XV Congreso Peruano de Geología. Resúmenes Extendidos.
Sociedad Geológica del Perú, Pub. Esp. N° 9 (2010), Cusco p. 316-319

SYSTEMATIC MAPPING OF UNSTABLE ROCK SLOPES WITH THE POTENTIAL OF FORMING ROCK AVALANCHES IN NORWAY

Hermanns, R. L. (1), Anda, E. (2), Saintot, A. (1), Henderson I. (1), Dahle, H. (2), Böhme, M. (1), Dehls, J. (1), Blikra L.H. (3), Lauknes, T.R. (4), Redfield, T. (1), Oppikofer, T. (1), Fischer, L. (1), Bunkholt, H. (1), and Eiken, T., E. (5)

(1)NGU, Norges geologiske undersøkelse. reginald.hermanns@ngu.no
(2)The county of Møre og Romsdal. Norway.
(3)Åknes Tafjord Beredskap IKS, Stranda, Norway.
(4)NORUT Tromsø, AS. Norway.
(5)University of Oslo, Norway.

ABSTRACT

Historically, large rock slope failures impacting into a fjord and causing a several tens of meter high displacement wave have been one of the natural hazards in Norway claiming most of lives. Since 5 years the Norwegian Geological Survey has started a systematic mapping approach to characterize unstable rock slopes prone to cause catastrophic failures so that future events can be recognized before they happen and society can adapt to the hazard. So far systematic mapping has been carried out in three provinces and 253 unstable slopes have been found. Of these sites 58 are monitored periodically at the moment and 3 have been characterized as high risk objects and continuous monitoring systems installed. Mapping is carried out with a risk approach focussing only on those sites where settlements or transportations routes can be affected. Rock slope mapping is a two step approach, first focussing on regional mapping and second on a detailed analysis of the object including the analyses of slide kinematic, velocity of the slide accompanied with other indicators of slide activity and an analysis of recurrence of previous events in the surrounding of the unstable rock slopes.

INTRODUCTION

In the 20th century three rock avalanches occurred in Norway, all of them impacting into a lake or a fjord causing displacement waves with run up heights of several tens of meters. These events caused a total of 175 casualties. Historic documents indicate that this number was similar also in previous centuries. This makes rock avalanching the natural hazard which claimed second largest number of lives in Norway topped only by snow avalanches. However in contrast to snow avalanches which claimed most victims in open mountain terrain or along transport corridors all victims caused by rock avalanches were caused in settlements. Therefore in contrast to snow avalanches, where potential victims voluntarily move into the hazard zone, victims of rock avalanches live within the hazard zone. A systematic mapping approach focussing on characterizing unstable slopes prone to fail catastrophically in future has a high potential to reduce victims during future natural disasters if monitoring systems coupled with early-warning systems get installed, the population warned and evacuated from the hazard area. This paper focuses on the systematic mapping approach in Norway to characterize unstable slopes, while scientific and technical challenges on the early-warning systems have been discussed in a previous paper (Blikra et al., 2008).

GEOLOGICAL SETTING

The landscape of Norway is characterised by an extreme alpine relief with steep slopes, heavily over-steepened U-shaped glacial valleys reaching below sea level and forming a several tens of thousands kilometre long coast line with strongly ramified fjords intruding into the continent for up to 200 km. The bedrock comprises mainly metamorphic rocks of Precambrian to Palaeozoic age. The bedrock is highly tectonized due to protracted intense ductile and brittle tectonics acting since Precambrian times over the entire region. In the Quaternary multiple glacial cycles covered the landscape with kilometre thick ice caps and eroded into the fault controlled valleys and causing loading and isostatic rebound. The high concentration of structures due to tectonics and glacial unloading in the bedrock and the steepness of the relief would be the two main parameters that render the slope susceptible to development of large gravitational rock-slope deformation (e.g. Braathen et al. 2004; Saintot et al. 2010).

METHODOLOGY

Two principal assumptions are the base of our mapping and monitoring approach: A) that large rock slope deformation occurs prior to catastrophic failure and B) that there is an acceleration phase prior to collapse. The development of historic catastrophic events in Norway (Hermanns et al., 2006) support that these assumptions are realistic especially for the tectonic setting of Norway along a passive continental margin were high magnitude earthquakes have been absent in the historic past. In addition these observations also fit with the development of large rock slope failures in other mountain areas in the world.

Do to the large size of the mountainous area in Norway, systematic mapping has up to now concentrated on three provinces only: Møre og Romsdal, Sogn og Fjordane, Troms country. These are the provinces with most historic large rock slope failures and most victims in the past centuries. Further provinces will be systematically mapped using frequency of failures in the past and an analysis of potential risk (relation of events in the past and elements at risk).

