Hazard Zoning in Areas with Major Deep-Seated Landslides: Case Study from Switzerland

Daniel Tobler and Hans-Rudolf Keusen

Abstract

The large, deep-seated Gryfenbach landslide in Lauterbrunnen, Switzerland, endangers part of the village as well as the main entrance to the whole valley. A mass of about 25 million m^3 is situated at the left valley entrance and moves with an average of cm a year. In the steep frontal part of the sliding mass two large spontaneous landslides have been recorded (secondary processes). Following the abnormally intensive snowmelt in spring 1999 the movement increased 30-fold. Important infrastructures within the landslide were destroyed. A complicated monitoring system has been installed to understand the landslide's behaviour and hazard potential in detail.

At the same time the authorities start to elaborate the hazard map of the valley. Through extensive field investigations, analyses of monitoring data and conclusions by analogy from other large landslides the relevant scenarios for the hazard assessment have been formulated. In 2003 the first draft of the hazard map existed GEOTEST AG (Technischer Bericht zur Gefahrenkarte Lauterbrunnen, Nr. 00063.5, Zollikofen (unpublished), 2003), see Fig. 10). In 2011 a revised hazard map has been published GEOTEST AG (Lauterbrunnen, Naturgefahren, Bericht zur Teilrevision Gefahrenkarte, Nr. 10151.01, Zollikofen (unpublished), 2011). This product is based on today's hazard assessment methods. The paper focuses on the Swiss hazard assessment methodology, on the scenario definition of large, deep-seated landslides illustrated on the case study in the Lauterbrunnen valley.

Keywords

Landslide hazard assessment • Hazard map • Case study

Introduction

A thorough assessment of the prevailing hazards and risks in a specific region is imperative for any kind of development activity that has a spatial impact. This is particularly important in disaster-prone areas, like narrow valleys dominated by landslides and rock fall processes (Bonnard et al. 2004). Today, a number of tools and instruments are available to analyse, visualize and evaluate major hazards and risks (Lateltin 2009; PLANAT 2011).

In the past few years, Switzerland developed a number of such instruments (e.g. BUWAL 1998, 1999a; PLANAT 2003, 2005a, 2005b; OFAT, OFEE and OFEFP 1997 or Wilhelm 1999). They serve as an indispensable basis for an integrated disaster reduction approach, which is not only being discussed presently in Switzerland, but equally on an international level. The methodology fulfils many of the demands but also gives rise to a number of problems and disadvantages. This refers to the production of the instruments as well as the implementation and transformation of the hazard information into practical use.

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The new Federal Ordinances on Flood and Forest Protection (OACE 1994) require the cantons to establish hazard maps which have to be incorporated in regional master plans and local development plans. The cantons are responsible initiating hazard mapping.

Landslide Hazard Assessment

Landslide Classification

The Swiss classification of landslides for hazard mapping relies on AGN (2004). Landslides can be classified according to their estimated depth of the slip surface (<2 m: shallow; 2–10 m: intermediate; >10 m: deep) and the long-term mean velocity of the movements (<2 cm/year: substable; 2–10 cm/year: slow; >10 cm/year: active). Depth and velocity parameters are not always sufficient to estimate the potential danger of a slide. Differential movements must also be taken into account as well as the potential of reactivation of a sliding mass (Lateltin et al. 2005).

Due to heavy precipitation, debris flows and very shallow slides are frequent in Switzerland. Most of them are moderate in volume (<20,000 m^3) and of rapid velocity (1–10 m/s). Debris flows and shallow slides are dangerous and annually cause fatalities and traffic disruptions.

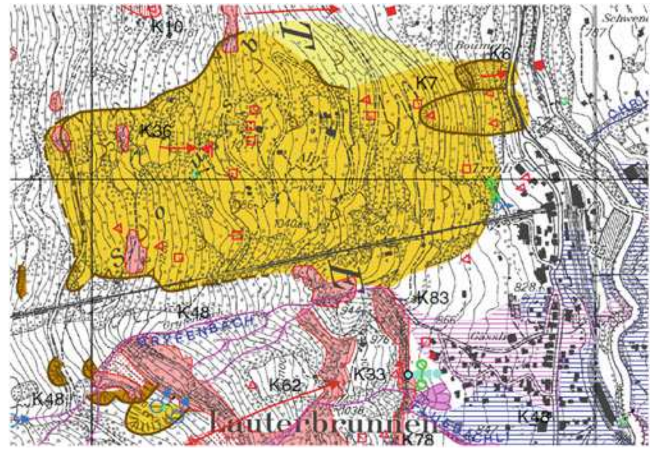

Fig. 1 Landslide phenomena map of the Gryfenbach landslide in Lauterbrunnen (Bernese Oberland, central Swiss Alps). The phenomena map is a major product in hazard assessment (GEOTEST AG 2003). For the legend see OFEE and OFEFP (1995)

