Mountain hazards –
Local structural protection within integral risk management

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Preface

The content presented within this cumulative PhD thesis is the result of previous research projects focusing on individual issues within mountain hazard risk management. Related research activities were undertaken at the University of Natural Resources and Life Sciences in Vienna, Austria and at Risk Consult – Sicherheits- & Risiko-Managementberatung Ges.m.b.H. in Vienna.

The thesis is structured into a core paper which includes the hypotheses, a definition of terms used within this thesis, the general framework of institutional dealing with hazard in Austria, a classification of mitigation measures, and a discussion on local structural protection. The subsequent individual chapters of this thesis are composed from papers published in international scientific journals. These chapters are addressed to: (1) legislation, risk transfer, and awareness building; (2) benefits of local structural protection; (3) state of the art and future needs of constructional preventive measures; and (4) reducing vulnerability by adapted building design. Finally, in a conclusion section the most relevant findings of this work are summarised, and the initially formulated hypotheses are discussed with respect to the results presented in the individual chapters.

The compilation of the presented content is a result of extensive scientific works as well as applied contract work undertaken by the author.

Tracing back to the time of being a researcher and lecturer at the Institute of Mountain Risk Engineering (University of Natural Resources and Life Sciences), the fundamental research issues about structural preventive mitigation measures against mountain hazards has been carried out within several scientific projects. About two thirds of the relevant publications related to the topic can be allocated to that time, which all show a significant relationship to natural and technical sciences.

The more recent publications originate from the stage of being a consultant for applied natural hazard risk management in the framework of international insurance business. Supporting the industrial company business in terms of natural hazard risk mitigation, economic and legal findings have been derived and published by papers targeting applied risk management, fundamentals of building legislations, risk transfer and awareness building.

All chapters are based on both, a review of international methods and practices in the field of risk research but also – and in particular – on the author’s own research activities.

1 Introduction

In recent years, the increase in the number of natural hazards occurring world-wide was repeatedly claimed, e.g., by large reinsurers such as Munich Re (Munich Re, 2011) or Swiss Re (Swiss Re, 2011). In parallel, the losses that incurred were similarly increasing globally (Munich Re, 2011; Keiler, 2012). Acknowledging these issues, several attempts were already made by international institutions such as the United Nations during the last decades to reduce the threat to the population. Most prominent with respect the global scale is the *International Decade for Natural Disaster Reduction* in the 1990s (United Nations General Assembly, 1989) or the *Hyogo Framework for Action* 2005-2015 (United Nations, 2005), aiming at an increasing resilience of nations and communities to disasters. The objective of such international efforts is to promote concerted action in order to reduce loss of life, property damage and economic disruption caused by natural hazards not only with a particular focus on developing countries, but also with respect to most developed countries. As a result, an increased global awareness of the social and economic consequences of natural disasters developed (White, 1994), and several subsequent actions were set, such as on the European level (Commission of the European Communities, 2007) or with respect to mountain regions (Price and Hofer, 2005).

Mountain regions such as the Alps are particularly prone to natural hazard processes, and therefore considerable losses are continuously reported (e.g. Berz, 2009) from a scientific point of view, and BMLFUW (2006) from the point of view of the public administration. In recent years, the amount of natural hazards and associated losses occurring in mountain regions, but also on the overall European level, have shown to the European Commission and the Member States of the European Union the importance of protection of the environment and the citizens (Barredo, 2007): Around 20 % of the total population in Europe inhabits mountain regions which cover almost 40 % of the total land area of Europe (Nordregio, 2004). European mountain regions therefore provide a significant proportion of human settlements and areas used for economic purpose and recreation. The overlap of human activity and natural hazards processes is the main trigger of the development of losses. Thereby, as argued by Slaymaker and Embleton-Hamann (2009), mountain geosystems show a greater range of susceptibility to disturbance than many other landscapes. As a result, a dynamic process pattern may be overlain by an increase of human activity (Fuchs and Keiler, 2012), which in turn requires a careful assessment of vulnerability (Fuchs, 2009) and risk (Kienholz et al., 2004).

Despite considerable efforts undertaken to reduce the adverse effects of natural hazards and associated expenditures in mitigation measures, a considerable number of hazard processes has occurred in alpine regions in recent years (e.g., Hilker et al. 2009) with respect to the Swiss Confederation, and Hübl et al. (2011) with respect to the Republic of Austria. The latter study was based on an Austrian database of historic events compiled by the Institute of Mountain Risk

Engineering at the University of Natural Resources and Life Sciences. Information on a local and regional scale has been gathered from records of the Austrian Torrent and Avalanche Control Service and the transcription of the so-called “Brixner Chronicle”. In total, more than 20,100 torrent events were recorded, a subset showing a time series between 1950 and 2009 was recently published by Totschnig et al. (2011, see Fig. 1-1).

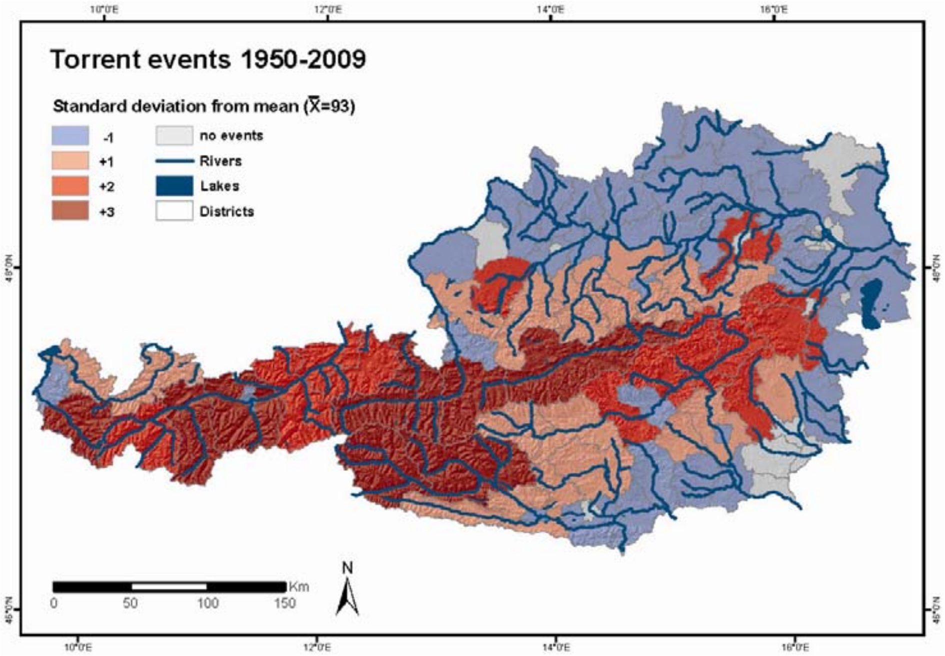

Figure 1-1. *Compilation of the number of torrent events between 1950 and 2009 within the Republic of Austria. Obviously, the areas with an above-average incurrence of events is spatially overlapping with those regions of Austria with a high relief. Source: Totschnig et al. (2011) based on data from Hübl et al. (2009b).*

Based on an analysis of number of torrent events (Hübl et al., 2009) it becomes obvious that torrent processes matter in Austria, as also reported by Oberndorfer et al. (2007).

In Austria, a database of destructive torrent events was established and analysed concerning monetary losses by Oberndorfer et al. (2007). A total number of 4,894 damaging torrent events was reported for the period between 1972 and 2004. For almost 4,300 events the process type could be determined ex-post due to the event documentation carried out by the Austrian Torrent and Avalanche Control Service, resulting in a classification between floods (0.3 %), flooding with bed-load transport (21.8 %), hyper-concentrated flows (49.2 %), and debris flows (28.7 %). The average direct loss per event due to these 4,300 records amounted to approximately € 170,000, and annually losses due to torrent events amounted to around € 25 million. Approximately two third of the losses could be ascribed to buildings, and one third to infrastructure facilities. Within the period under investigation, 21 people were physically harmed and 49 people died. The annual distribution of the losses showed that considerable cumulative damage exceeding € 1 million per event occurred in 1975, 1978, and 1991. In contrast, in 1976 and 1984, the average damage per event summed up to € 11,000 and € 16,000, respectively. A considerable number of events was reported from 1974, 1990, and 2002, leading to the conclusion that a high number of events does not necessarily result in high losses, and vice versa. This was also a main conclusion from the works by Hübl et al. (2011).

With respect to snow avalanches, information related to destructive events is rather sparse in Austria. Between 1967 and 1992, a total of 5,135 avalanches had been reported by Luzian (2002), 4,032 of which caused damage to settlements and infrastructure. The data did not show any trend; however, large events were reported from 1969, 1974, 1980, 1981, and 1983 during the period under investigation. For a separately studied period between 1998 and 2003, 172 avalanches causing damage to settlements and infrastructure were reported by Luzian and Eller (2007); 94 of which resulted from the winter 1998/1999 and 47 from the winter 1999/2000. The amount of losses was not reported in these sources, apart from the figure of 718 destroyed and 570 damaged structures between 1967 and 2002 (Luzian, 2002), and 29 lives lost in buried buildings between 1998 and 2003 (Luzian and Eller, 2007).

Hence, the society in Austria is affected by a considerable amount of mountain hazards resulting in the respective height of losses. Consequently, the management of mountain hazards is necessary, and the development of appropriate management strategies becomes evident with respect to a sustainable use of mountain regions for economic purpose, recreation and settlement.

A sustainable use of mountain areas includes (a) hazard assessment, (b) an assessment of possible effects of the impact of these hazards on the built environment or any other elements at risk exposed, (c) the assessment of vulnerability of these elements at risk, and (d) the development of tailored management options to reduce the adverse effects. Taking the Republic of Austria as an example, the principles are laid down in the Forest Act (Republik Österreich, 1975) and – for example – in the related procedures and service regulations of the Federal Ministry of Agriculture, Forestry, Environment and Water Management (2001); as extensively discussed by Kanonier (2006) as well as in Chapter 2 (Holub and Fuchs, 2009). In Austria a long tradition exists in analysing the hazard potential of mass movements, the related assessment of design events and the planning and implementation of conventional technical mitigation, forest-biological mitigation, and mitigation by spatial planning (e.g., Rudolf-Miklau, 2005). Additional mitigation strategies which supplement these traditional concepts of protecting the areas endangered by hazard processes include the concept of local structural protection. Local structural protection can be – on the one hand – traced back to early attempts of hazard prevention, such as deflection walls or the integration of the hillside part of a building in the slope, which were constructed since the Medieval Age to protect individual buildings. Nevertheless, on the other hand, this concept was further developed and includes a series of technical measures based on different mitigation approaches. Therefore, only little is known so far related to the general constructive possibilities available. Consequently such information has not been systematically collected and analysed so far with respect to possible effects and the overall embedding in the different management concepts of mountain hazards.

