2.8. Mass movements: landslides, blockfalls and rock avalanches

Hugo Raetzo and Olivier Lateltin

Where a large input of water persists over longer periods, it can lead to mass movement. Unstable slopes represent approximately 7% of the land area in Switzerland. In western Switzerland, the increase in precipitation has led to more frequent movements in many landslide areas since the early 1970s. In recent times, heavier winter precipitation in combination with large volumes of snow water have also provoked more frequent landslides. Receding glaciers, thawing of permafrost in the ground, increasing winter precipitation and the rising snow line could cause a general increase in slope instability.

Definition

Mass movement is defined as a downward displacement of compact and/or loose rock. It mainly comprises gravitational processes (stonefalls, blockfalls and rock avalanches), landslides und earth flows. These can occur either quickly and suddenly, or slowly and continuously.

It is estimated that about 7% of the land area of Switzerland is affected by slope instability. Extensive landslide areas occur particularly in flysch formations[1] containing a high fraction of clay and silt, making them susceptible to instability. Owing to the fine-grained soils in these areas, rainwater seepage is hindered, so that the water content is high the whole year round. The presence of water in the soil and the rock renders the ground more vulnerable to instabilities.

Smaller mass movements often occur unnoticed in uninhabited areas; larger mass movements are perceived as extreme when they cause losses to assets. Smaller earth flows too, can have devastating effects at the local level (e.g. Gondo on 14.10.2000, Lutzenberg on 1.9.2002 and Schlans on 16.11.2002). In this chapter, large and infrequent movements of very large landslide-prone slopes (with a volume exceeding 1 million m^3) and concentrated occurrences of several smaller landslides (up to several 100000 m^3) are designated as extreme events. Following abundant precipitation in the summer of 2002, approximately one-thousand spontaneous landslides occurred in Switzerland, several hundred of which occurred in central and eastern Switzerland.

Critical weather conditions and tendency towards instability

Mass movements occur when a large input of water occurs over longer periods. In the mountains, this is only the case for temperatures above the freezing point, since otherwise the precipitation is stored in the form of snow and ice. Large quantities of water are available in the spring in cases where heavy thawing and heavy precipitation coincide, and before and during summer and autumn in the case of heavy and

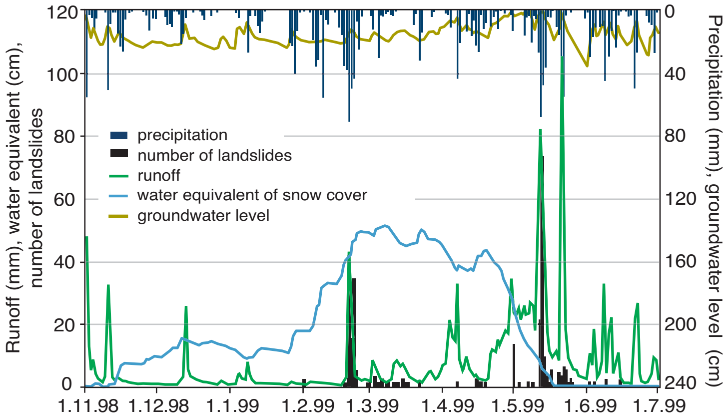

Fig. 41 Precipitation and groundwater variations in the storm year 1999.[2] The figure shows the precipitation (top: blue), the groundwater level (top: brown), runoff (bottom: red) and the water equivalent of snow cover (bottom: light blue) in Alptal in the Canton of Schwyz (WSL data). For comparison purposes, slope instabilities are shown at daily intervals (bottom: black). The first period of high landslide activity occurred between 20 and 23 February 1999 following the last snowfalls in the mountains. A second landslide period occurred between 12 and 17 May 1999 in the course of heavy precipitation, coinciding with the end of the thawing season.

enduring precipitation (cf. Chapters 2.5 and 2.7). For example:

- In the avalanche winters of 1888/89, 1950/51 and 1998/99 (cf. Chapter 2.9), large quantities of snow lay on the ground in late winter. Owing to higher temperatures the following spring, the snow thawed rapidly. At the same time, it rained prolifically over a long period. This resulted in increased movement of numerous landslide-prone slopes, and many debris flows occurred (cf. Fig. 41). A similar but locally more confined event occurred in Falli Hölli in the Canton of Fribourg in spring 1994, when large quantities of snow water caused a rapid acceleration of the landslide. Forty houses were carried 200 metres down the slope and completely demolished.
- In 1987, 1993 and 2000, numerous Alpine valleys were visited in summer and autumn by intensive precipitation over a period of several days (cf. Chapters 2.5 and 2.7). These carried with them large quantities of water, causing slope instabilities and flooding. On 13/14 October 2000, an extreme event occurred in the area of the Simplon Pass. A southerly flow situation carried hot and humid air from the South towards the Alps for 8 days. Almost 500 mm of rain fell within two days, corresponding statistically to a 300 to 1000-year event. On 14 October 2000, the safety barrier above Gondo broke. The resulting landslide with earth flow claimed 13 human lives.

Slope instabilities in the past

Prehistoric age

Towards the end of the last ice age when the glaciers receded, and at the beginning of the Holocene about 11 600 years ago, the large landslide areas in the Alps were very active (Fig. 42). In the absence of the retaining forces of the ice masses, the flanks of the valleys that were formed by glacial action loosened. At the same time, extensive areas of permafrost, in which compact and loose rock masses had been held together, thawed out. This resulted towards the end of the last ice age, and to a lesser extent at the end of the little ice age, in landslides and numerous rockfalls[3,4]. The Alpine valleys were filled with landslide debris and in some places mass movements dammed the rivers, forming lakes and swamps (e.g. in Davos, Flims, Pfynwald and Schwarzsee).

Over the last 9000 years (Holocene), temperatures remained fairly constant. Over that period, slope instability was probably caused mainly by fluctuations in precipitation. However, the temperature and precipitation data for the Holocene still remain incomplete and imprecise, so that the relationship between slope instability and climate is poorly defined. Significantly more landslides occurred, for example, in the Löbben ice age about 3000 years ago. During this high precipitation epoch, numerous mass movements occurred all over Europe (Fig. 42).

Historical era and 20th century

In the period after the 15th century, climatic data can be reconstructed with considerable precision. The duration and trend of the so-called little ice age (late 13th to mid 19th century) are known within close limits. In this phase, years of high precipitation can be correlated with years of high landslide activity.

Since the early 1970s, heavier precipitation has led to an increase in mass movements in various landslide areas in western Switzerland. In the recent past, an increasing number of landslides have occurred due to increasing winter precipitation in conjunction with snow water.

Statistically, the events that occurred in the years 1951 (Alpine winter), 1987 (summer precipitation in the Alpine region), 1993 (heavy storm in Brigue), 1999 (thawing season and spring precipitation) and 2000 (heavy autumn storm in Valais and Ticino) were extreme events.