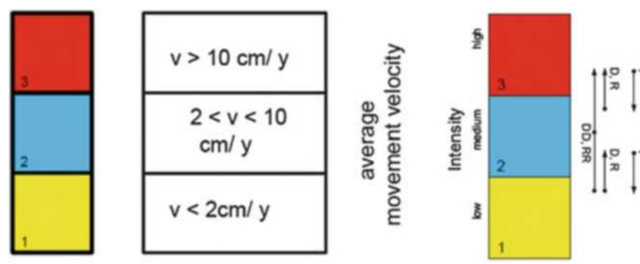

Fig. 2 Classification of landslides for hazard maps (AGN 2004). $_{D}$, $_{R}$ and $_{T}$ indicate an intensification/decrease of the hazard level depending on the reactivation potential ($_{R}$), the amount of differential movements ($_{D}$) or the depth of a moving mass ($_{T}$). Deep-seated landslides (RT) may have code like $RT2_{DR}$

Landslide Phenomena Map

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 (e.g. Fig. 1 example of a map of mass movements and water hazard processes) and delineates vulnerable areas.

Field interpretations of these phenomena allow landslide-prone areas to be mapped, based on the observation and interpretation of landforms, on the structural and geotechnical properties of slope instabilities and on historical traces of previous slope failures (Riemer et al. 1988). The different phenomena are represented by different colors and symbols (Lateltin et al. 2005). The recommendations for the uniform classification, representation and documentation of natural processes have been established by the federal administration (OFEE and OFEFP 1995).

Landslide Hazard Map

Hazard assessment implies the estimation of the intensity of an event over time. The hazard is defined as a threatening event or as the probability of a potentially damaging natural phenomenon within a specific period of time in a given area (IDNDR 1993). Landslides normally correspond to gradual phenomena (constant slides) or unique events (spontaneous, shallow landslides). It is indeed difficult to make an assessment of the return period of a large rock avalanche, or to predict when a dormant landslide may reactivate (Raetzo et al. 2002; AGN 2004).

Most slides are characterized by continuous movements, sometimes with associated phases of reactivation. Herefore three levels of intensity are considered, high, medium and low (Fig. 2).

A low intensity movement has an annual mean velocity of less than 2 cm/year. A medium intensity corresponds to a velocity ranging from 2 to approximately 10 cm/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 (AGN 2004; Lateltin et al. 2005). In the area affected by slides, field intensity criteria can be directly converted to

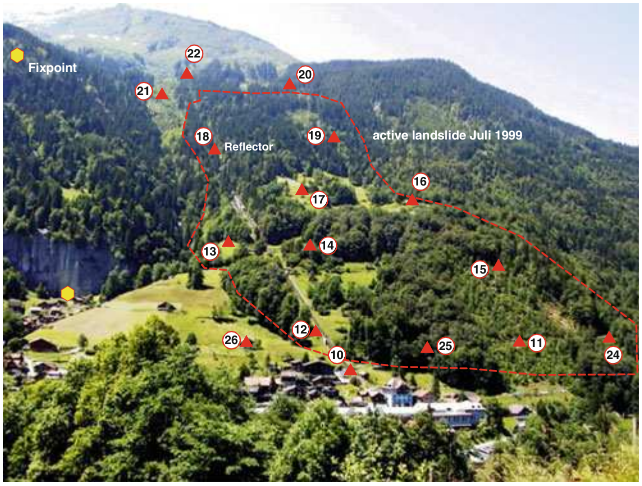

Fig. 3 Landslide of Gryfenbach as an example of a continuous landslide with indication of boundaries and tachymetric measuring points. Without the tachymetrc dataset velocities can hardly defined