The following Sections of this core paper address different issues that emerge from managing mountain hazards, with a particular focus on the Republic of Austria. Therefore, in Section 1.1, a set of definitions is provided for terms used throughout this PhD thesis. In Section 1.2, the development and current approaches of dealing with mountain hazards in Austria is presented. Subsequently, mitigation measures will be characterised according to their properties and effectiveness with respect to different demands in mountain hazard management (Section 1.3). In Section 1.4, the concept of local structural protection is discussed, and underlying concepts are presented. In Section 1.5, the purpose of this PhD thesis is summarised and hypotheses are deduced from the overall framework of dealing with mountain hazards in Austria.

1.1 Definitions

In this section, a set of definitions for technical terms related to mountain hazards, vulnerability, risk, and mitigation is provided. Thereby, the overall aim is not to list every available conceptual and operational definition that could be picked up in relevant literature (e.g., Gauch, 2003; Nola and Sankey, 2007), but rather to provide information on the accurate and precise utilisation of language within this cumulative PhD thesis.

In a European context, the term torrent refers to steep rivers within a mountainous environment. Torrents are defined as constantly or temporarily flowing watercourses with strongly changing perennial or intermittent discharge and flow conditions (Aulitzky, 1980; ONR, 2009), originating within small catchment areas (Slaymaker, 1988). Catchment characteristics, such as watershed area and longitudinal slope are alternatively used to define torrents (Summerfield, 1991), whereas the delimitation criteria are often not as clear. While some authors refer only to the area of the watershed for a delimitation of torrents from other types of linear watercourses, others additionally include information on the longitudinal slope. Torrent events include a process group which shows a variety of different flow characteristics including discharge composed from pure water runoff, discharge with variable sediment concentration and debris flows (Costa, 1984). Therefore, the major characteristics of the respective events in the different test sites have to be defined. The sediment concentration is employed in conventional engineering approaches to distinguish between different processes, although the use of one individual parameter as a decision rule is reported to be insufficient (Costa, 1984). However, Hungr et al. (2001) recommend peak discharge as a reliable criterion to differentiate between different process types, i.e., debris flows and debris floods. While debris floods are usually associated with considerable transport of coarse sediment, hyperconcentrated flows, partly used as a synonym for debris floods (Costa, 1984, 1988), are characterised by larger amounts of fine sediment in suspension (Scheidl and Rickenmann, 2010). A sediment concentration of 70 % by weight (47 % by volume) as a threshold between hyperconcentrated flows and debris flows is suggested (Costa, 1988). Since in this study the focus is on the effects of torrent processes in general, the precise distinction between processes remains arbitrary. Nevertheless, while debris floods typically produce relatively thin, wide sheets of material, debris flows produce thicker, more hummocky and lobate depositions affecting elements at risk exposed (Hungr et al., 2001). Fluvial sediment transport, in contrast, also referred to as water floods (Costa, 1988) or sediment-laden flow (Wan and Wang, 1994), is characterised by a lower sediment concentration than debris floods (Scheidl and Rickenmann, 2010). A sediment concentration of 40 % by weight (20 % by volume) as a threshold between fluvial sediment transport and hyperconcentrated flows is suggested (Costa, 1988). Within fluvial sediment transport processes, sediment and water are moving with different velocities as two distinct and separate phases. During one individual event, the respective processes in the torrent often change due to the temporal and spatial variability of sediment concentration. As a result, the dominant process in the central part of the deposition zone should be used to define the entire event characteristics (Hungr, 2005).

Snow avalanches are defined as a type of fast-moving mass movement (Bründl et al., 2010). They can also contain rocks, soil, vegetation or ice. Avalanche size is classified according to its destructive power (McClung and Schaerer, 1993). A medium sized slab avalanche may involve 10,000 m^3 of snow, equivalent to a mass of about 2,000 tons (snow density 200 kg/m^3). Avalanche speeds vary between 50 and 200 km/h for large dry snow avalanches, whereas wet slides are denser and slower (20-100 km/h). If the avalanche path is steep, dry snow avalanches generate a powder cloud. In general, snow avalanches are defined as a moving mass of snow with a dislocation > 50 m (Kienholz et al., 1998). Starting zone occur at elevations above the winter snowline, having slopes in the range of 30°-45° in inclination (Goudie, 2004), and are generally lee to the main storm wind direction. Avalanches are classified according to their mechanisms of flow into dense flow and powder avalanches. With respect to mechanisms of avalanche formation, both slab and loose snow avalanches are separated (Keylock, 1997). This distinction has an influence on the susceptibility of elements at risk exposed, and is comprehensively discussed in Chapter 5.

Following Varnes (1984) and Fell et al. (2008b), a hazard is in general a condition with the potential for causing an undesirable consequence. A natural hazard is defined as a geomorphic phenomenon rooted in gravitational forces and endangering any element at risk exposed. Therefore, a natural hazard represents the potential interaction between humans and their environment (Tobin and Montz, 1997). With respect to natural processes, the description of hazard should include the location of occurrence, volume (or area) affected, classification, and information on frequency and magnitude. Frequency is conceptualised as the number of occurrences within a given time period, and magnitude refers to scientifically based measures of the strength of physical processes, such as flow velocity. If measures of magnitude concern impacts of an event on the elements at risk exposed, intensity is used instead. With respect to mountain hazards, assessments are repeatedly based on intensity estimates that incorporate variables as indices of destruction since direct measurements of process magnitude are not regularly available (compare e.g., BWW et al., 1997; BUWAL et al., 1997).

Elements at risk refers to the population, buildings and engineering works, economic activities, public service utilities, other infrastructures and environmental values in the area potentially affected by the natural hazard (e.g., Hollenstein, 1995; Smith and Petley, 2009). If elements at risk are monetised, the term values at risk is used.

Vulnerability is considered by taking an engineering approach (Fell et al., 2008a, 2008b), and refers to the susceptibility of elements at risk (Fuchs, 2009). Vulnerability means the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural hazard of a given frequency and magnitude. It is expressed on a scale from 0 (no damage) to 1 (total loss), and is usually provided in terms of a vulnerability function (Totschnig et al., 2011).

Risk is a measure of the probability and severity of an adverse effect to health, property or the environment (Fell et al., 2008a). This is often estimated by a function of probability of a phenomenon of a given magnitude times the consequences (Kienholz et al., 2004). Generalised, risk results from an interaction between hazards and vulnerable conditions (United Nations, 2004), and is conceptualised within this PhD thesis by using the engineering definition of an expected degree of loss due to a particular natural phenomenon. Consequently, risk is expressed by the product of hazard times vulnerability times values at risk (Hübl et al., 2009a), initially neglecting any responsibility related to the structure of society, or any other human dimension (Wisner et al., 2004).

Mitigation is an organised and comprehensive action to decrease the adverse effects of hazards on society, and includes structural and non-structural measures undertaken to limit the undesirable impact of natural hazards (United Nations, 2004), including early warning systems (Kienholz, 2003). The overall classification of different mitigation alternatives is extensively discussed within this thesis in Chapter 4 as well as Holub and Hübl (2008).

1.2 Dealing with mountain hazards in Austria

A sustainable use of mountain areas must include the analysis, assessment and the management of natural hazard risk due to the relative scarceness of utilisable areas. Taking the Republic of Austria as an example, only 38.7 % of the territory is suitable for such purposes (Statistik Austria, 2004). As a result, considerable spatial overlap between the run-out area of hazard processes and elements at risk exposed arise (Sinabell et al., 2008), a challenging issue that demanded attention already during the last centuries.

In European mountain regions, strategies to prevent or to reduce the effects of natural hazards for settlements and other areas used for economic activities, started in the Ancient World with the concept of taboo and sin (compare Bernstein, 1998) and developed towards a normative notion due to the spread and increasing influence of Christian faith in the Early Middle Ages (Wiedemann, 1993). During these periods, however, the effects of natural hazards were taken as a punishment or nemesis of God; it was only since the period of Enlightenment with the associated increase in natural scientific knowledge that humans dealt actively with efforts to reduce the negative effects of hazards on society (Keiler and Fuchs, 2010). From a scientific point of view, a debate developed in the outgoing 18th century such as Zallinger zum Thurn (1778), Freiherr von Aretin (1808), or Duile (1826). In Austria, official authorities dealing with mountain hazards were only founded in 1884 (Länger, 2003), in parallel with similar actions in other alpine countries (e.g., Landolt, 1886). These authorities were in charge of protecting the areas used for settlements as well as infrastructure lines from the impact of hazard processes. Since 1850, protection against natural hazards was mainly targeted at implementing technical constructions in the release areas of hazard processes, such as the upper part of torrent catchments to retain solids from erosion, and in the avalanche starting zones. These constructions were increasingly supplemented by silvicultural efforts to afforest high altitudes as well as by forest-biological and soil bio-engineering measures. Since the 1950s, such mitigation concepts, which aimed at decreasing both, the magnitude and the frequency of events, were complemented by more sophisticated technical mitigation measures to be implemented with considerable engineering efforts; these constructions were aimed at a retention of material. Since the 1970s this approach was progressively diversified, and additional mitigation measures were developed (compare Rudolf-Miklau, 2009 for an overview).

In general, conventional engineering mitigation concepts consider technical structures within the catchment, along the channel system or channel track and in the deposition area (Holub and Hübl, 2008). According to the approach of disposition management (reducing the probability of occurrence of natural hazards) and event management (interfering the transport process of the hazard itself), a wide range of technical measures is applicable for a prevention (ONR, 2009, see Tab. 1-1). Technical mitigation inevitably has its limitations, and such conventional constructive measures against mountain hazards, such as deflection and retention walls as well as torrential barriers, were supplemented by land use control through planning instruments, i.e. hazard zoning, since the 1970s (Aulitzky, 1994). As discussed in detail later in this thesis (Chapter 2; Holub and Fuchs, 2009), the Forest Act was introduced in 1975 in Austria. Within this Act, fundamentals in dealing with natural hazards in Austria were laid down (Republik Österreich, 1975), and subsequently, additional regulations in particular applicable to torrent and avalanche control were implemented (Republik Österreich, 1976). Further approaches include warning and monitoring, evacuation procedures, civil protection and disaster management norms and codes (Hübl et al., 2009a). The overall aim of such preventive measures is to reduce losses without directly influencing the process behaviour by separating process trajectories from elements at risk.

Apart from the multiple legal regulations, the main challenge for the implementation of these regulations is the different responsibility and competence between the Länder level and the federal level in the Republic of Austria. Since the protection against the effects of natural hazards is laid down in the Forest law on the federal level, but the implementation of land-use regulations is within the competency of the individual Länder, the hazard maps have no direct legal influence on the regional planning acts of the Länder, and the subsequent zoning maps and development plans on the district and community level, respectively (see Fig. 1-2). As a result, local structural protection, if directly connected to the building envelope, is legally at the same level than the local development plan, while solely the implementation of conventional technical mitigation is situated on the federal level. Hence, some shortcomings with respect to a combination of both approaches may arise, which will be discussed in more detail in Chapter 2.

