **ICG Publication numbers 1 – 295 are listed in previous ICG Annual Reports. Some earlier references missing in the previous lists are included below, and some of the articles will be published in 2011.**

296. Erener, A. and Düzgün, H.S.B. (2010)
Improvement of statistical landslide susceptibility mapping by using spatial and global regression methods in the case of Møre and Romsdal (Norway)
Landslides, Volume 7, Number 1, March 2010, pp 55-68; DOI 10.1007/s10346-009-0188-x

297. Fenton, C.R., Hermanns, R.L., Blikra, L.H., Kubik, P.W., Bryant, C., Niedermann, S., Meixner, A., and Goethals, M.M. (2010)
Regional ^{10}Be production rate calibration for the past 12 ka deduced from the radiocarbon-dated Grøtlandsura and Russenes rock avalanches at 69° N, Norway
(Submitted to Earth and Planetary Science Letters).

298. Polom, U., Hansen, L., Sauvin, G., L'Heureux, J.-S., Lecomte, I., Krawczyk, C., Vanneste, M. and Longva, O. (2010)
High-resolution SH-wave reflection seismics for characterization of onshore ground conditions in the Trondheim harbor, central Norway.
Book chapter in *Geophysics References*

299. Breien, H., De Blasio, F.V., Elverhøi, A., Nystuen, J.P. and Harbitz, C.B. (2010)
Transport mechanisms of sand in deep-marine environments – insights based on laboratory experiments.
Journal of Sedimentary Research, 2010, v. 80, pp. 975-990, DOI 10.2110/jsr.2010.079

300. B. Kalsnes, F. Nadim & S. Lacasse (2010)
Managing Geological Risk
IAEG, Auckland, New Zealand, Sept. 2010, pp. 111-126, ISBN 978-0-415-60034-7

301. Lacasse, S., Nadim, F. & Kalsnes, B. (2010)
Living with landslide risk
Keynote Lecture, Proceedings International Conference on Slope 2010, Geotechnique and Geosynthetics for Slopes, Chiang Mai, Thailand, pp.83-99

302. Degago, S.A., Grimstad, G., Jostad, H.P., Olsson, M. and Nordal, S. (2010)
Use and misuse of the isotache concept with respect to creep hypotheses A and B.
Accepted for publication in Geotechnique journal.

303. Hansen, L., L'Heureux, J.S. and Longva,O. (2010)
Turbiditic, clay-rich event beds in fjord-marine deposits caused by landslides in emerging clay deposits - paleoenvironmental interpretation and role for submarine mass-wasting.
Sedimentology (2010). doi: 10.1111/j.1365-3091.2010.01188.x

304. Elverhøi, A., Breien, H., De Blasio, F.V., Harbitz, C.B. and Pagliardi, M. (2010)
Submarine landslides and the importance of the initial sediment composition for run-out length and final deposit
Ocean Dynamics (Springerlink.com), 20 p, doi. 10.1007/s10236-010-0317-z.

305. Redfield, T.F., Hermanns, R.L., Oppikofer, T., Duhart, P., Mella, M., Derch, P., Basuñan, I., Arenas, M., Fernandez, J., Sepulveda, S., Rebolledo, S., Löw, S., Yugsi Molina, F.X., Abächerli, A., Henderson, I.H.C., Jaboyedoff, M. and Kveldsvik, V. (2011)
Analysis of the 2007 earthquake-induced Punta Cola rockslide and tsunami, Aysén Fjord, Patagonia, Chile (45.3º S, 73.0° W)
5th International Conference on Earthquake Geotechnical Engineering, Santiago, Chile.

306. Oppikofer, T., Jaboyedoff, M., Pedrazzini, A., Derron, M.-H. and Blikra, L.H. (2010)
Detailed DEM analysis of a rockslide scar to characterize the basal sliding surface of active rockslides
Submitted to the *Journal of Geophysical Research (Earth Surface)* on rockslide studies in the Storfjord area (Møre og Romsdalen).

