Hazard assessment in Switzerland – Codes of Practice for mass movements

H. Raetzo · O. Lateltin · D. Bollinger · J.P. Tripet

Abstract More than 6% of Switzerland is prone to slope instability. New federal regulations require regional authorities (cantons) to generate natural hazard maps and the zoning of mass movements to restrict development on hazard-prone land. The paper discusses the proposed three-step procedure of hazard identification, hazard assessment and risk management. The Codes of Practice concerning the hazard maps involve the standard use of three colours (red, blue and yellow) to indicate areas of prohibited construction, construction with certain safety requirements and construction without restriction.

Résumé Plus de 6% du territoire suisse est soumis à des phénomènes d'instabilités de terrain. De nouvelles bases légales exigent des autorités régionales l'établissement de cartes de danger et le zonage pour les mouvements de terrain afin de restreindre le développement dans les zones sensibles. Une procédure en trois étapes comprend l'identification du danger, l'évaluation du danger et la gestion du risque. L'application dans l'aménagement de ces cartes de danger peut être résumée ainsi: dans les zones rouges les constructions sont interdites, dans les zones bleues les constructions sont autorisées lorsque des prescriptions techniques de sécurité sont respectées et dans les zones jaunes les constructions sont autorisées.

Keywords Hazard maps · Hazard assessment · Codes of Practice · Landslides · Switzerland

Mots clés Analyse de dangers · Cartes de danger · Recommandations · Glissements · Suisse

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Introduction

Switzerland is a country exposed to many natural hazards. Concerted efforts have been made to apply the same strategy and similar approaches for dealing with all kind of natural hazards. Therefore the assessment of landslides and rockfalls is carried out in a similar manner as that used for the evaluation of floods, debris flows and snow avalanches. More than 6% of Switzerland is affected by hazards due to slope instability. These areas occur mainly in the Alps and Pre-Alps. The Randa rock avalanches of 1991 are a good example of the potential of such hazards. Thirty million cubic metres of fallen debris cut off the villages of Zermatt, Täsch and Randa from the outside world for 2 weeks. In another case, in 1994, a prehistoric landslide was reactivated with historically unprecedented rates of displacement of up to 6 m/day, causing the destruction of the village of Falli-Hölli which contained 41 houses. Future climatic warming and degradation of forests could lead to increased debris flows in the periglacial belt of the Alps.

The legal and technical background conditions for protection against landslides have undergone considerable changes over the past few years. The flooding of 1987 resulted in the federal authorities reviewing the criteria governing natural hazard protection. The Federal Flood Protection Law and the Federal Forest Law came into force in 1991. Their purpose is to protect the environment, human lives and property from the damage caused by water, mass movements, snow avalanches and forest fires. Following the promulgation of these new regulations, greater emphasis has been placed on preventative measures. Consequently, hazard assessment, the identification of protection objectives, purposeful planning of preventative measures and the limitation of the residual risk are of central importance in a three-step prevention procedure (Anonymous 1997a, 1997b). The cantons are now required to establish registers and maps denoting areas of hazards and to take them into account in their guidelines for land-use planning. For the improvement of the hazard registers and the hazard maps, the federal government provides

subsidies to the cantonal authorities for up to 70% of the costs incurred.
The paper describes the three-step procedure with particular reference to mass movements.

First step: hazard identification

Classification of landslides

Landslides can be classified according to the estimated depth of the sliding plane (<2 m: shallow; 2–10 m: intermediate; >10 m: deep) and the long-term mean velocity of the movements (<2 cm/year: sub-stabilised; 2–10 cm/year: slow; >10 cm/year: active). These depth and velocity parameters are not always sufficient to estimate the potential danger of a landslide. Differential movements must also be taken into account as they can initiate the toppling of buildings or opening of cracks.
Rockfalls are characterized by their speed (<40 m/s), the size of their elements (stone diameter <0.5 m, block diameter >0.5 m) and the volumes involved. Rock avalanches with huge volumes (>1 million m^3) and high speed (>40 m/s) can also occur, although these are rare. Due to the heavy precipitation, debris flows and very shallow landslides are frequent in Switzerland. These are moderate in volume (<20,000 m^3) and of high speed (1–10 m/s). These phenomena are very dangerous and annually cause fatalities and important traffic disruptions.

Maps of landslide phenomena

A map of landslide phenomena and an associated technical report record evidence and indications of slope instability as observed in the field. The map presents phenomena related to dangerous processes and delineates the vulnerable areas. Field interpretation of these phenomena allows areas vulnerable to landslides to be mapped. This is based on the observation and interpretation of landforms, on the structural and geomechanical properties of slope instabilities and on historical traces of previous slope failure (Raetzo-Brülhart 1997). Extensive knowledge of past and current events in a catchment area is essential if zones of future instability are to be identified.
Some recommendations for the uniform classification, representation and documentation of natural processes have been established by the Swiss federal administration. Consequently, the definition of features on a natural hazard map are based on a uniform legend for landslides, floods and snow avalanches. The different phenomena are represented by different colours and symbols. An additional distinction is made between potential, inferred or proved events. According to the scale of mapping (e.g. 1:50,000 for the Master Plan, 1:5,000 for the Local Plan), this legend may contain a large number of symbols. This approach allows maps from different parts of the country to be easily compared.