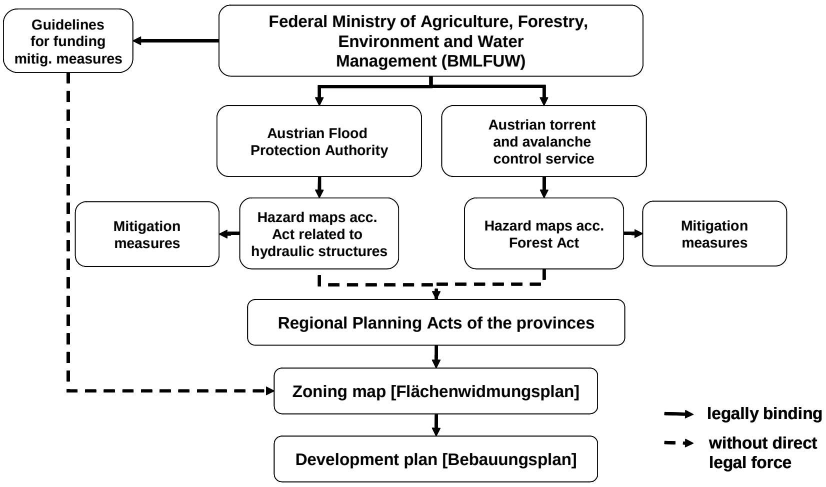

Figure 1-2. *Overview legal regulations (after Habersack et al., 2009).*

There cannot be any doubt, though, that the investments of considerable amounts of public money in constructive mitigation, and the implementation of hazard maps, is not able to guarantee for a absolute safety of endangered areas. This was particularly proven in the 1990s, when – despite of the efforts in protection – severe losses occurred throughout the alpine area (avalanches 1998/1999, torrents 1999, 2002, 2005, flooding 2002, 2005, 2006). This resulted in discussions about whether or not a comprehensive protection of any endangered area is affordable on a sustained basis from an economic point of view as well as from an ecological point of view. From these discussions, a modified regulation on cost-benefit analysis for technical mitigation (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2005) and adapted guidelines for the assessment of cost-efficiency of mitigation (Hübl and Kraus, 2003) resulted in Austria. The proof of such issues is – basically – nothing else than the implementation of the concept of risk into the concept of mountain hazard mitigation. The concept of risk, additionally, is also required from a political side for the management of hazards by the implementation of the *Directive on the Assessment and Management of Flood Risks* addressed to all Member States (Commission of the European Communities, 2007) as well as the *European Action Programme on Flood Risk Management* (Commission of the European Communities, 2004).

The concept of risk is based on a functional relationship between hazard and exposure; the latter usually defined as values at risk exposed and vulnerability (Kienholz et al., 2004). To implement this concept, as discussed in Chapter 4, information on the probability of occurrence of the considered hazard scenario is required (p_{Si}), as well as the value of individual elements j at risk (A_{Oj}), the related vulnerability of these elements in dependence on the hazard scenario i ($v_{Oj,\,Si}$), and the probability of exposure ($p_{Oj,\,Si}$) of mobile elements j to scenario i (Eq. 1-1).

$$R_{i,j} = f(p_{Si}, A_{Oj}, v_{Oj,Si}, p_{Oj,Si}) \qquad \text{(Eq. 1-1.)}$$

This quantitative definition of risk provides the framework for probabilistic risk assessment and has its roots in both technical risk analyses (e.g., Schneider, 1991; Fritzsche, 1986) and actuarial analyses and the insurance business (Erdmann, 1991; Schwarz, 1996; Freeman and Kunreuther, 2003).

The concept of risk is pillared on both, mitigation and prevention. Mitigation includes all efforts to actively and/or passively reduce the impact of hazard process on elements at risk exposed (compare Section 1.3). Studies related to the effectiveness of mitigation measures concluded that a combination of active and passive mitigation concepts is very reliable and, moreover, cost-efficient. Hence, a combination of different mitigation strategies is also recommended from an economic point of view (Fuchs and McAlpin, 2005; Holub and Fuchs, 2008, see Chapter 2). A well-balanced mitigation strategy, in turn, is an effective preventive concept and includes conventional constructive measures as well as local structural protection (compare Chapter 5) and early warning.

Comprehensive information on conventional constructive mitigation concepts was recently compiled by Bergmeister et al. (2008), and promising attempts towards a similar compendium for local structural protection have been made by Egli (2005) based on an earlier classification scheme (Egli, 1999). Nevertheless, the latter studies were focused on technical aspects of local structural protection but were neglecting several issues, in particular (a) a comparison with conventional constructive mitigation (compare Chapter 4), (b) a proof of possible economic efficiency of such attempts (compare Chapter 3), as well as (c) a detailed assessment of costs necessary for such measures (compare Chapter 5).

1.3 Classification of mitigation measures

In general, mitigation concepts for mountain hazards can be classified either according to their properties into active and passive mitigation measures, or with respect to an aspect of temporal availability in permanent and temporary protection (see Tab. 1-1).

(1) Active mitigation measures can influence the initiation, transport and depositions of mass movements. Active mitigation strategies include preventive measures and measures in reaction to an event. The first is targeted at a change of characteristics such as magnitude and frequency of mass movements, and can be achieved either by influencing the event disposition (reducing the probability of occurrence of a hazardous event), or by manipulating the hazardous process itself (event management), see Hübl and Fiebiger (2005). With respect to the latter, emergency response is an important issue to reduce the adverse effects of mountain hazards.

(2) Passive mitigation measures are based on the principle of spatial separation of the endangered elements at risk from the area affected by the hazard process (Wilhelm, 1997). Passive mitigation strategies include preventive measures and measures in reaction to an event. As a result of such measures, the area of overlap between the hazardous process and the elements at risk will be reduced. Preventive measures include all aspects

of spatial planning (e.g., hazard mapping, hazard-adjusted land use) but also management aspects (e.g., management plans, information, and evacuation). Measures in reaction to an event include catastrophe management. Both strategies usually supplement active mitigation measures.

(3) Permanent mitigation includes such measures where during an event no intervention is necessary to assure the protective effects of the measure. Consequently, these measures include all constructive measures in the starting area of hazardous processes, in the transit area and in the run-out area. Furthermore, forest-biological measures and all land-use measures are included, as well as management plans.

(4) Temporary mitigation is characterised by the premise that this measure is only effective if it is available during an event (preventive technical measure, as well as information, alert, warning, evacuation and closure) or after an event (emergency response and catastrophe management).

Table 1-1. *Matrix of mitigation measures to mitigate mountain hazards (adapted from ONR 2009).*

			Permanent protection	**Temporary protection**
Active measures	Preventive effect	Influencing the event disposition	Forest-biological measures	
			Technical protection measures	
		Influencing the process	Technical protection measures	
	Reaction to event			Emergency response
Passive measures	Preventive effect		Hazard map Hazard-adjusted land use Local structural protection Management plans (evacuation)	Information Warning Alert Evacuation Closure
	Reaction to event			Catastrophe management

Within this classification scheme published in ONR (2009), local structural protection is classified as (a) passive preventive mitigation measure, and (b) permanent preventive mitigation alternative. As some types of local structural protection measures are targeted at a deflection of mass movements, and consequently at an avoidance of deposition in the run-out area, they could also be classified as an active measure. Nevertheless, since local structural protection measures are mostly implemented in direct connection to the building envelope, they do not necessarily avoid a deposition of mass movements, they are rather aiming at an increase in resistance of the object at risk; therefore, they could also be classified as passive mitigation measure. However, this issue will not be further discussed here.

Apart from the classification scheme of ONR (2009), mitigation measures can be grouped according to the underlying purpose within the overall management strategy into (a) spatial measures, (b) structural measures, (c) organisational measures, and (d) institutional measures. Such a classification scheme is discussed comprehensively in Chapter 4.

1.4 Local structural protection

During the last centuries, local structural protection measures such as deflection walls composed from natural stone without mortar were technically neither highly-developed nor highly sophisticated. Therefore, they were not particularly innovative but rather oriented to the respective contemporary design used for other construction types. As discussed above, the development of such measures was in general reactive (Keiler and Fuchs, 2010) as they were usually constructed following a destructive hazardous event. Hence the mitigation was based on an ex-post approach rather then in terms of ex-ante and therefore pro-active modern preventive approach (Greminger, 2003). As a consequence, local structural protection was based on individual experiences that may have been different in different regions rather than on scientific findings and related technical guidelines.

The development of alternative construction materials during the last century, such as steel, reinforced concrete, or multi-layer glass, resulted in radically changed possibilities of construction as well as of design; in parallel, the resistance and stability of buildings constructed with these new materials increased. Simultaneously, it was possible to design innovative technical protection measures, often following distinct design principles or certain design rules, and the constraint of topographic conditions was negligible when local structural protection has to be implemented.

Local structural protection measures should be effective and efficient in reducing vulnerability to mountain hazards and corresponding losses, and are therefore the result of systematic hazard analyses (Kletzan et al., 2004; in: Habersack et al., 2004, Floodrisk I; p72). Local structural protection, however, is directly connected to the overall mitigation concept, and is therefore related to conventional mitigation strategies and the implementation of spatial planning strategies through hazard maps (Habersack et al., 2009). In dependence on the type of hazard process, the associated degree of protection to be achieved, and the appropriate concept of mitigation, local structural protection can be constructed adjacent to buildings to be protected or directly connected with the building envelope. The decision about the design of individual measures is dependent on whether it is essential to avoid an impact resulting from a hazardous event, or if the element at risk should be strengthened or retrofitted in order to increase the structural resistance of the envelope and simultaneously decrease the loss potential of the hazard. Examples for the first include local structural protection located in the environment of the element at risk, such as splitting wedges or deflection dams; and examples for the latter include constructive measures at the building envelope such as an enforcement of the process-side outer wall, an mounting of avalanche-resistant windows resistant up to a certain impact pressure, and the sealing of building openings. When implementing such local structural protection measures it is obvious that these measures constructed in the direct environment of an element at risk exposed are optically conspicuous and therefore impact the aesthetics (Hauer et al., 2010), moreover, they are characterised by higher land consumption then these measures integrated into the building envelope.

Apart from these constructive aspects related to positioning and design further criteria may be used to characterise and classify local structural protection measures (Holub, 2008), such as

(1) the type of process or process chain endangering the element at risk;

(2) the desired period of protection (permanent or temporary protection);

(3) the point in time of implementation (whether the measure should be implemented while the element at risk is still under construction or the measure should be implemented in terms of retrofitting an already existing building stock); and

(4) the construction materials to be used.

Due to typical damage patterns, differently designed local structural protection and different construction materials used show varying load effects and impact behaviour (Holub et al., 2011). Therefore, the following basic principles have to be considered when local structural protection is planned:

(1) The interaction of all relevant hazard processes within the endangered run-out area has to be considered, including possible interactions resulting from several different threats which are considered jointly, and possible hazard chains (Kappes et al., 2010).

(2) In general spatial planning measures should be preferred to technical mitigation (Kanonier, 2006). In this context the most effective mitigation alternative would be to prevent any land-use activity in endangered areas (e.g., Roy et al., 2003).

(3) Usually permanent mitigation is better able to resist the relatively high impact forces and flow velocities of hazard processes. Therefore such measures are superior to temporary (mobile) alternatives, in particular since the short lead times of mountain hazards (Kienholz, 2003) significantly reduce the available mounting time for mitigation types such as mobile dam elements used for flood protection.