307. L'Heureux, J.S., Glimsdal, S., Longva, O., Hansen, L., Harbitz, C.B. (2010)
The 1888 shoreline landslide and tsunami in Trondheimsfjorden, central Norway.
Marine Geophysical Researches, DOI 10.1007/s11001-010-9103-z. Published online.

308. Hermanns, R. and Niedermann, S.(2010)
Late Pleistocene - early Holocene paleoseismicity deduced from lake sediment deformation and coeval landsliding in the Calchaquíes valleys, NW Argentina
Submitted to ?????

309. Vanneste M., Madshus, C., Socco, L.V., Maraschini, M., Sparrevik, P.M., Westerdahl, H., Duffaut, K. and Skomedal, E. (2010)
On the use of NGI's prototype seabed-coupled shear wave vibrator for shallow soil characterization – Part I: Acquisition and processing of multi-modal surface waves.
Geophysical Journal International, in press.

310. Socco, L.V., Maraschini, M., Boiero, D., Vanneste, M., Madshus, C., Westerdahl, H., Duffaut, K. and Skomedal, E. (2010)
On the use of NGI's prototype seabed-coupled shear wave vibrator for shallow soil characterization – Part II: Joint inversion of Love and Scholte Surface Waves. *Geophysical Journal International*

311. Verbicaro, M.I., Lang, D.H., Polese, M., Verderame, G.M., and Manfredi, G. (2009)
Development of structural vulnerability functions for schools and hospitals in Central American Countries
XIII Convegno di Ingegneria Sismica (ANIDIS), Bologna (Italy), June 2009.

312. Bommer, J.J., J. Douglas, F. Scherbaum, F. Cotton, H. Bungum and D. Fäh (2010)
On the selection of ground-motion prediction equations for seismic hazard analysis. Seismological Research Letters, 81(5), 772-782.

313. Erduran, E. and Kunnath, S.K. (2010).
Enhanced displacement coefficient method for degrading multi-degree-of-freedom systems.
Earthquake Spectra 26(2), 311-326 (May 2010) [DOI: 10.1193/1.3381157]

314. Erduran, E. and K.L. Ryan (2010)
Effects of torsion on the behavior of peripheral steel-braced frame system, Earthquake Engineering & Structural Dynamics (in press) [DOI: 10.1002/eqe.1032]

315. Erduran, E., J. Crempien, D.H. Lang, C.D. Lindholm, and S. Molina (2010).
Sensitivity of Earthquake Risk Models to Uncertainties in Hazard, Exposure and Vulnerability Models, 14th European Conference on Earthquake Engineering, Ohrid, Macedonia.

316. Ryan, K.L., Erduran, E., Sayani, P. And Dhao, N.D. (2010).
Comparative seismic response of code designed conventional and base-isolated buildings to scenario events.
Proc. 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada, Paper no. 1617.

317. Erduran, E. and Ryan, K.L. (2010).
Torsional behavior of steel braced frames.
Proc. 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada, Paper No. 1080

318. Gutierrez, F.V., Manso, M.A., Lang, D.H., Wachowicz, M. and Bernabe, M.A. and Strauch, W. (2010).

The design of web-enabled services for providing damage estimation maps caused by natural hazards.
Proc. GI4DM 2010 Conference on Geomatics for Crisis Management, Torino (Italy).

319. Lang, D.H., Verbicaro, M.I., Singh, Y., Prasad, JSR, Wong Diaz D. and Gutiérrez, M. (2010).
Structural and non-structural seismic vulnerability assessment for schools and hospitals based on questionnaire surveys: Case studies in Central America and India, Proc. 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada, Paper No. 978

320. Lang, D.H. (2010).
The World Housing Encyclopedia: A means to stimulate seismic risk reduction efforts in developing countries
Extended abstract, Paper No. 1701, 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada.