Register of events

Recommendations for the definition of a uniform register for slope instability events have been developed, including special sheets for each phenomenon (landslides, floods, snow avalanches). For landslides the Federal Office for Water and Geology (FOWG) is working on a register of events called "InfoSlide"; these features will be introduced into the World Landslide Inventory. For natural hazards in general, each canton is currently compiling the data for its own register. These databases, called "StoreMe", are transferred to the Federal Forest Agency to allow an overview of the different natural disasters and potential associated damage in Switzerland.

Second step: hazard assessment

Hazard is defined as the occurrence of a potentially damaging natural phenomenon within a specific period of time in a given area. Hazard assessment implies the determination of the magnitude or intensity of an event over time. Mass movements often correspond to gradual (landslides) or unique (falls, debris flows) events. It is sometimes difficult to make an assessment of the return period of a massive rock avalanche, or to predict when a dormant landslide may reactivate. For processes such as floods or debris flows, it is much easier to evaluate the event intensity and the associated return period.
Some federal recommendations for land-use planning in landslide-prone areas (Anonymous 1997a, 1997b) and in flood-prone areas (Anonymous 1997c, 1997d) have been proposed to cantonal authorities and to planners, to allow for the development of hazard maps using an intensity/probability diagram. Since 1984 similar recommendations have existed for snow avalanches (Anonymous 1984a, 1984b).

Hazard maps

Hazard maps, according to the federal "recommendations" (guidelines), express three degrees of danger, represented by corresponding colours: red, blue and yellow (Fig. 1 and Table 1). The various hazard zones are delineated according to the landslide phenomena maps, the register of slope instability events and, if necessary, additional basic documents. Numerical models (analysis of block trajectories, calculations of factors of safety) may sometimes be used to determine the extent of the areas endangered by rockfalls, or to present quantitative data on the stability conditions of a potentially unstable area.

Degrees of danger

A chart of the degrees of danger has been developed in order to guarantee a homogeneous and uniform means of assessment of the different kinds of natural hazards affecting Switzerland (floods, snow avalanches, landslides, etc.); see Fig. 1. Two major parameters are used to classify the danger: the intensity and the probability (frequency or return period). Three degrees of danger have been defined. These are represented by the colours red, blue and yellow. The estimated degrees of danger have implications for land use. They indicate the level of danger to people and to animals, as well as to property. In the case of mass movement, people are considered safer inside the buildings than outside.

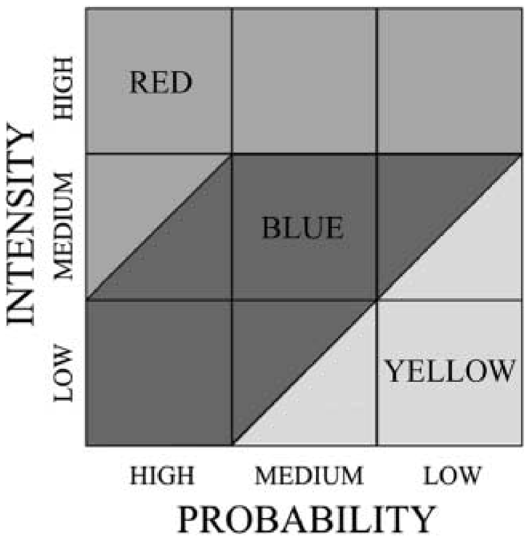

Fig. 1
Chart of the degrees of danger for fall and earth flow processes

Intensity and criteria

A description of the magnitude of damage that could be caused by an event is based on the identification of threshold values for degrees of danger, according to possible damage to property. The intensity parameter is divided into three degrees: (1) high intensity: people and animals are at risk of injury inside buildings; heavy damage to buildings or even destruction of buildings is possible; (2) medium intensity: people and animals are at risk of injury outside buildings, but are at low risk inside buildings; lighter damage to buildings should be expected; and (3) low intensity: people and animals are slightly threatened, even outside buildings (except in the case of stone and block avalanches, which can harm or kill people and animals); superficial damage to buildings should be expected.