(4) As laid down in the respective regulations (Hattenberger, 2006), any mitigation concept and therefore also local structural protection must not cause any damage to third parties by increasing the hazard potential for adjacent or downstream riparian properties.

Apart from local structural protection sensu stricto, the potential of loss may be considerably reduced by an adapted use of the elements at risk (Habersack et al. 2004, 2009). Such an adapted use includes the adjusted utilisation of the building interior, or the respective re-design of the interior. The basic principle of such a concept is a reduction of the duration of stay of persons inside those parts of the building that are exceptionally exposed, such as in a hill-side location or a location towards the impact side of a hazard. Similarly, elements with a commonly short duration of stay, such as staircases or carports may be situated between the building and the potential areas of hazard impact.

To conclude, local structural protection is targeted at a reduction of loss potential for elements at risk exposed (Egli, 2005). For an efficient and effective planning and implementation of such mitigation, knowledge on process characteristics and respective load assumptions is necessary, as well as the technical feasibility of individual measures and their possible combinations, respectively. While a limited amount of studies and reports are available on the general characterisation and classification of local structural mitigation, most of them originating in European mountain regions (Egli, 1999, 2000, 2005; Holub and Hübl, 2008; compare Chapter 4), only little is known so far on economic aspects (Egli, 2002; Holub and Fuchs, 2008; compare Chapter 3). Moreover, comprehensive information on the design is almost missing, as recently claimed by Suda and Rudolf-Miklau (2012) and Holub et al. (2011). As a result, an appropriate implementation in legal regulations or on a political level is missing (Gamerith and Höfler, 2006; ÖROK, 2005), and associated incentives for a risk-minimising behaviour of the affected population are not yet set in the Republic of Austria (Holub and Fuchs, 2009; compare Chapter 2; Habersack, 2004, 2009).

1.5 Purpose of the study

The purpose of this thesis is to provide comprehensive information on local structural protection measures since these measures were identified as having considerable potential to reduce the losses incurring from mountain hazards. As introduced above, until now, there is a particular lack of studies related to such measures even if they are supposed to be very cost-effective and can reduce the effects of the process impact on the building envelope significantly.

With respect to static flooding, it is repeatedly argued that local structural measures are effective in decreasing vulnerability, in particular if flood levels are below two metres (Egli, 2002a, 2002b) and if static flood intensities are small, respectively (Kreibich et al., 2005). This issue was also addressed but not supported by quantitative data by Fuchs et al. (2007) with respect to the vulnerability of buildings to torrent processes. Similarly, with respect to dynamic flooding, Kimmerle (2002) had stated that buildings with local protection measures suffered less damage than unprotected ones, and concluded without any further quantification that particular combinations of different local structural measures are effective in sheltering values at risk from impacts due to torrential floods. Hence, one purpose of this study is to evaluate the potential of local structural protection to decrease the vulnerability of buildings and consequently to reduce corresponding losses. In order to assess this potential, different strategies in risk management were reviewed with a particular focus on legislation, risk transfer, and awareness building. Subsequently, the overall effectiveness of local structural protection in comparison to conventional mitigation concepts was exemplarily studied in a small Austrian test site. Design and performance seem to be the most important issues considering the effectiveness of local structural measures; nevertheless, in-depth information is still outstanding. Taking these findings, a catalogue of local structural protection measures was compiled for mountain hazards, i.e., static and dynamic flooding, fluvial bedload transport, debris flows, land slides, rock falls, and snow avalanches. Until now, however, there is a particular gap with respect to the cost-efficiency of such measures. In order to close this gap, a prototype of a typical Austrian residential building was designed that is equipped with various local structural protection measures to reduce the effects of torrent processes and snow avalanches, and the investments necessary for these measures were quantified. The hypotheses underlying this thesis can be summarised as follows:

(1) The legal situation in Austria with respect to hazard and risk assessment and mitigation does not sufficiently take into account mitigation measures other than technical mitigation and land-use. Therefore, local structural protection may not be mirrored accordingly, consequently, the respective awareness seems to be not built, and incentives for the implementation of such measures seem to be outstanding. This hypothesis is extensively discussed in Chapter 2.

(2) Local structural protection is generally very effective in comparison to conventional technical mitigation, in particular with respect to high-frequency low-magnitude events. However, this effect has not been sufficiently addressed so far. Therefore, local structural protection was assessed in Chapter 3 according to the potential to supplement conventional approaches in order to reduce small and medium-size losses.

(3) While for some hazards, information on possible local structural protection is available such information is not available so far for the entire variety of mountain hazards. Hence, it has to be assessed which range of local structural mitigation is available and suitable for reducing the effects of mountain hazards on the building envelope, and which measures can be implemented during new developments or in order to retrofit already existing buildings (Chapter 4).

(4) Compared to conventional mitigation, it is repeatedly but vaguely assumed that local structural protection is particularly cost-effective if mean annual losses resulting from mountain hazards are opposed. Nevertheless, this assumption has not been proven so far with respect to mountain hazards, and will therefore be quantitatively studied in Chapter 5.

Within this thesis, the respective research needs have been identified, specific suggestions have been made and appropriate methods have been developed in order to contribute to necessary implications for risk management and to the scientific debate on the underlying research gaps.

The overarching purpose of the studies undertaken for this thesis is to develop concepts and methods for an enhanced natural hazard risk management in mountain regions by integrating knowledge from civil engineering, mountain risk engineering, spatial planning and related fields and by developing concepts to be applied in the insurance business, but also in the field of applied risk management.

2 Mitigating mountain hazards in Austria – Legislation, risk transfer, and awareness building

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Abstract

Embedded in the overall concept of integral risk management, mitigating mountain hazards is pillared by land use regulations, risk transfer, and information. In this paper aspects on legislation related to natural hazards in Austria are summarised, with a particular focus on spatial planning activities and hazard mapping, and possible adaptations focussing on enhanced resilience are outlined. Furthermore, the system of risk transfer is discussed, highlighting the importance of creating incentives for risk-aware behaviour, above all with respect to individual precaution and insurance solutions. Therefore, the issue of creating awareness through information is essential, which is presented subsequently. The study results in recommendations of how administrative units on different federal and local levels could increase the enforcement of regulations related to the minimisation of natural hazard risk. Moreover, the nexus to risk transfer mechanisms is provided, focusing on the current compensation system in Austria and some possible adjustments in order to provide economic incentives for (private) investments in mitigation measures, i.e. local structural protection. These incentives should be supported by delivering information on hazard and risk target-oriented to any stakeholder involved. Therefore, coping strategies have to be adjusted and the interaction between prevention and precaution has to be highlighted. The paper closes with recommendations of how these efforts could be achieved, with a particular focus on the situation in the Republic of Austria.

2.1 Introduction

In Austria, strategies to prevent or to reduce the effects of natural hazards in areas of settlements and economic activities trace back in the mediaeval times; official authorities were only founded in 1884 (Länger, 2003) based on a first legal regulation (Österreichisch-Ungarische Monarchie, 1884). In the second half of the 19th and the early 20th century protection against natural hazards was mainly organised by implementing permanent measures in the upper parts of the catchments to retain solids from erosion and in the release areas of avalanches. These measures were supplemented by silvicultural efforts to afforest high altitudes. Since the 1950s such conventional mitigation concepts – which aimed at decreasing both, the intensity and the frequency of events – were increasingly complemented by more sophisticated technical mitigation measures. Until the 1970s, mitigation concepts mainly aimed at the deflection of hazard processes into areas not used for settlements.

In the Republic of Austria conventional mitigation of natural hazards institutionally originates from the 1890s when the French system of forest-technical torrent and avalanche control was adopted. Watershed management measures, forest-biological and soil bio-engineering measures as well as technical measures (construction material: timber and stone masonry) had been implemented. Thus, conventional mitigation concepts only consider technical structures within the catchment, along the channel system or track and in the deposition area. According to the approach of disposition management (reducing the probability of occurrence of natural hazards) and event management (interfering the transport process of the hazard itself), a wide range of technical measures is applicable.

Conventional technical measures against mountain hazards, such as deflection and retention walls as well as torrential barriers, are not only very cost-intensive in construction, moreover, because of a limited lifetime and therefore an increasing complexity of maintenance in high-mountain regions, the feasibility of technical structures is restricted due to a scarceness of financial resources provided by responsible authorities. If maintenance is neglected mitigation measures will become ineffective and can even increase the catastrophic potential of natural hazards. Since conventional technical measures do neither guarantee reliability nor complete safety, a residual risk of damage to buildings, infrastructure and harm to people remains.

Experiences from last years suggested that values at risk and spatial planning should be increasingly considered within the framework of natural hazard risk reduction (Fuchs et al., 2005; Zischg et al., 2005a, b; Kanonier, 2006; Keiler et al., 2006). To meet this goal, integral risk management strategies seem to be a valuable instrument to reduce the susceptibility of buildings and infrastructure to natural hazards and to develop strategies for a strengthened resistance (Fuchs et al., 2007a), above all by means of local protection measures.

Besides conventional technical mitigation measures, structural precaution is achieved by an adapted construction design and the appropriate use of an object. Structural precaution is the main application domain for local structural measures, since the individual vulnerability of buildings can be fundamentally decreased by strengthening e.g. brick walls with reinforced concrete components, and/or the adopted interior design of the different rooms according to occupancy time and hazard potential (Holub and Hübl, 2008).

The principles of planning and implementation of local structural measures to reduce vulnerability against natural hazards are neither highly sophisticated nor very innovative (Fuchs, 2009). However, the overall framework of dealing with mountain hazards in Austria does not explicitly take into account such principles.

Firstly, the legislation related to natural hazards is diverse due to the federal structure of the Republic of Austria. Several articles at federal level are supplemented by various regulations on the level of the federal states (Länder level) and even below at community level, in particular with respect to land use planning. Secondly, different strategies to mitigate and thus compensate the effects of mountain hazards exist in Austria. These strategies, above all the governmental disaster fund and private insurance solutions, are neither particularly coordinated with respect to risk minimisation nor do they create considerable incentives for individuals to prevent losses. Thirdly, risk awareness is not very prevalent throughout the country due to an information deficit related to the general occurrence of mountain hazards and mitigation strategies and concepts to avoid losses.

In this paper aspects on legislation related to natural hazards in Austria are summarised, with a particular focus on spatial planning activities and hazard mapping, and possible adaptations focussing on enhanced resilience are outlined. Furthermore, the system of risk transfer is discussed, highlighting the importance of creating incentives for risk-aware behaviour, above all with respect to individual precaution and insurance solutions. Therefore, the issue of creating awareness through information is essential, which is presented subsequently.