321. Lecomte, I., Köllner, F., Petrakov, D., Chernomorets, S., Shakhmina, M., Hamran, S.-E., Juliussen, H., and Kääb, A. (2010)
Geophysics in Glacial-hazard Initiation Zones, Russian Caucasus.
Near Surface 2010 conference, 16th European Meeting of Environmental and Engineering Geophysics, Extended Abstracts, Zurich 6-8 September, A39.

322. Glimsdal, S., Løvholt, F., Harbitz, C.B., Smebye, H.C. and Pedersen, G.K. (2010)
An efficient method for establishing a tsunami impact metric and hazard on a regional scale
Proceedings of the Indian Ocean Tsunami Modelling Symposium, Fremantle, Australia, 12-15 October 2010

323. Løvholt, F., Glimsdal, S. and Pedersen, G.K. (2010)
Combining a dispersive tsunami propagation model and the inundation model ComMIT/MOST
Proceedings of the Indian Ocean Tsunami Modelling Symposium, Fremantle, Australia, 12-15 October 2010

324. Lacasse, S. (2010)
Landslide Risk Assessment
XV Peruvian Congress of Geology, Second Symposium for Landslides in the Andes, Cusco, Peru, 27 September-1 October 2010.

325. Harbitz, C.B., Romstad, B., Glimsdal, S., Domaas, U. and Løvholt, F. (2010)
Hazard and risk assessment of rock slide tsunamis in lakes and fjords.
Proceedings of the International Conference Mountain Risks: Bringing Science to Society, Firenze, Italy, 24-26 November 2010, (in press)

326. Degago, S.A. (2011)
Analysis of Väsby test fill using creep hypothesis A and B
IACMAG 2011 conference.

327. Paniagua, P. & Nordal, S. (2011)
Three dimensional FE simulations of bearing capacity of footings with focus on shape factors.
Proc., Second International Symposium on Computational Geomechanics (ComGeo II) Cavtat-Dubrovnik, Croatia, 27-29 April.

328 Hanssen, S.B., Gylland, A.S., and Nordal, S. (2011)
Simulation of the Smaaroed Landslide in Soft Sensitive Clay Using a Rate Dependent, Strain Softening Material Model.
Proc., Second International Symposium on Computational Geomechanics (ComGeo II) Cavtat-Dubrovnik, Croatia, 27-29 April.

329. Fabio Vittorio De Blasio, Hedda Breien and Anders Elverhøi (2010)
Modelling a cohesive-frictional debris flow: an experimental, theoretical, and field-based study.
Earth Surface Processes and Landforms

330. Gylland A.S., Nordal S., Jostad, H.P. & Mehli, M. (2011)
Pragmatic Stability Estimation for Progressive Slope Failure in Soft Sensitive Clay.
Proc., Second International Symposium on Computational Geomechanics (ComGeo II) Cavtat-Dubrovnik, Croatia, 27-29 April.

331. Li, Z., Huang, H., Nadim; F. and Xue, Y. (2010)
Quantitative Risk Assessment of Cut-Slope Projects under Construction
Journal of Geotechnical and Geoenvironmental Engineering © ASCE, december 2010, pp. 1644-1654.

332. Harbitz, C., F. Løvholt, U. Domaas, S. Glimsdal, & B. Romstad (2010)
Hazard and risk assessment of rock slide tsunamis in lakes and reservoirs
Proceedings ICOLD symposium.

333. Haugen, E.D. and Kaynia, A.M. (2008)
A comparative study of empirical models for landslide prediction using case histories. *Proc. 14th World Conf. on Earthquake Engineering,* Beijing, China, 12-17 Oct., Paper 04-02-0022.

334. Madani Syed, N., Maheshwari, B.K., Kaynia, A.M. (2009).
Numerical modelling for liquefaction using simple constitutive models. *Proc. ACSGE, Int. Conf. on Advances in Concrete, Structural and Geotechnical Engineering*, Oct. 25-27, Pilani, India.