Criteria for the intensity assessment

There is no generally applicable measure to define the intensity of slope movements. However, indicative values can be used to define classes of high, medium and low intensity (see Table 2). Applied criteria usually refer to the zone affected by the process, or to the threatened zone. For rockfalls, the significant criterion is the impact energy in the exposed zone (translation and rotation energy). The 300 kJ limit corresponds to the impact energy that can be resisted by a reinforced concrete wall, as long as the structure is properly constructed. The 30 kJ limit corresponds to the maximum energy that oak-wood stiff barriers can resist (e.g. rail sleepers). For rock avalanches, the high intensity class ($E > 300$ kJ) is always reached in the impact zone. The target zones affected by block avalanches

Table 1
Hazard maps, according to the federal "recommendations" (guidelines), express three degrees of danger, represented by corresponding colours

RED: high hazard
People are at risk of injury both inside and outside buildings
A rapid destruction of buildings is possible
or: Events with a lower intensity, but a higher probability of occurrence. In this case, people are mainly at risk outside buildings, or buildings can no longer house people
The red zone mainly designates a prohibition domain (area where development is prohibited)
BLUE: moderate hazard
People are at risk of injury outside buildings. Risk is considerably lower inside buildings
Damage to buildings should be expected, but not a rapid destruction as long as the construction type has been adapted to the present conditions
The blue zone is mainly a regulation domain, in which severe damage can be reduced by means of appropriate protective measures (area with restrictive regulations)
YELLOW: low hazard
People are at slight risk of injury
Slight damage to buildings is possible
The yellow zone is mainly an alerting domain (area where people are notified of the possible hazard)
YELLOW–WHITE HATCHING: residual danger
Low probability of a high intensity event can be designated by yellow–white hatching. The yellow–white hatched zone is mainly an alerting domain, highlighting a residual danger
WHITE: no danger or negligible danger, according to currently available information

Table 2
Criteria for the intensity assessment. *E* Kinetic energy; *v* long-term mean speed; *e* thickness of the unstable layer; *h* height of the earth-flow deposit

Phenomena	Low intensity	Medium intensity	High intensity
Rockfall	E < 30 kJ	30 < E < 300 kJ	E > 300 kJ
Rock avalanche			E > 300 kJ
Landslide	v ≤ 2 cm/year	v: dm/year (>2 cm/year)	Large differential movements: v > 0.1 m/day for shallow landslides; displacement > 1 m per event
Earth flows and debris flows			
Potential	e < 0.5 m	0.5 m < e < 2 m	e > 2 m
Real	–	h < 1 m	h > 1 m
Settlement	–	Presence of dolines or sinkholes	–

of low to medium intensity can only be roughly delineated (Schindler et al. 1993). It is recommended not to artificially delineate zones affected by low to medium intensities.
Most landslides are characterised by continuous movements, sometimes with associated phases of reactivation (Dapples et al. 2001). A low intensity movement has an annual mean speed of less than 2 cm/year. A medium intensity has a speed ranging from one to a few tens of centimetres per year. The high intensity class is usually assigned to shear zones or zones with clear differential movements. It may also be assigned if reactivated phenomena have been observed or if horizontal displacements greater than 1 m per event may occur. Finally, the high intensity class can be assigned to very rapid shallow landslides (speed >0.1 m/day). In the area affected by landsliding, field intensity criteria can be directly converted to danger classes.
For earth flows and debris flows, the intensity depends on the thickness of the potentially unstable layer. The boundaries defining the three intensity classes are set at 0.5 and 2 m. Intensity criteria for settlement particularly depends on the thickness of the soil layer overlying a rock formation that is affected by dissolution processes (e.g. moraine over karstified limestone). The presence of dolines or sinkholes is an indication of medium intensity. No other intensity class should be assigned to this process.

Probability

Probability of landsliding is defined according to three classes. The class limits are set at 30 and 300 years and are equivalent to those established for snow avalanches and floods (Anonymous 1984a, 1984b, 1997c, 1997d). The 100-year limit corresponds to a value applied in the design of flood protection structures. The results of probability calculations to determine whether mass movements will occur remain very uncertain. Unlike floods and snow avalanches, mass movements are usually non-recurring processes. The return period, therefore, only has a relative meaning, except for events involving stone and block avalanches and earth flows which can be correlated with recurrent meteorological conditions. The probability of a mass movement should generally be established for a given duration of land use. Thus the probability of potential damage during a certain period of time or the degree of safety of a specific area should be taken into account, rather than the frequency of an event.
The probability of occurrence and the return period can be mathematically linked, if attributed to the same reference period:

$$p = 1 - (1 - 1/T)^n \qquad (1)$$

where p is the probability of occurrence, n represents the given time period (for example, 30 or 50 years) and T is the return period.
For example, considering a time period of 30 years, an event with a 30-year return period has a 64% probability of occurrence (or about 2 in 3), of 26% (or about 1 in 4) for a 100-year return period and of 10% (or about 1 in 10) for a 300-year return period (Table 3). The calculation of the probability of occurrence clearly shows that even for a relatively long return period (300 years), the residual danger is not significant.