2.2 Legislation

In the Austrian legislation, multiple regulations with respect to natural hazards exist (Fig. 2-1). However, no uniform and consistent text of law with respect to the protection from the effects arising from natural hazards is given. In contrast, implications governed by public law are large in number and multifaceted, and include articles in the Austrian Forest Act, the Austrian Hydrography Act and the Disaster Fund Act at federal level as well as laws regulating spatial planning and land use planning on the Länder level, just to name the most prominent. Further articles with implications for natural hazard risk management are covered by individual articles of the federal traffic law and the law related to disaster management. On the Länder level, articles of the laws related to fire brigades and of the policies for disaster aid include individual regulations with respect to natural hazards. Subsequently, multiple agreements between the federal state and the Länder exist, above all regulating financial issues with respect to early warning systems, mutual rights related to alerts, and several articles on financial compensation. Hence, due to the strong federal character of the Republic of Austria, legislation and execution of issues arising from dealing with the effects of mountain hazards are assigned to different federal, Länder, and local authorities depending on their respective jurisdiction and competence (Fig. 2-

1). Accordingly, these authorities get also individually active with respect to the administration of the private sector, e.g., concerning aspects of prevention and loss adjustment.

Despite these multiple responsibilities at different governmental levels, the most important and fundamental laws – the Austrian Forest Act and the associated decree related to hazard mapping – will be addressed in the following sections.

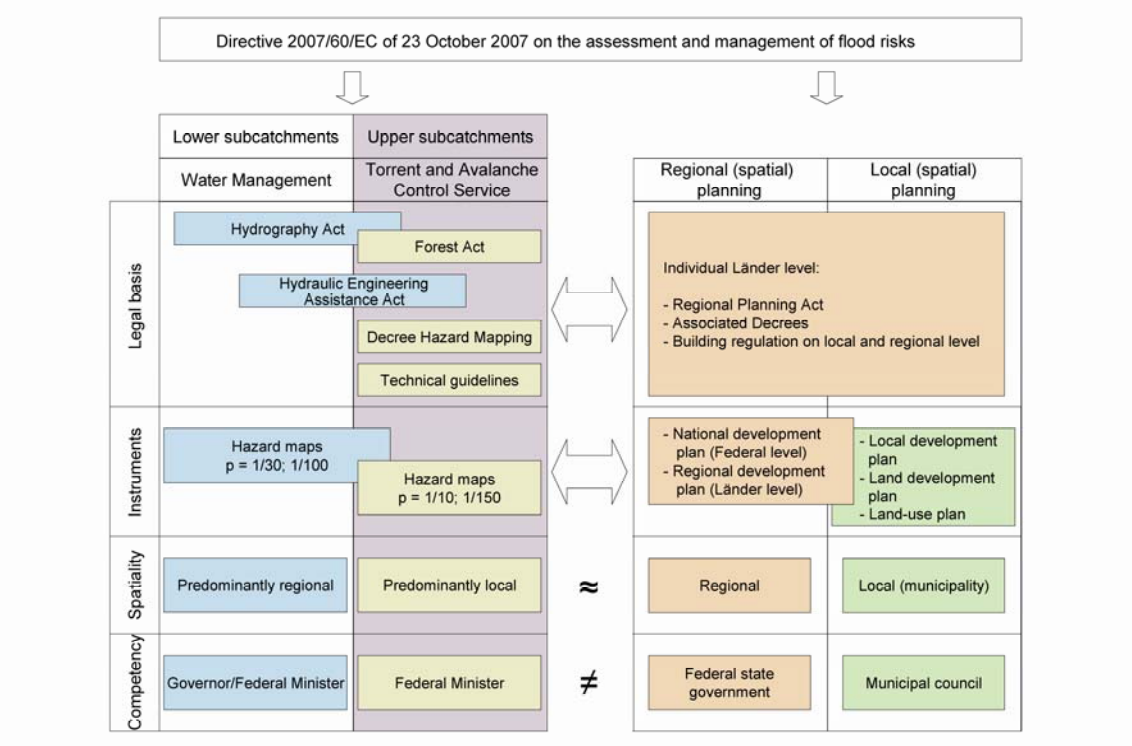


Figure 2-1. *Structure of the planning system related to mountain hazards in Austria (modified from ÖROK, 2005).*

2.2.1 Hazard mapping and spatial planning

In Austria, the methodology for delimiting hazard zones is regulated by a national legal act (Republik Österreich, 1975) and an associated decree (Republik Österreich, 1976). The implementation of these regulations is assigned to the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) and administrated by the governmental departments of the Austrian Service for Torrent and Avalanche Control (WLV) in the upper parts of the catchments and the Federal Water Engineering Administration in the lower parts of the catchments. The Austrian Forest Act (§ 8b) of 1975 prescribes the delimitation of hazard zones in catchment areas susceptible to natural hazards such as torrential floods or avalanches (Forest Act § 99) and areas reserved for mitigation measures. In § 11, the compilation of hazard maps and the involvement of communes and population are regularised. The contents and designs of these maps are specified by a decree associated to the Forest Act (Republik Österreich, 1976). According to § 5(2) of this Decree on Hazard Zoning, all available data and information on natural hazards as well as interactions between individual hazard processes have to be considered during the compilation of hazard maps. Furthermore, interferences with the human environment, such as infrastructure facilities and settlements have to be taken into account. Hazard maps are usually based on the area of an individual community, and should be compiled in a reproducible manner to allow for validation during the approval process by the Federal Ministry of Agriculture, Forestry, Environment and Water Management. Hazard maps are based on a design event with a return period of 1 in 150 years, and an event occurring more frequent with a return period of 1 in 10 years (Republik Österreich, 1976). In § 6 of the Decree on Hazard Zoning, the criteria for delimitation of hazard zones is prescribed. According to these prescriptions, red hazard zones indicate those areas where the permanent utilisation for settlement and traffic purposes is not possible or only possible with extraordinary efforts for mitigation measures. Yellow hazard zones indicate those are as where a permanent utilisation for settlement and traffic purposes is impaired by hazard processes. Furthermore, specific other areas have to be displayed in the hazard map: blue colours mark areas to be provided for future mitigation measures, above all silvicultural measures, brown colours indicate areas affected by landslides and rockfall, and purple colours indicate areas that can be used as protection due to their natural properties, such as protection forests or natural retention basins.

From a legal point of view, the hazard map does not bind land use planners directly in their decisions since the delimitation of hazard zones is not statutory regulation in accordance with the Austrian Superior Administrative Court (VwGH 27.03.1995, 91/10/0090, Hattenberger, 2006; Kanonier, 2006). As a consequence, hazard maps are not normative acts resulting in certain external effects or actions but they are classified as an opinion of experts providing a forecast for prospective developments of natural hazards effects. Accordingly, if the protection against natural hazards is intended to be fundamental for the decision-making of an administrative body, any conflicts arising between these decisions and the content of hazard maps have to be at least technically justified. Approaching this issue differently, administrative responsibility will be neglected considerably if the content of hazard maps is not taken into account accordingly in any governmental action. Hence, hazard maps are not legally binding for spatial planning purpose unless there is particular reference in the individual spatial planning law of the individual Länder, e.g. the Tyrolean Act on Spatial Planning explicitly addresses the protection of areas suitable for building activities against the adverse effects of natural hazards (Amt der Tiroler Landesregierung, 2006 § 1 Abs. 2 lit d). Nevertheless, the content of hazard maps is internally binding for any administrative body in terms of an order, in particular for the governmental departments of the Austrian Service for Torrent and Avalanche Control (WLV) and the Federal Water Engineering Administration (Hattenberger, 2006). Furthermore, due to European and international law, i.e. the Alpine Convention (CIPRA, 1998) and the European Flood Risk Directive (Commission of the European Communities, 2007), areas endangered by natural hazards have to be depicted accordingly in order to exclude them from further development activities.

Regional planning and regional development are a matter of the Austrian Länder and related legal regulation is within the individual Länder responsibility. Hence, for the regional as well as local planning level multiple regulations with respect to land utilisation, land use planning and building development exist. Considering areas endangered by natural hazard processes the traditional way to direct development activities in areas not exposed is an overall major principle but also a major task for local administrative bodies responsible, since areas for development are relatively scarce. However, as outlined by Kanonier (2006) the principle of Länder legislation providing higher-order environmental policy guidelines and establishing mandatory regulations to support municipalities for executions on a local level is no longer traceable in the present spatial planning reality. Although regional planning and the subordinated land development plan as main administrative tool are statutory, an implementation on the local level is not necessarily deducible. Because of the particular interests of stakeholders involved, higher-order regulations might be solved with respect to individual local needs differently. Furthermore, recently introduced participative approaches are gaining increasingly importance in order to provoke cooperation with parties affected. These affected parties regularly experienced restrictions for development of existing building land due to defined hazard zones (as a consequence of updated hazard information), including prohibition of development within a defined period in time and within a certain location. Consequently, stakeholders on the local level might disesteem Länder requirements, which will be mirrored directly on the local political decision level. An additional problem is the different horizon of spatial planning activities (5-10 years on the local level, 30-50 years on the regional level) and the hazard mapping process (10-20 years). In this regard, the implementation of the European Flood Risk Directive will contribute to a harmonisation since according to Art. 4, preliminary flood risk maps have to be compiled until December 2011, and according to Art. 6 the Member Countries are obliged to prepare area-wide flood risk maps until December 2013. Furthermore, these maps have to be regularly updated during a six-year interval (Commission of the European Communities, 2007).

Until now, a considerable diversity of interpretation is detectable with respect to the inclusion of natural hazard prevention in the spatial planning process in different Länder in Austria. Since regulations related to regional planning and development include – besides the prevention against the adverse effects of natural hazards – several other aims, multiple interests in utilisation and possibilities of development are confronted with the need to protect settlements and infrastructure against possible losses resulting from hazard processes. Hence, a conflict of objectives is inevitable. In order to implement a minimum standard of protection against natural hazards, building regulation is a purposeful tool to convert prevention into action.

2.2.2 Building regulation

To implement long-term planning policies and related spatial planning aims into practice, multiple measures and instruments on different administrative levels are possible. Two major principles to avoid an increasing risk potential exist, the avoidance to extend development land into areas affected by natural hazards, and the prescription of certain building regulations and structural measures, such as local structural protection. Thereby, spatial planning activities are not able to lower existing values exposed in already built-up areas. In contrast, by limiting rezoning at local governmental level, constructional development activities of plots located in endangered areas are adjusted in order to not increase values at risk exposed considerably. These mandatory restrictions in development on the local level are part of a hierarchical multi-stepped system within the regional planning and land use planning legislation as well as in the building laws at the Länder level and below in the municipalities (Kanonier, 2006). The regional development plan is therefore an appropriate tool to prescribe in a top-down approach certain regulations to individual municipalities on the local level. Hence, a minimum requirement is the depiction of hazard zones in these plans, whereas the level of detail varies considerably between individual Länder in Austria. While in the Federal State of Vorarlberg areas of certain relevance for the planning process have only to be visualised, it is mandatory in the Federal State of Salzburg to identify areas necessary for flood runoff and flood retention as well as areas indicated in hazard maps (Amt der Salzbuger Landesregierung, 2004, Slbg ROG § 16 Abs. 2 lit. c; Amt der Vorarlberger Landesregierung, 1996, Vlbg RplG 1996 § 12 Abs. 5).

However, the communal administrative opportunity for judgement might be considerable, above all with respect to possible exceptions applicable to guarantee the economic development of a certain region. The extent of consequences arising from natural hazard processes is directly influenced by the legal execution in the respective community or region.