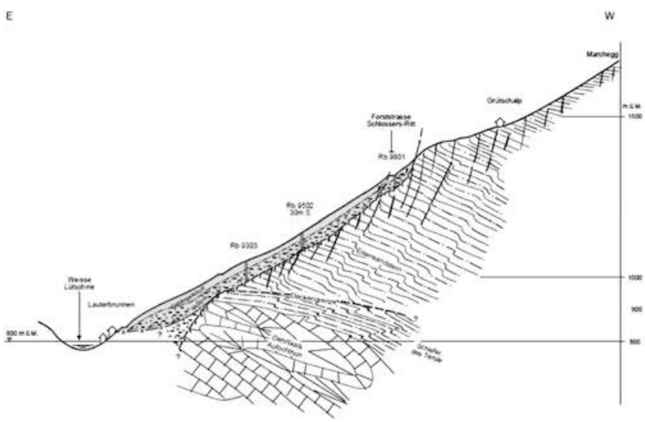

Fig. 4 Geological cross-section through the landslide of Gryfenbach with indication of borehole locations (GEOTEST AG 2007). The weathered and jointed bedrock shows a high hydraulic conductivity which leads to high pore water pressures in the depth. It is one of the major causality for this mass movement

danger classes. Especially with large, deep-seated landslides the difficulty is to define the velocity. The larger the slide the harder is the estimation of velocity without technical support (recordings, surveys, monitoring data, Fig. 3, see also Korup 2006).

Gryfenbach Landslide, Lauterbrunnen

History: Location

The Gryfenbach landslide is located in the sedimentary Helvetic nappes of the Canton Bern, in the central Swiss Alps (Fig. 1). This deep-seated, creeping landslide is extraordinary in many ways, chief amongst which is its immense size. The slide mass reaches depths of more than 60 m and incorporates approximately 25 million m^3 of quarternary sediments and weathered bedrock (Fig. 4; Keusen 2000). The bedrock consists of fractured and sagged limestones (Strozzi et al. 2005).

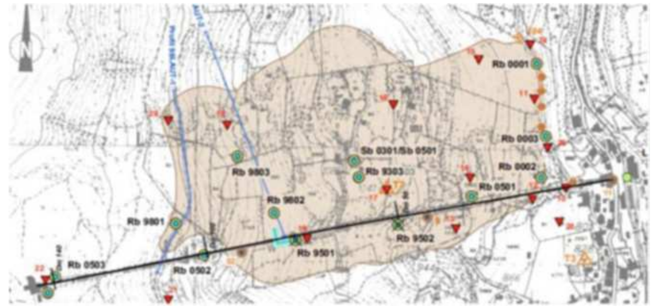

Fig. 5 Landslide with indication of all components of the monitoring system (*circles* = boreholes with inclinometer; *red triangle* = reflector for tachymetric measures, *blue lines* = seismic profiles, *black line* = Lauterbrunnen-Mürren railway; GEOTEST AG 2007)

The large, deep-seated landslide endangers part of the village Lauterbrunnen as well as the main entrance to the whole valley. Based on surveys, it could be registered that the average displacement lies between 1 and 2 cm a year. Measurements all over the 30–40 ha landslide area, show an increase of movement in springtime (snow melt) and a decrease in autumn. In the steep frontal part of the sliding mass two large spontaneous landslides have been recorded in 1966 and 1983 (secondary processes, CSD 1973 and CSD 1983). These events buried the two lifelines (main road, railway) for several days. Fortunately there were no fatalities. Following the abnormally intensive snowmelt in spring 1999 the movement increased 30-fold. Important infrastructures within the landslide were destroyed. Interactions with a nearby creek, which is prone to debris flow tightened the situation even more.

Landslide Monitoring

A complicated monitoring system (Fig. 5), consisting of inclinometer drillings, tachymetric measures, pore water pressure measurements, has been installed in the years 1999–2003 to measure the movement and to understand the landslide's behaviour and hazard potential in detail.

The hydrogeological situation is complex (Fig. 6). The water infiltrates in a higher valley, the Soustal. From there the groundwater flows through fractures of the sagged bedrock into the sliding mass and produces an uplift (high pore water pressure) in the frontal part of the landslide.