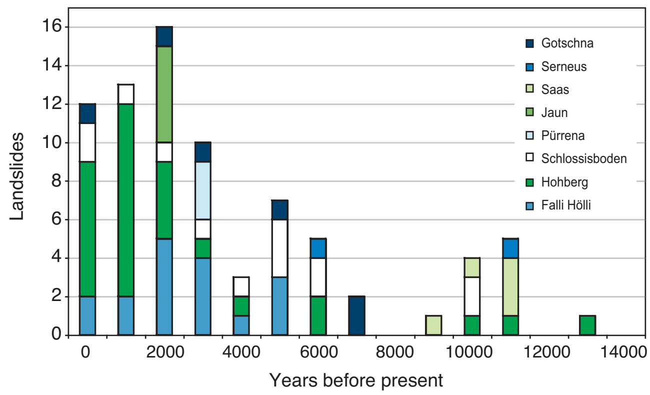

Fig. 42 Frequency of landslides in Switzerland in the Holocene.[5,6] The selection covers large landslide-prone slopes with a volume of several million m³. These large volume landslides have experienced several acceleration phases since the last ice age. By means of C14 dating of fossilised tree trunks embedded in the debris in the course of earlier events, qualitative conclusions may be drawn for the Holocene both on the physical activity and, to a more limited extent, the climatic conditions. Samples are obtained using borings or excavations, whereby the probability of finding younger wood fossils is greater, since these lie closer to the surface than older wood. Thus for the last 2 to 3 millennia, more C14 datings are available than for the period prior to that. In the Hohberg landslide, the oldest dating goes back to the Young Dryas (12 700 years ago). After the glaciers had receded, several large debris flows occurred in the course of the 12th and 11th millennia in the Freiburg and Grisons Alps (Hohberg, Schlossisboden, Saas and Serneus). This epoch is characterised by climate warming. Numerous slope instabilities occurred between 7000 and 5000 years ago during a variable climatic phase. Following a relatively quiescent phase about 3400 years ago, landslide activity increased steeply in several areas, i.e. Falli Hölli, Hohberg, Schlossisboden, Pürrena and Gotschna. From a climatological standpoint, the end of the Sub-boreal is significant for the whole of Europe. The cold phases of the Löbben (3500 to 3100 years ago) and the Göschenen I (2830 to 2270 years ago) periods are also characterised by glacial expansion. The phase of high landslide activity continued into the second century BC, after which the frequency declined slightly, while continuing to vary in concert with the wet phases.

Consequences of climate change

The frequency of mass movements is influenced by changes in the temperature, the hydrological cycle, the glaciers and permafrost. The rise in winter and spring temperatures changes the form that precipitation takes, the amount of snow cover and the ground temperatures. Climate change gradually alters the stability of large landslide masses. Extreme events such as heavy precipitation and thunderstorms can, however, trigger smaller landslides and earth flows.

Glaciers and permafrost

By virtue of receding glaciers and thawing permafrost, large volumes of debris are free to move. In the presence of water, this can lead to mass movements. Global warming will have drastic effects on the glacial and periglacial mountainous areas.[3] However, quantitative predictions of the effects of climate change on permafrost are difficult.

In general, it is probable that the long-term temperature increase will cause slow, retarded, thawing of the permafrost. This trend is coupled with seasonal fluctuations depending mainly on the thickness of snow cover. In autumn and winter, early snow cover retards cooling of the ground. Ground heat is thus stored, reinforcing the trend to thawing the following summer. In distinction, the cold ground in spring is insulated by enduring snow cover. Large quantities of snow extend the period required for complete thawing. Owing to later thawing in spring, less heat can be absorbed by the ground during the summer months. However, the seasonal fluctuations mentioned will probably have little effect on long-term thawing of permafrost.

The permafrost system reacts sluggishly, since the heat capacity of ice and the ground are larger that of air. Thus only the long-term changes will have an influence, and this will persist over a long period. The permafrost will first warm up in the topmost strata, in snow-free zones and in smaller and shallower permafrost areas. In these areas, blockfalls, erosion, landslides und debris flows will increase. As an example, debris flows have repeatedly broken loose in the Ritigraben (Canton of Valais) over the past ten years, having their origin in the block glacier at 2500 m. Also, smaller – and some larger – rock masses have descended from permafrost zones into the valleys (e.g. in Tschierva, Piz Scerscen, Mättenberg, Monte Rosa (Italian side), and Gruben[7,8]).

Precipitation

The acceleration of the hydrological cycle (cf. Chapter 2.5) has a negative influence on slope stability. Owing to the increase in winter precipitation, landslide activity could increase in future. Higher temperatures will result in more rain and less snow. Through the increased quantities of water in supply in the winter months, slope stability will decrease.

Climate scenarios show that southerly flow situations, leading to greater quantities of water vapour being transported from the Mediterranean region towards the Alps, will increase. One such southerly flow situation led to the extreme event of 13/14 October 2000 in the Simplon region. If during southerly flow situations of several days' duration the frost line also lies very high, an increase in landslides and debris flows would be expected.