The historical shift of a traditionally agricultural society to a service industry- and leisure-oriented society is mirrored by socioeconomic development in mountain environments and foreland regions. This shift is reflected by an increasing use of those areas for settlement, industry, and recreation. Due to an increasing concentration of tangible and intangible assets and to an increasing number of persons exposed to natural processes, there is an emerging need for the consideration of risk in land use development. Long-term analyses of risk evaluating these changes provided a general idea about the development of assets in endangered areas. Regarding the long-term development in values at risk, a significant increase could be proven for the period between 1950 and 2000 in the Eastern Alps (Fuchs et al., 2005; Keiler et al., 2006).

This development strengthens the need for due diligence processes in spatial planning and land development, above all with respect to building regulations to be increasingly implemented in planning processes on the local level. Even if the consideration of natural hazard processes is already implemented in the planning procedure on different administrative levels under the responsibility of multiple authorities, there is a particular need to enact the mandatory authorisation of planned constructions in areas influenced by natural hazard risk. The designation of development land requires the general adequacy of the plots for the intended use; consequently, building bans should be enacted for those areas that are due to their natural conditions not suitable for such purpose. However, such building bans are rarely implemented in practice and are often only applicable to red hazard zones (Kanonier, 2006). Moreover, the legally prescription of protection in areas less endangered by natural processes also seems to be not very successful in practice. Examples include in particular situations when the planned constructions intend not to increase the values at risk considerably, or if the developed land will not be extended into areas with a significantly increased hazard potential. Among others, corresponding regulations can be found in the Federal State of Upper Austria and in the Federal State of Tyrol (Amt der oberösterreichischen Landesregierung, 2004 § 21 Abs. 1a lit 2; Amt der Tiroler Landesregierung, 2006 § 37 Abs. 2 lit b).

As outlined above, the prescription of local structural protection is a promising principle in order to minimise risk. Considering different mass movement processes and their impacts on the built environment, multiple solutions for the protection of new buildings and the upgrade of existing inventory exist (Holub and Hübl, 2008). Recent studies related to torrential hazards in Austria (Fuchs et al., 2007a) and Switzerland (Romang et al., 2003) suggested a considerable decrease in vulnerability, if local structural protection is implemented. However, until now risk-minimising effects of local structural measures have only rarely been quantified so far (Holub and Fuchs, 2008), presumably since mandatory legal regulations are almost missing therefore. Only the Federal State of Vorarlberg explicitly addresses the possibility to prescribe legal requirements for local structural measures, if economically reasonable and technically feasible, in the respective land use planning act (Amt der Vorarlberger Landesregierung, 1996, Vlbg RplG 1996 § 13 Abs. 2 lit a).

2.2.3 Future needs

Land use planning activities such as hazard maps are based on the concept of recurrence intervals of hazard processes. Since the hazard potential and thus the delimitation of hazard zones is subject to temporal changes, the resulting coping strategies in order to minimise risk have to be variable. From the point of view of spatial planning dealing with such changes is of particular difficulty since the required stability of the law restricts short-term modifications in land use planning regulations to a minimum. In particular building bans and re-zoning of already permitted land development activities remain an unsolved task since once enacted and approved by the regulatory authority additional prescriptions or prohibitions could hardly be accomplished. Hence, the overlap between hazard areas and areas used for settlement purpose and economic activities increasingly provokes conflicts of interest that need to be addressed in natural hazard management.

Nevertheless, due diligence as legal obligation resulting in usage limitations and prohibitions executed during the individual construction process is inevitable, in particular with respect to the prescription of local structural protection. Ongoing inspections by the respective authorities, associated certification and final approval of work should be legally prescribed. Furthermore, the increased consideration of hazard maps already during the constructing permit procedures as well as the mandatory involvement of the respective authority (Austrian Torrent and Avalanche Control Service) during the entire process seems promising with respect to create more disaster-resilient communities.

Apart from the cost-efficiency (Holub and Fuchs, 2008), local structural protection is a serious and promising approach in mitigating natural hazards with respect to legal requirements in accordance with local planning regulations. This is of particular relevance considering the fact that building regulations other than local structural measures are hardly to be implemented ex post. Due to the overall principle of reliance on legal acts, planning decisions affirmed in the past have to be persistent over a certain period in time.

With respect to natural hazard management, legal regulations related to land use decisions are accompanied by the principle of governmental loss compensation in Austria.

2.3 Loss compensation in Austria – the disaster fund

As a basic principle, different strategies are applicable as instruments to mitigate the effects of natural hazards. Within the scope of integral risk management, their individual benefits and possible weaknesses have to be balanced against each other. Hence, mitigation measures can be classified according to the idea of integral risk management by their ability to raise individual awareness and to facilitate the willingness of people affected becoming proactive and investing private money. In order to achieve this goal, mitigating natural hazards is pillared by regulatory instruments as well as other management strategies in dependence on their applicability as preventive (modification of the natural hazard process and/or damage potential) or subsequent reactive measures (maintenance, see Tab. 2-1). With respect to the latter emphasis is placed on the compensation of resulted damages, e.g. by shifting the costs for compensation to an insurance pool or by disbursing public expenditures or governmental aids. In Austria, such governmental aids play a major role in loss compensation since natural hazards are not subject to compulsory insurance. Apart from the inclusion of losses resulting from hail, pressure due to snow load, rock fall and sliding processes in an optional storm damage insurance, no standardised product is currently available on the national insurance market. Moreover, the terms of business of this storm damage insurance explicitly exclude coverage of damage due to avalanches, floods and inundation, debris flows, earthquakes and similar extraordinary natural events (Schieferer, 2006; Weiß, 2008).

Table 2-1. *Possible preventive and reactive measures to mitigate natural hazards.*

Preventive measures	Subsequent/reactive measures
Administration (e.g., evacuation)	Disaster fund
Planning tools (e.g., hazard mapping, land use planning, building codes)	Insurance pools
Technical structures	Liability
Forestal-biological measures (e.g., protection forest)	

2.3.1 Background

According to the constitution of the Republic of Austria, losses resulting from natural hazards do not fall under the national jurisdiction. Thus, any responsibility for potential aids to repair damage to assets of individuals, companies and legal entities resulting from natural hazards generally is assigned to the Länder (Fuchs et al., 2007b).

Nevertheless, assistance for compensation was required on the federal level in 1950/51 due to the avalanche disasters that occurred in large areas of the Austrian Alps. Subsequently, the Republic of Austria issued a special law for the financial support of and governmental aid for persons harmed by avalanches. Further major hazard events required additional specifications of this law until the floods of 1965/66 necessitated the establishment of a permanent so-called disaster fund.

The Federal Act related to the Disaster Fund of 1966 (Republik Österreich, 1966) provided the legal basis for the provision of national resources for

(1) preventive actions to construct and maintain torrent and avalanche control measures, and

(2) financial support for the Länder to enable them to compensate individuals and private enterprises for losses due to natural hazards in Austria.

To provide financing of the disaster fund, tied surcharges were put on income taxes, wage taxes, taxes on capital yields, and corporate taxes. After being subject to several amendments, the legal act from 1966 was revised by the so-called Federal Act related to the Disaster Fund of 1996 (Republik Österreich, 1996). This law is still in force in the prevailing form. The budget of the disaster fund originates from a defined percentage (since 1996: 1.1 %) of the federal share on the income taxes, taxes on capital yield, and corporate taxes, which amounts to approximately € 7 for private households and € 30 for business entities per year (Vetters and Prettenthaler, 2004). Financial means which are not spent in a respective year are subject to a reserve. In accordance with the Austrian Court of Audit, the prescribed maximum reserves of the disaster fund is limited to 29 million € (Republik Österreich, 1996). This regulation resulted in a redistribution of additional reserves to other budget items in years with below-average incurrence of losses, which is one of the major problems of the strain on liquidity of the disaster fund if above-average losses occur.

Within the Federal Act related to the Disaster Fund of 1996 (Republik Österreich, 1996, BGBl. 201/1996) the allocation of resources is legally prescribed. A considerable share of the budget has to be provided for the prevention of damage resulting from floods and avalanches, as well as the funding of passive flood mitigation measures. Further provisions include the survey of water quality, the funding of early warning devices, and the subsidising of the crop hail insurance in Austria. The prevention of flood and avalanche losses not only includes direct financial aids, but also the measurements undertaken by respective institutions under public law, i.e. the Austrian Torrent and Avalanche Control Service. Further financial resources have to be spent for remedial actions to be undertaken for losses resulting from natural hazards that occurred at properties and assets of local public authorities, and the acquisition of equipment for the locally-based voluntary fire brigades.

A major budgetary item, also from the point of public perception, is the regular support of the Länder by the disaster fund in providing subsidies for disaster compensation to individuals and legal entities affected by natural hazards. Losses of private households and companies due to natural hazards are compensated to a certain degree by the disaster fund. The disaster fund, respectively the Republic of Austria, subsidises the Länder up to 60 % of that financial aid that was paid out by the Länder in order to support parties aggrieved by natural hazards. By these compensations, affected parties can receive an average indemnity up to a total of 20-30 % of the overall amount of losses suffered.

The disaster fund also provides financial assistance to any level of government. At the local and Länder, damages to infrastructure facilities are subsidised, and on the federal level damages to waterways and motorways are compensated by 50 % of the overall amount of loss.

Since the competence of compensating losses that incurred due to natural hazards is allocated at the Länder level, the Länder are not only responsible for assessing damages but also for the loss payment. In general, after damage has been recorded by a locally-based expert commission, compensations are paid out by the respective federal province directly to the people affected. Thereby, financial aids of the Länder are reduced by the share received as compensation paid out by optional hazard insurance companies. However, there is neither any enforceable legal right for financial assistance, nor a certain level of guaranteed financial assistance resulting from the disaster fund act. The Federal Ministry of Finance administrates the resources of the disaster fund.

2.3.2 Future needs

Societal and political decisions about mitigation measures concerning natural hazards are generally based on a multiplicity of interests due to the variety of parties involved. One major characteristic of mitigation measures is that the private sector does not supply them in a sufficiently great enough quantity given the potential economic benefits to society, therefore mitigation measures have characteristics of public goods or common (pool) resources (Fuchs and McAlpin, 2005). In the theory of public goods it is assumed that individuals are aware of their preferences. However, consumers might not always be aware of their preferences for protection measures, which can be partly attributed to free supply, passive consumption – and governmental subsidies for disaster compensation to individuals and legal entities affected by natural hazards. This somehow insufficient starting position, tracing back to the non-excludability and non-rivalry in consumption, requires a centralised coordination of the government. Hence, until now, market failure is the normative rationale for governmental intervention in order to mitigate natural hazards, and the provision of protection against natural hazards is commonly regarded as a governmental duty. However, direct governmental interventions do not offer any explicit incentive for individuals to react risk minimising and voluntarily to a threat, and to subsequently provide prevention measures on an individual basis (which in case of local structural protection would be characterised by excludability and rivalness). Limited public resources and steadily increasing financial losses from natural hazards demand a more efficient allocation of public expenditures (Raschky and Weck-Hannemann, 2007), which might be – until now – solely achievable by raising risk awareness and consequently encouraging private expenditures in local structural protection measures.