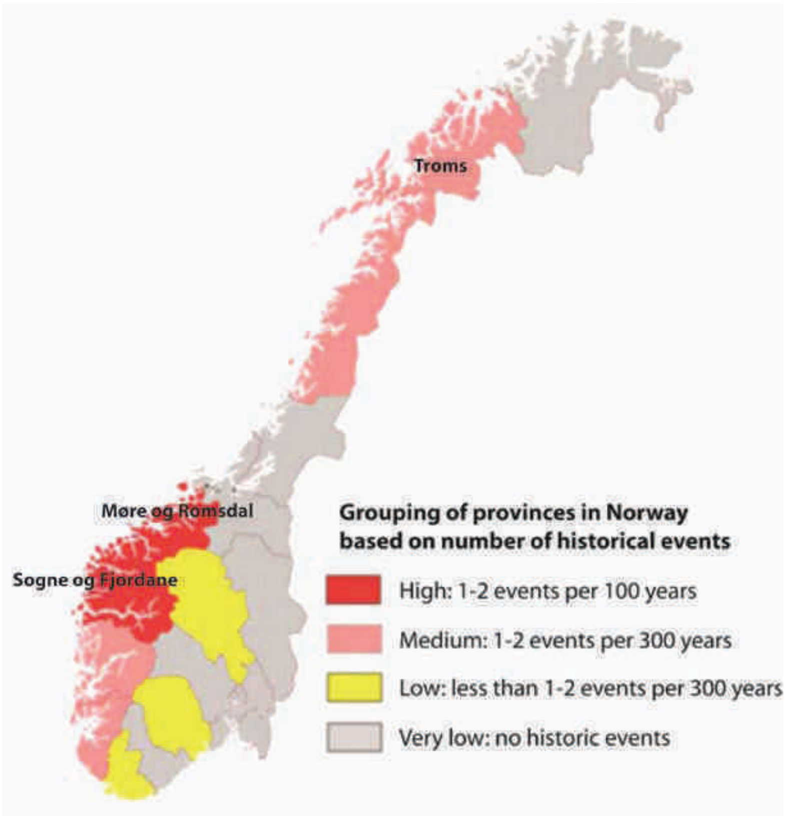

Figure 1: Analyses of historic large rock slope failures in Norway (after Høst 2006).

Systematic mapping is based on a wide range of approaches including remote sensing using InSAR satellite images on a scale of various hundreds of square kilometre (Lauknes et al., 2010), systematic mapping using high and low resolution aerial photographs, helicopter reconnaissance on fjord or valley scale, airborne LIDAR analyses on the fjord and valley scale (Oppikofer & Jaboyedoff, 2008), field mapping and interrogations of local population.

RESULTS OF SYSTEMATIC MAPPING

Figure 2: Inventory of unstable large rock slopes in the Møre og Romsdal, Sogn og Fjordane and Troms county.

Our systematic analyses in the Møre og Romsdal, Sogn og Fjordane and Troms counties is ongoing and new sites are likely to be added. 3-5 years of systematic mapping in these three provinces resulted in a number of 253 unstable rock slopes (Böhme et al., in press, Saintot et al., in press., Henderson et al., 2010).
Once potential rock slope instabilities have been recognized a preliminary risk assessment is carried out. This is to divide the potential unstable rock slopes in three groups: a) those where a rock slope failure or a secondary effect of the rock slope failure (rockslide triggered tsunami, rockslide dam) can effect residents, b) those where a rock slope failure or a secondary effect of the rock slope failure (rockslide triggered tsunami, rockslide dam) can effect a transportation route, and c) those where no settlement or transportation route can be effected.

Further detailed investigations are only carried out at sites were either settlement or transportations routes can be affected by a potential rock slope failure. Detailed investigation focus on understanding the recurrence of historic and prehistoric large failures in the area of the slope instability, developing a kinematic model of the unstable rock slope, determining the state of activity of the unstable rock slope and assessing based on those observations a relative ranking of hazard and likelihood of future failure. A quantitative hazard and risk classification of unstable rock slopes is in preparation (Hermanns et al., 2010).
The recurrence of past events is determined by absolute and relative dating of deposits of rock slope failures. The kinematic model is developed based on detailed structural analyses using structural mapping in the field, airborne and ground based LIDAR data. Repeated high accuracy GPS measurements and repeated ground based LIDAR measurements as well as RADAR measurements on selected sites are used to verify the

kinematic model (Oppikofer et al., 2009; Osmundsen et al., 2009; Lauknes et al., 2010). The state of activity of the slope is determined in a first step by using satellite InSAR data (Lauknes et al., 2010, Henderson et al., 2010), damage to vegetation and historic rock fall activity. At those sites with apparent ongoing activity, slide velocities are determined using differential GPS measurements with annual or multiannual repetition cycles, InSAR analyses and repeated LIDAR scanning. A total of 58 sites is monitored by these techniques at present. Slide velocities at those sites range between under detection limit over a 3 years period up to ~10 cm/year. Those sites with high movement velocities and a slide kinematic favouring failure are classified as high risk objects and recommended to be continuously monitored. At present three such sites are established in Norway and early-warning systems have been installed or are under construction.

CONCLUSIONS

In Norway unstable rock slopes get mapped systematically. The approach is risk based starting with mapping activities in those provinces with highest number of historic incidents and focussing on those slopes in areas with settlement or transportation routes. So far systematic mapping has been carried out in three provinces resulting in 253 sites characterized as unstable slopes. Of these sites 58 are monitored periodically and three sites have been characterized as high risk objects yet. High risk objects are monitored continuously and early-warning systems have been installed or are in progress to be installed.

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