In the field, the evidences for movements concentrate along the border of the landslide. Within the sliding mass there are nearly no indications of movement. This can be

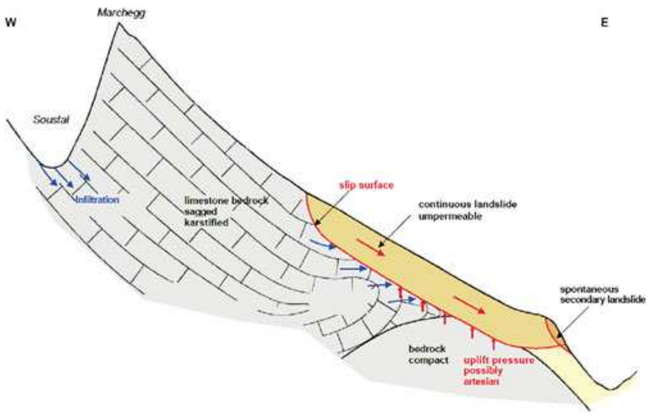

Fig. 6 Schematic cross-section with indication of hydrogeological situation. Water from the Sous valley infiltrates and leads to high pore water pressures at the slip surface (GEOTEST AG 2007)

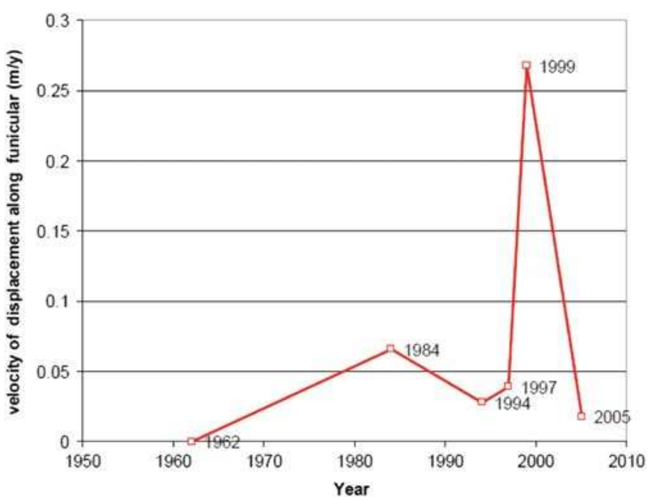

Fig. 7 Velocity of the funicular's displacement during the last 60 years (GEOTEST AG 2007)

justified on one hand by the big depth of the mass; on the other hand through the compact landslide body which moves as a whole.

Landslide Intensity

The first section of the Lauterbrunnen-Mürren Mountain Railway (BLM), which was built in 1891 to facilitate the access to the village of Mürren located on a plateau above Lauterbrunnen, is crosscutting the landslide on its southern fringe (Fig. 3). Whereas average rates of displacement measured on the railway superstructures in the last 100 years were in the order of 20 mm/year before 1999, in the spring of that particular year a displacement rate of 10 mm/day was observed over a short time period (Fig. 7). Overall, a displacement of several decimetres was observed, threatening the operation of the funicular (Strozzi et al. 2005).

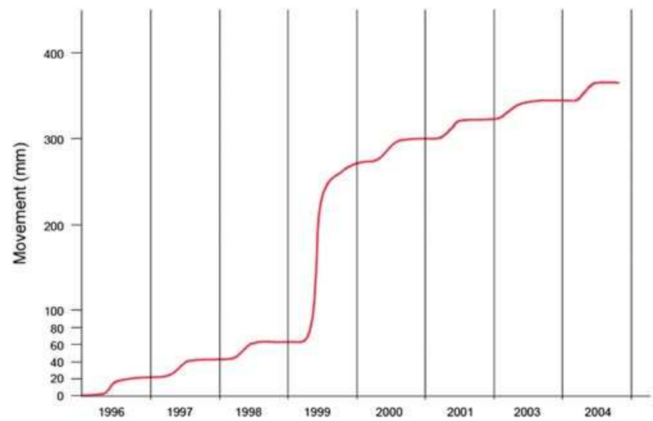

Fig. 8 Monitoring of the landslide's movement between 1996 and 2004. The abnormally intensive snowmelt in spring 1999 intensified the movement to the decuple (10 mm/day) of a normal year

During snowmelt period there seems to be a rapid build-up of pore pressure. It becomes manifest in an acceleration of the movement in early summer (May to June). After the snowmelt the velocities decrease and in winter time the landslide is normally nearly stable (Fig. 8).

The inclinometer measures were carried out once to twice a year. The results confirm the mean yearly displacement rates of the tachymetric measures. In the inclinometer data two different sliding surfaces are visible; a minor one in a depth of about 30 m and the major rupture in 60 m (Fig. 9).

Landslide Hazard Map

With all the information of the monitoring, the field investigations, the historic dataset of past events (spontaneous, secondary landslides in the frontal part) and the recording of the movements before the 1999 event, it is possible to draw the hazard map of the Gryfenbach landslide (Fig. 11).