It is widely accepted that living in areas endangered by natural hazards belongs to the category of involuntary risks – even if this is only partly true since citizens and other people affected in principle could choose between different alternative locations for living and economic activities. Hence, losses from natural hazards not only can be ascribed to the geographic location itself (hazards-of-place model of vulnerability, Cutter, 1996; Cutter et al., 2003), but are also a result from individual choices and preferences. Accordingly, voluntariness and awareness will become influencing factors in the near future with respect to the ongoing discussion on a possible implementation of a compulsory hazard insurance system in Austria (Schieferer, 2006; Holub and Hübl, 2008). If these ideas will become reality, according to the principle that the party responsible is liable for the damages a certain contribution will be demanded from those people living in endangered areas. From the economic point of view, and thus from the viewpoint of the disaster fund as a governmental constitution, this instrument of liability represents a solution-orientated and efficient incentive in order to provoke risk-reducing behaviour, and in order to create disaster-resilient communities.

However, until now, the disaster fund has to be considered as the only available compulsory nation-wide solution in Austria, showing the following characteristics:

(1) Independently from the exposure to natural hazards, premiums are levied on a legal basis as a certain percentage of the federal share on the income taxes, taxes on capital yield, and corporate taxes.

(2) These premiums have to be paid by every citizen and business entity, independently from the individual exposure to certain hazards.

(3) There is no legal claim to a compensation of losses.

(4) Due to divergent legal regulations in the Länder, the conditions of damage compensation are considerably different within the Republic of Austria, leading to social injustice if large areas are affected by hazardous events (e.g., during the 2002 and 2005 flood events).

(5) Preventive measures are not considered in terms of a smaller premium rate; in contrast, private precaution in terms of individually contracted insurances will reduce the compensation paid out from the disaster fund.

As laid down in the Federal Act related to the Disaster Fund of 1996 (Republik Österreich, 1996, BGBl. 201/1996) and outlined above, the capped resources amount to 29 million € per year. Consequently, accumulated resources above this amount are regularly removed from the fund, and alternatively used within the national budget of Austria. The result of this procedure is shown in Fig. 2-2 by the red line, indicating the continuous annual withdrawal of reserves. The green line, alternatively, indicates the theoretical development of the accumulated reserves if the fund was not fixed upwards by 29 million €. In 2002 and 2003, major compensations were paid out by the budget of the Disaster Fund, consequently, additional resources had to be made available by the Republic of Austria in order to cover the occurring financial gap (red line). Alternatively, if the fund was not fixed, the accumulated budget would have been sufficient to compensate these losses (green line).

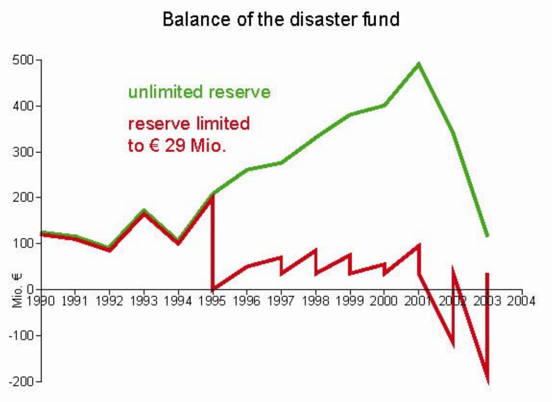


Figure 2-2. *Balance of the disaster fund with and without capped budget (modified from Prettenthaler and Vetters, 2005).*

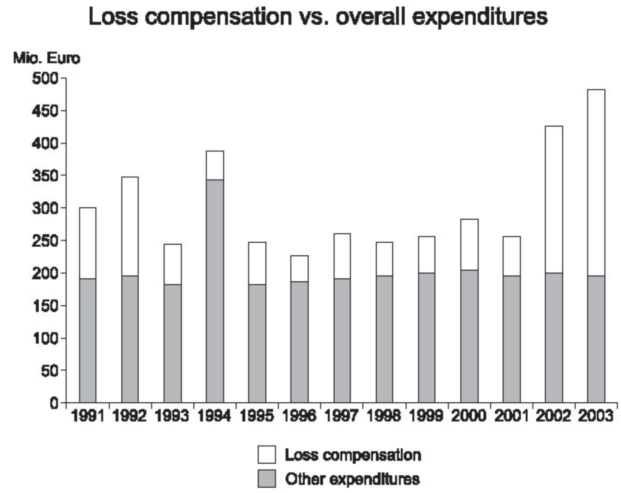


Figure 2-3. *Expenses for loss adjustment versus total expenditures 1991-2003 (modified from Prettenthaler and Vetters, 2005).*

In Fig. 2-3, the overall expenditures of the disaster fund are indicated for the period 1991-2003. The budget used for loss compensation (white bars) is shows considerable fluctuations, while the other expenditures incurred according to the Federal Act related to the Disaster Fund of 1996 (Republik Österreich, 1996, BGBl. 201/1996) are relatively stable (grey bars). Therefore, measures of the budgetary risk management are required to supplement the budgeting of the reserves, arguing for an independent organisation of the loss adjustment. e.g. by splitting-off this sector according to the procedure in actuarial business (Prettenthaler et al., 2005) to allow for independent hedging transactions. Since so far, risk-averse behaviour is not taken into account during loss compensation, a decoupled organisation of the loss-compensating share would allow for the initiation of measures that create considerable incentives to implement mitigation measures, i.e., privately financed local structural protection systems. In contrast, by the present system, negative incentives for households and business entities are provided, in particular since private insurance indemnities are subtracted before governmental compensation is paid out.

Among others, Prettenthaler and Vetters (2005), Schieferer (2006), and Weiß (2008) suggested adjustments of the current system of loss compensation in Austria, which include

(1) a splitting of different financial sectors of the disaster fund, i.e. the prevention and loss adjustment into different budgetary units, a loss adjustment pool and a pooled prevention funds;

(2) an outsourcing of the loss adjustment pool under supervision of the Austrian Financial Market Authority including the possibility of

(3) a mandatory coverage extension for property insurers in Austria by a combined natural hazard package with basic premiums charged commensurate with the risk in order to avoid averse selection;

(4) a fixed distribution of the related premium income achieved with a share of 30 % for the insurer and 70 % for the disaster fund; and accordingly

(5) a proportionate loss adjustment with a share of 30 % from the insurers' own funds and 70 % from the disaster fund.

(6) Insurers only accept risks if these are in line with the capacity limits they have set. Capacity is the maximum amount of coverage that could be offered by an insurer over a given period. Hence, a stop-loss coverage by the disaster fund should be introduced if the annual compensations paid out by the insurers exceed the sevenfold annual premiums. Thereby, the possibility of cession should remain unaffected.

By these adjustments of the current system of loss compensation, incentives to implement local structural protection can be set with respect to an efficient risk management facing future challenges emerging from natural hazards in Austria. Thereby, a diversified portfolio balance is essential, which will only be possible by an adoption of the current national system of disaster aid to the items outlined above.

2.4 Risk transfer in Austria

Shifting risk from one party to another is the basic principle of risk transfer, and a key issue in (economic) risk management. Insurance as a form of risk management is primarily used to hedge against the risk of a contingent loss. Insurance is defined as the equitable transfer of the risk of a loss, from one entity to another, in exchange for a premium, and can be thought of a guaranteed small loss to prevent a large loss. As outlined by Schieferer (2006) and Weiß (2008), insurance coverage against losses resulting from natural hazards is available in Austria since the mid-1950s, in particular with respect to losses occurring due to windstorm (airflow with velocities > 60 km/h), hail, snow load (application of force due to naturally accumulated static snow packs), rockfall, and landslides (down slope movement of soil and rock masses along a subsurface shear plane). It is only since the mid-1990s that other natural hazard processes may be included in insurance contracts, namely by individually extended coverage since in general they are excluded of liability (Weiß, 2008).

2.4.1 Background

Besides the system of the disaster fund outlined in the previous section, private or business entities may also insure against the losses incurring from natural hazards with private insurance companies. However, until now, private insurance companies only provide policies with very limited coverage for damage arising from natural hazards. According to the Austrian Underwriting Association, most insurance companies cover for damages to private buildings and households up to a sum between 3,700 € and 15,000 € per contract, while only few insurers compensate up to 50 % of the insured sum (Gruber, 2008). These relatively small contractual amounts covered are been effected without any risk assessment on the insurers' side, and therefore do neither mirror commensurate premiums nor incentivise individuals to a risk-aware behaviour with respect to e.g. an private investment in preventive measures. Business entities are granted more flexible contract conditions than private households, in particular since they have access to combined policies (specifically "all risk policies"), hence, higher coverage against losses resulting from natural hazards is available.

On request, some contractors offer higher coverage based on appropriate premium rates; therefore, detailed risk assessments are regularly undertaken (Schieferer, 2006). The associated extended cover is carried out either up to a fixed maximum sum amounting to 20,000 € per insurance policy, or up to 25-50 % of the building value. However, even these policies cannot cover for all types of hazardous events and obviously exclude extraordinary, i.e. extreme, events.

Since natural hazard insurance is not compulsory in Austria so far, the main obstacle private insurers have to deal with is adverse selection, which is the adverse impact on an insurer when risks are selected that have a higher probability of loss than that contemplated by the applicable insurance rate. With respect to natural hazards, adverse selection occurs since only those persons and business entities being located in endangered areas tend to contract insurances. In order to encounter adverse selection, insurance companies try to reduce exposure to large claims either by limiting coverage or by raising premiums.

Apart from the effect of adverse selection, the market penetration of insurance policies is relatively low due to the mechanism of loss compensation by the disaster fund. To benefit from these compensations, people do need neither to pay written premiums nor do they have to contribute to the available funds otherwise – a strong incentive for more risky behaviour. Thus, the issue of third-party intervention, i.e., governmental funding, turned out to be a crucial aspect for the Austrian insurance market (e.g., Froot, 2002). Furthermore, and this is presumably the second reason for low market penetration, in most of the Länder the compensations paid out by the disaster fund are shortened by (private) insurance compensations. Hence, risk-aware people underwriting private natural hazard insurances are de facto worse off than less aware people not taking precaution actions, which leads again to decreasing demand in natural hazard insurance policies in Austria.

2.4.2 Future needs

Mountain hazards are defined from an engineering point of view as a function of the probability of occurrence of a specific scenario and the corresponding losses (Varnes, 1984) or – more generally and thus including perspectives from social sciences – the result of human economic activity in mountain regions (Fuchs et al., 2007b; Raschky, 2008). Focussing on the latter, both theoretical and empirical research had shown that the market for risk-transfer tends to work imperfectly or even fail completely with respect to natural disasters (Kunreuther and Pauly, 2004). Adverse selection and moral hazard, occurring when individuals behave in ways to satisfy themselves, but their behaviour comes at the detriment of others because they do not bear the full cost, can only partly explain these market imperfections (Jaffee and Russell, 2003). Kunreuther (2000) defined situations of distorted demand and insufficient supply on the market for natural hazard insurance as the disaster syndrome: individuals tend to underinsure because of the underestimation of risk of low-probability high loss events, and the expected financial relief by governmental compensation or private donation, the latter being described as charity hazard by Raschky and Weck-Hannemann (2007). This market failure led to different forms of government intervention in the market for disaster insurance (e.g., Ungern-Sternberg, 2004), i.e., the disaster fund in Austria. In addition to an inefficient amount of insurance coverage, financial assistance from the government does rarely meet the needs of the disaster victims and therefore results in an inefficient allocation of public resources, a phenomenon that was extensively observed by Garrett and Sobel (2003) with respect to FEMA disaster aid in the US.

