Geophysical Research Abstracts
Vol. 14, EGU2012-10051, 2012
EGU General Assembly 2012

A hazard and risk classification system for catastrophic rock slope failures in Norway

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The Geological Survey of Norway carries out systematic geologic mapping of potentially unstable rock slopes in Norway that can cause a catastrophic failure. As catastrophic failure we describe failures that involve substantial fragmentation of the rock mass during run-out and that impact an area larger than that of a rock fall (shadow angle of ca. 28-32° for rock falls). This includes therefore rock slope failures that lead to secondary effects, such as a displacement wave when impacting a water body or damming of a narrow valley. Our systematic mapping revealed more than 280 rock slopes with significant postglacial deformation, which might represent localities of large future rock slope failures. This large number necessitates prioritization of follow-up activities, such as more detailed investigations, periodic monitoring and permanent monitoring and early-warning. In the past hazard and risk were assessed qualitatively for some sites, however, in order to compare sites so that political and financial decisions can be taken, it was necessary to develop a quantitative hazard and risk classification system. A preliminary classification system was presented and discussed with an expert group of Norwegian and international experts and afterwards adapted following their recommendations. This contribution presents the concept of this final hazard and risk classification that should be used in Norway in the upcoming years.

Historical experience and possible future rockslide scenarios in Norway indicate that hazard assessment of large rock slope failures must be scenario-based, because intensity of deformation and present displacement rates, as well as the geological structures activated by the sliding rock mass can vary significantly on a given slope. In addition, for each scenario the run-out of the rock mass has to be evaluated. This includes the secondary effects such as generation of displacement waves or landslide damming of valleys with the potential of later outburst floods. It became obvious that large rock slope failures cannot be evaluated on a slope scale with frequency analyses of historical and prehistorical events only, as multiple rockslides have occurred within one century on a single slope that prior to the recent failures had been inactive for several thousand years. In addition, a systematic analysis on temporal distribution indicates that rockslide activity following deglaciation after the Last Glacial Maximum has been much higher than throughout the Holocene. Therefore the classification system has to be based primarily on the geological conditions on the deforming slope and on the deformation rates and only to a lesser weight on a frequency analyses.

Our hazard classification therefore is primarily based on several criteria: 1) Development of the back-scarp, 2) development of the lateral release surfaces, 3) development of the potential basal sliding surface, 4) morphologic expression of the basal sliding surface, 5) kinematic feasibility tests for different displacement mechanisms, 6) landslide displacement rates, 7) change of displacement rates (acceleration), 8) increase of rockfall activity on the unstable rock slope, 9) Presence post-glacial events of similar size along the affected slope and its vicinity.

For each of these criteria several conditions are possible to choose from (e.g. different velocity classes for the displacement rate criterion). A score is assigned to each condition and the sum of all scores gives the total susceptibility score. Since many of these observations are somewhat uncertain, the classification system is organized in a decision tree where probabilities can be assigned to each condition. All possibilities in the decision tree are computed and the individual probabilities giving the same total score are summed. Basic statistics show the minimum and maximum total scores of a scenario, as well as the mean and modal value. The final output is a cumulative frequency distribution of the susceptibility scores that can be divided into several classes, which are interpreted as susceptibility classes (very high, high, medium, low, and very low).

Today the Norwegian Planning and Building Act uses hazard classes with annual probabilities of impact on buildings producing damages (<1/100, <1/1000, <1/5000 and zero for critical buildings). However, up to now there is not

enough scientific knowledge to predict large rock slope failures in these strict classes. Therefore, the susceptibility classes will be matched with the hazard classes from the Norwegian Building Act (e.g. very high susceptibility represents the hazard class with annual probability >1/100). The risk analysis focuses on the potential fatalities of a worst case rock slide scenario and its secondary effects only and is done in consequence classes with a decimal logarithmic scale. However we recommend for all high risk objects that municipalities carry out detailed risk analyses.

Finally, the hazard and risk classification system will give recommendations where surveillance in form of continuous 24/7 monitoring systems coupled with early-warning systems (high risk class) or periodic monitoring (medium risk class) should be carried out. These measures are understood as to reduce the risk of life loss due to a rock slope failure close to 0 as population can be evacuated on time if a change of stability situation occurs. The final hazard and risk classification for all potentially unstable rock slopes in Norway, including all data used for its classification will be published within the national landslide database (available on www.skrednett.no).