Residual danger

In principle, the probability scale does not exclude very rare events, nor the intensity scale high magnitude events. Hazards with a very low probability of occurrence are usually classified as residual dangers under the standard classification. In the domain of dangers related to mass movements, the limit for a residual danger has been set for an event with a 300-year return period.

Table 3
Probability of landsliding as defined according to three classes

Probability		Return period
Category	Example for a 50-year return period	Return period as an indication of the probability (years)
High	100 to 82%	1 to 30
Medium	82 to 40%	30 to 100
Low	40 to 15%	100 to 300

Criteria for probability assessment

The probability of rockfalls occurring should be estimated by taking into account traces of former events that occurred during the last 30 years. This allows zones of low, medium or high probability of mass movement to be established. Rock avalanches are usually unique events, hence it is recommended not to subdivide them into high, medium or low probability zones. On the other hand, it is important to estimate whether the probability of occurrence (p) is greater than 1 in 10 and thus should be designated as a red zone. Sectors with active movements, widening cracks or isolated stone avalanches originating in a dangerous zone must be considered as red zones.
Most landslides are continuous processes, therefore no strict probability of occurrence exists for such mass movements (Lateltin et al. 1997). Periods of landslide activity are often related to precipitation events and therefore should be related to the probability of specific meteorological conditions (for example, continuous precipitation associated with snow melting). Increased differential movements are particularly dangerous.

Third step: risk management and land-use planning

The hazard map is a basic document for land-use planning. Natural hazards should be taken into account particularly in the following situations:

- Elaboration and improvement of Cantonal Master Plan and Communal Local Plans for land use.
- Planning, construction and transformation of buildings and infrastructures.
- Granting of concessions and planning for construction and infrastructure installations, as well as for laws related to land use.
- Granting of subsidies for building and development (road and rail networks, residences), as well as for slope stabilisation and protection measures.

Cantonal master plan

According to Article 6 of the Federal Law for Land-use Planning, the cantons must identify in their Master Plan all areas that are threatened by natural hazards. The Cantonal Master Plan is a basic document for land-use planning, infrastructure co-ordination and accident prevention and consists of a map and a technical report, based on field studies.

- It shows how to coordinate activities associated with different land uses.
- It identifies the goals of planning and specifies the necessary stages.
- It provides legal constraints to the authorities in charge of land-use planning.

The objectives of the Master Plan with respect to natural hazards are:

- Early detection of conflicts between land use, development and natural hazards.
- To refine the survey of basic documents concerning natural hazards.
- To formulate principles that can be applied by the cantons to the issue of protection against natural hazard.
- To define necessary requirements and mandates to be used in subsequent planning stages.

Communal local planning

The constraints on local planning already allow/ensure appropriate management of natural hazards with respect to land use. The objective of these constraints is to delineate danger zones by highlighting restrictions, or to establish legal frameworks leading to the same ends. At the same time danger zones can be delineated on the local plan together with areas suitable for construction or zones where additional protection is required. The degrees of danger are initially assigned according to their consequences for construction activity. They must minimise risks to the safety of people and animals, as well as possible damage to property. In agricultural zones, buildings affected by different degrees of danger are constrained by the same conditions as those in built-up areas.

Conclusions

The relatively small alpine country of Switzerland is exposed to a number of natural hazards including earthquakes, floods, forest fires, snow avalanches, rockfalls and debris flows. The paper describes the new federal regulations requiring regional authorities to generate natural hazard maps to restrict development on hazard-prone land using a three-step procedure, with particular emphasis given to the specific case of mass movements.
Firstly, an indispensable prerequisite for the *hazard identification* step is to obtain information about past slope failure events. Some recommendations have been developed to allow maps of these phenomena to be produced. In the second step, a *hazard assessment* of the magnitude or intensity of slope movements over time is made. Hazards are mapped into one of four classes or hazard grades: high danger (red zone), moderate danger (blue zone), low danger (yellow zone) and no danger (white zone). The third step defines the *risk management*. The hazard maps being prepared by each of the canton authorities will act as reference documents for the integration

of natural hazard information into land-use planning (Cantonal Master Plan or Local Communal Plans, including the delineation of hazard zones, construction conditions, building licences, etc.) as well as for the development of protective measures to minimise damage to property.

Conflicts may occur when the hazard map is compared with existing land use. As it is difficult or impossible to alter land use, specific construction codes are required to reach the desired protection level. Hazard maps are also valuable when planning protective measures including the installation of warning systems and emergency plans.

In order to create a set of maps that can be used throughout the country, it is a federal requirement that the maps used standard colour coding: red where construction is prohibited, blue where construction is allowed when certain safety requirements are met and yellow where construction is possible without any restrictions.

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