335. Erduran, E, Dao, N.D., and K.L. Ryan (2010).
Comparative response assessment of minimally compliant low-rise conventional and base-isolated steel braced frames, *Earthquake Engineering & Structural Dynamics* (DOI: 10.1002/eqe.1078).

336. Gharti, H.N., Oye, V., Roth, M. and Kühn, D. (2010).
Automated microearthquake location using envelope stacking and robust global optimization.
Geophysics, Vol. 75, No. 4, MA27-MA46. 10.1190/3432784

337. Mundepi A.K., Galiana-Merino, J.J., Kamal and Lindholm, C.D. (2010).
Soil characteristics and site effect assessment in the city of Delhi (India) using H/V and *f–k* methods.
Soil Dynamics and Earthquake Engineering **30** (2010), 591–599 doi:10.1016/j.soildyn.2010.01.016.

338. Gharti, H. N., V. Oye, M. Roth, and V. Maupin (2010).
Microearthquake location using envelope stacking and robust global optimization -- application to mine and rock slope monitoring.
Abstract, *Doctoral Student Congress, IPGP*, France.

339. Haldar, P., Singh, Y., Lang, D.H. and Paul, D.K. (2010).
IVARA – A tool for seismic vulnerability and risk assessment of Indian Housing.
Proc. 14th Symposium on Earthquake Engineering Indian Institute of Technology, pp. 1405-1415, Roorkee, December 17-19, 2010.

340. Khose, V.N., Singh, Y. and Lang, D.H. (2010).
Limitations of Indian seismic design codes for RC buildings.
Proc. 14th Symposium on Earthquake Engineering Indian Institute of Technology, pp. 1416-1423, Roorkee, December 17-19, 2010.

341. Lang, D.H., Singh, Y., Verbicaro, M.I., and Prasad, JSR (2010).
Index-based methodology for structural and non-structural vulnerability assessment of schools and hospitals.
Proc. 14th Symposium on Earthquake Engineering Indian Institute of Technology, pp. 1395-1404, Roorkee, December 17-19, 2010.

342. Lindholm, C.D. & the Indo-Norwegian project team (2010).
The Indo-Norwegian institutional cooperation on earthquake risk reduction.
Proc. 14th Symposium on Earthquake Engineering Indian Institute of Technology, pp. 1305-1322, Roorkee, December 17-19, 2010.

343. Kaynia, A.M., Saygili, G. and Skurtveit, E. (2010).
Earthquake-induced landslides using Shakemaps.

Proc. 14th European Conference on Earthquake Engineering, Ohrid, Republic of Macedonia, August 30 – September 3, 2010. Paper No. 1753.

344. Gharti, H. N., J. Tromp, V. Oye, and M. Roth (2010).
Seismic wave propagation modeling based on the Spectral Element Method - Applications to microearthquakes and acoustic emission.
Petroleum Geology and Geophysics seminar, Oslo University.

345. Lang, D.H., S. Molina, C.D. Lindholm, E. Erduran, J. Crempien, M. Belen Benito, V. Gutiérrez C. (2010).
Earthquake Hazard and Risk Assessment in Central America.
2010 Meeting of the Americas, Foz do Iguacu, Brazil.

346. Roth, M. and Blikra, L. H. (2009).
Seismic monitoring of the unstable rock slope at Åknes, Norway, *Geophysical Research Abstracts,* Vol. 11, EGU2009-3680, EGU General Assembly 2009.

347. Roth, M. and Blikra, L. H. (2010).
Seismic monitoring of the unstable rock slope at Åknes, Norway.
Book of extended abstracts, Open workshop within the frame of the EU FP7 "SafeLand" Project. February 24th, 2010, Vienna. *Berichte der Geologischen Bundesanstalt* 82, ISSN 1017-8880 - Landslide Monitoring Technolgies & early Warning Systems, pp. 67-68. (Eds. Supper, R. and Baron, I.).

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