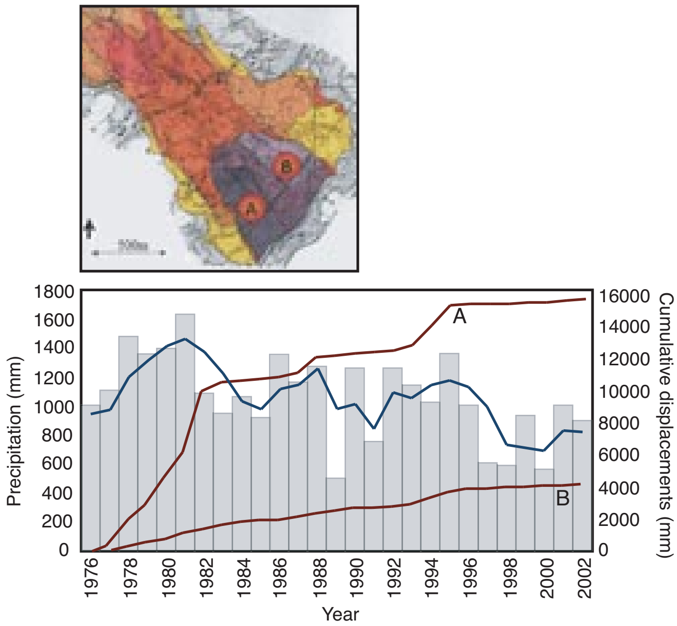

Fig. 43 Landslide in La Frasse near Aigle.[9] The net precipitation (grey bars) and the cumulative displacements (red lines) in zones A and B for the period 1976-2002 are shown for comparison purposes. The blue line shows the 3-yearly average of net precipitation. When this lies above 1150 mm, the landslide front accelerates towards the river bed of the Grande Eau. While zone A reacts with marked acceleration (particularly from 1977-1982), zone B displays only small speed changes. Thus the landslide front reacts more-or-less sensitively to the precipitation and the pressure of groundwater, that is to say, it reacts only indirectly to climatic changes.

1 Sediments from threshold zones above the ocean surface that concentrated in narrow troughs in the course of mountain formation (marine sandstones often rich in aconite, marl, shale and limestones in alternating strata).

2 Bollinger D., C. Hegg, H.-R. Keusen und O. Lateltin, Ursachenanalyse der Hanginstabilitäten 1999, Bulletin für angew. Geologie Nr. 5/1, 5-38, 2000.

3 Kääb A., J. M. Reynolds and W. Haeberli, Glacier and permafrost hazards in high mountains. In: Huber U. M., M. A. Reasoner, and B. Bugmann [Eds], Global change and mountain regions: a state of knowledge overview. Advances in global change research. Kluwer Academic Publishers, Dordrecht, 2003 (in press).

4 Haeberli W., A. Kääb, M. Hoelzle, H. Bösch, M. Funk, D. Vonder Mühll und F. Keller, Eisschwund und Naturkatastrophen im Hochgebirge. Schlussbericht NFP31, vdf, ETH Zürich, 1999.

5 Raetzo H., Massenbewegungen im Gurnigelflysch und Einfluss der Klimaänderung. Bericht des NFP31, vdf, ETH Zürich, 256 S., 1997.

6 Dapples F., Instabilités de terrain dans les Préalpes fribourgeoises (Suisse) au cours du Tardiglaciaire et de l'Holocène: influence des changements climatiques, des fluctuations de la végétation et de l'activité humaine. Thèse 1395 UNIFR, Multiprint S.A. Fribourg, 2002.

7 Noetzli J. , M. Hoelzle, and W. Haeberli, Mountain permafrost and recent Alpine rock-fall events: A GIS-based approach to determine critical factors. In: Phillips M. , S. M. Springman, and L. U. Arenson [Eds.], 8th International Conference on Permafrost, Zurich/Switzerland; Proceedings 2, 827 - 832, 2003.

8 Haeberli, W., C. Huggel, A. Kääb, A. Polkvoj, I. Zotikov, and N. Osokin, Permafrost conditions in the starting zone of the Kolka-Karmadon rock/ice slide of 20 September 2002 in North Osetia (Russian Caucasus). In: Haeberli W. and D. Brandova [Eds.], 8th International Conference on Permafrost, Zurich/Switzerland, Extended abstracts reporting current research and new information, University of Zurich, 49 - 50, 2003.

9 Bonnard, persönliche Mitteilung.