The average displacement velocities of the deep-seated landslide (RT) are in the central part around 2 cm/year, in the frontal part between 1 and 2 cm/year. According to the Swiss landslide classification for hazard maps (Fig. 2) these movements lead to low (yellow, 1) and medium (blue, 2) hazard intensities. It is well known that this landslide is prone to reactivations (e.g. 1999, indicated by $_{R}$ in the map). This fact will raise the hazard level for one class (yellow to blue, blue to red). The immense depth of the landslide (indicated by $_{T}$ in the map) decreases the hazard level again. The major body of the landslide show a medium hazard level ($RT2_{RT}$).

The frontal part of the landslide is prone to spontaneous secondary slides. This fact was taken into consideration in the hazard map (indicated by D). The depth of the mass movement is here about 10 m. According the recommendations (AGN 2004 and Fig. 2) the hazard level will increase (yellow to blue [$RT1_{DR}$], blue to red [$RT2_{DR}$]) (Figs. 10 and 11).

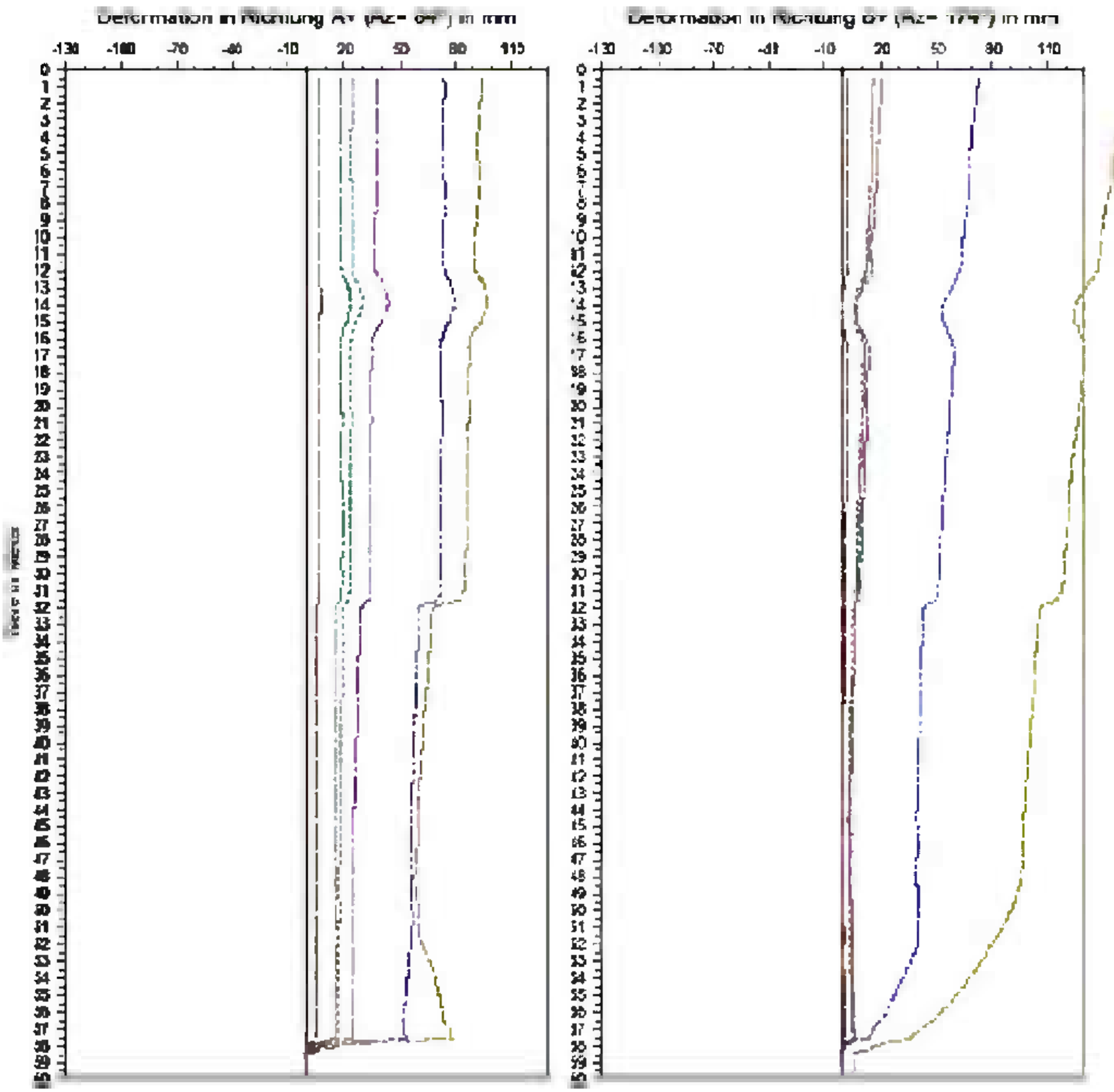

Fig. 9 Inclinometer dataset of a borehole in the frontal part of the landslide. The major slip surface can be located in a depth of about 60 m (GEOTEST AG 2007)

Conclusions

In the year of 2000 the authorities started to elaborate the hazard map of the valley. Through extensive field investigations, analyses of monitoring data and conclusions by analogy from other large landslides the relevant scenarios for the hazard assessment have been formulated. In 2003 the first draft of the hazard map existed (GEOTEST AG 2003). During the next years the Swiss authorities issued a uniform guidance for the assessment of landslide hazards (AGN 1998, 2004). Different types of landslides have to be evaluated separately. In the Lauterbrunnen area three types exist: shallow rapid landslide, rapid deep slides and slow deep-seated landslides. The overlay of these processes leads to a very complex and highly sophisticated hazard assessment. The product of this guideline is shown in the 2011 released and revised hazard map (GEOTEST AG 2011) with depth -, reactivation – and differential movement dependent hazard levels.

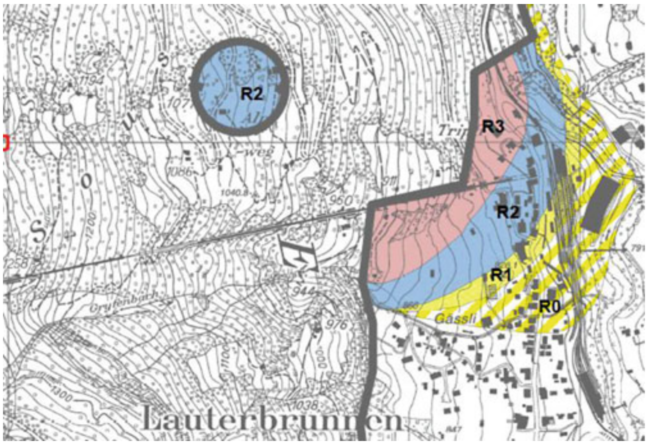

Fig. 10 Original hazard map 2003, section Gryfenbach for continuous landslides with hazard levels within the investigation area (GEOTEST AG 2003) Numbers indicate the average velocity of the moving mass (*1* low, *2* medium, *3* high)

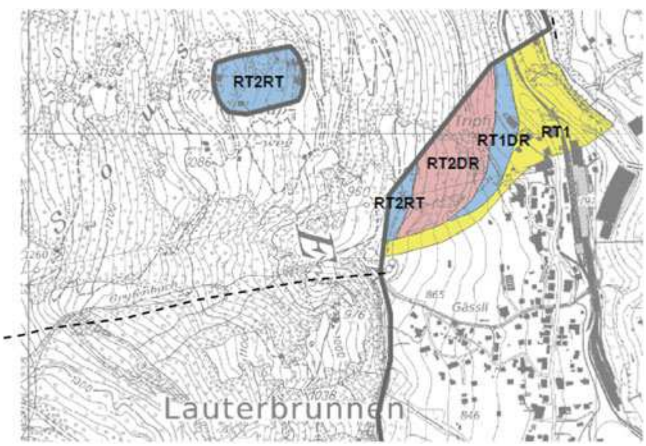

Fig. 11 Revised hazard map, section Gryfenbach for continuous landslides with hazard levels within the investigation area (GEOTEST AG 2011). RT indicates the deep-seated landslide. Numbers (*1* and *2*) indicate the average velocity of the moving mass (*1* low, *2* medium) and $_{R}$, $_{D}$ indicate the intensification/decrease of the hazard level depending on the reactivation potential ($_{R}$) and amount of differential movements ($_{D}$)

Nowadays detailed displacement data are essential to elaborate a trustful hazard map. Especially in cultivated areas official measurement datasets are available nearly nationwide. Based on this data long term information of landslide displacement may be generated (Eberhardt et al. 2007).

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