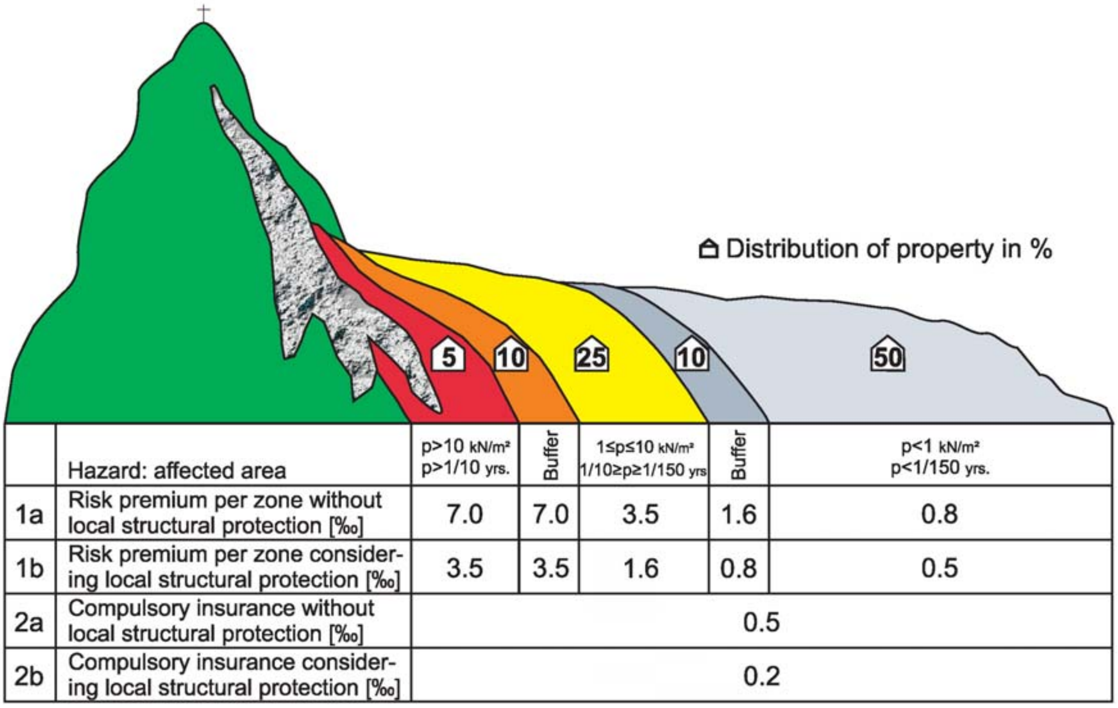
As outlined above, the current system of governmental intervention in Austria showed some weaknesses that might be overcome by the introduction of a system of risk transfer pillared by private insurers, reinsurance, and governmental stop-loss coverage. Therefore, premiums which are commensurate with the risk should be charged for hazard-prone property in order to overcome the phenomenon of adverse selection, including the offer of incentives to invest into mitigation measures. These mitigation measures should include local structural protection since it had been shown that such measures are cost-efficient with respect to the minimisation of losses (e.g., Holub and Fuchs, 2008).

A possible approach of how disaster insurance or mountain hazards could be organised is presented schematically in Fig. 2-4. Taking the 1 in 150 year event as design event and according to studies published by Fuchs et al. (2004) and Keiler (2004), approximately 50 % of all buildings in the Eastern Alps are located outside endangered areas. The residual number of buildings is located inside the red hazard zone (5 %), the yellow hazard zone (25 %) and the directly affected 10 m buffers (each buffer approximately 10 %). With increasing distance to the area affected by the hazardous process, the impact in terms of pressure or deposition height is decreasing. Hence, the property exposed is successively less susceptible to losses. Consequently, the premium rate to be levied by the insurance companies could be stepped according to such impact reductions based on defined reoccurrence intervals emerging from design events. The risk premium is further differentiated according to whether or not local protection measures had been implemented, which will create incentives to individuals and business entities to behave risk-aware. If insurance against natural hazards is not compulsory, premiums being charged might be stepped according to suggestions (1a) and (1b). Assuming an average value of approximately 300,000 € for a building located on a torrent fan in Austria (Fuchs et al., 2007a), the annual premium rate within the red hazard zone would amount to 2,100 € without and 1,050 € with local structural protection, probably in addition to a certain excess of a retention applicable for high-risk areas. In analogy, the annual premium rate within the yellow hazard zone would amount to 1,050 € without and 480 € with local structural protection. Areas neither located in the red and yellow hazard zones nor in a directly attached buffer will be charged with 240 € and 150 €, respectively. In addition, a suggestion for annual premium rates assuming a compulsory disaster insurance would result in 150 € per building affected without local protection (2a), and 60 € considering individual constructive mitigation measures (2b).

By establishing such a system of graduated premiums commensurate with the risk, the problem of adverse selection and moral hazard can be addressed and the loss compensation will become more equitable. To complement this system, information on hazard and risk at a specific location has to be communicated target-oriented to the stakeholders involved. In analogy to the Energy Performance Certificate providing home owners, tenants and buyers information on the energy efficiency of their property, a similar certificate approving the meeting of certain building code standards could encourage the adoption of cost-effective local mitigation structures. Such a certificate could in a subsequent step be valid as a basic requirement for getting insurance cover at reduced premium rates or presenting credit redemption agreements (e.g., Kleindorfer and Kunreuther, 1999). Furthermore, incentives might not only emerge from reduced premium rates but also from other benefits, e.g., reduced tax load on expenditures necessary to implement local structural protection.

2.5 Awareness-building

As a major part of the territory of Austria is located in mountain areas above 1,000 m a.s.l. (approximately 36 % of the territory; 50 % of which is situated even higher than 1,500 m a.s.l.), areas suitable for permanent settlements and economic activities are limited (Holub and Hübl, 2008). As a result, land development and building activities are concentrated on areas affected by natural hazards: in the mountainous regions of Austria, almost 50 % of all buildings are potentially exposed to hazards including flooding, and almost 15 % are considered to be at high risk (Fig. 2-4, Fuchs et al., 2004; Keiler, 2004).



	Hazard: affected area	p>10 kN/m² p>1/10 yrs.	Buffer	1≤p≤10 kN/m² 1/10≥p≥1/150 yrs	Buffer	p<1 kN/m² p<1/150 yrs.
1a	Risk premium per zone without local structural protection [‰]	7.0	7.0	3.5	1.6	0.8
1b	Risk premium per zone considering local structural protection [‰]	3.5	3.5	1.6	0.8	0.5
2a	Compulsory insurance without local structural protection [‰]	0.5				
2b	Compulsory insurance considering local structural protection [‰]	0.2				

Figure 2-4. *Development of risk premiums if property insured is successively less exposed (modified from a sketch in Swiss Re, 1998, and adapted to mountain hazards). The percental distribution of property was taken from estimates outlined in Fuchs et al. (2005) and Keiler et al. (2006).*

Apart from land use regulations and risk transfer, information is a third pillar in order to create disaster-resilient communities. Hence, knowledge about the individual and the collective (cumulative) risk is an essential prerequisite for an adapted and anticipatory dealing with natural hazards to promote risk-decreasing behaviour. In order to meet this goal public attention has to be attracted, in analogy to the debate on climate change a trigger is often needed therefore (Egner, 2007). Generating this public attention creates the ability to communicate risk in a purposeful and target-oriented manner to different stakeholders affected. The perception of risk is different between experts and laypersons. While some studies argue that considerable differences exist (e.g., Fischhoff et al., 1982; Lazo et al., 2000), often in dependence of whether or not affected people live in hazard-prone areas (Siegrist and Gutscher, 2006), other studies conclude that there is little empirical evidence for such a proposition (Rowe and Wright 2002). Information on risk is an essential step to enhance risk awareness and to create disaster-resilient communities. Nevertheless, until now only little information has been available related to the necessary design and impact of such maps and how they may be most effectively created as tools for risk communication and decision-making. However, it is undoubted that with respect to hazard mitigation information on risk is an essential step to enhance risk awareness and to create disaster-resilient communities.

Hazard and risk maps, in which areas endangered by defined design events are depicted, provide one opportunity to communicate natural hazard risk and to inform about possible risk-reducing behaviour. Little information is available so far related to the necessary design and impact of such maps in order to serve as a risk communication tool (Serrhini et al., 2008; Fuchs et al., 2009). Covello et al. (1987) identified four components of risk communication: the message source, the message design, the delivery channel, and the target audience. This model depicts risk communication as linear, viewed as a means of transmitting technical information regarding risk from a known, intentional source (the experts) along designed channels, to specified recipients (the public affected). As outlined in Fuchs et al. (2009), experts draft and devise risk maps and associated documentation, and end-users (public authorities, people concerned, and laypersons) receive these maps as finished products regardless of whether or not they understand the message included. Hence, a feedback loop has to be established reversing the traditional way of communication, e.g., by a cyclical model which was proposed to integrate visual and cognitive perception by the receiver (Serrhini et al., 2008). However, there might still remain a gap between understanding and persuasion at the receivers side (Bell and Tobin, 2007), in particular with respect to the 1 in 150 years design event providing the basis for hazard maps in Austria.

Furthermore, hazard maps are not yet fully available for the entire area of Austria endangered by natural hazards since a nation-wide coverage is only expected to be implemented with respect to the European Flood Risk Directive over the next years (Commission of the European Communities, 2007). Many stakeholders concerned (e.g., homeowners, insurance companies, banks granting credits, and decision makers) therefore do not have access to the respective information and thus are not fully aware of hazard and risk maps, and consequently do only take care of hazards if they do already have experienced losses recently. Related to the communicative purpose that hazard maps might evoke, an adopted and risk-sensitive behaviour is therefore limited so far in Austria. Consequently, access to alternative information sources is inevitable. One step towards enhanced information might be the web-based nationwide available risk zoning tool “HORA” which was developed by the Austrian Insurance Association in cooperation with the Federal Ministry of Agriculture, Forestry, Environment and Water Management, as well as the Swiss pendant “Aquaprotect”.

The extent of consequences resulting from natural hazard events is strongly influenced by the behaviour of the population in endangered areas and by the duties of local authorities with respect to legal implementation. Since the state of information related to hazard exposure seems to be not sufficient so far in Austria, in particular non-technical mitigation measures neither are optimally nor efficiently adjusted to the possible consequences of hazardous events, and citizens very often even are not aware of their own exposure. Moreover, the subjective feeling of safety is strongly related to the hazard perception and awareness of affected people, and usually decreases with decreasing information on recent events. These patterns are overlain by the increasing demand for zero risk emerging in recent years, accompanied by an increasingly less willingness to invest private money for the mitigation of hazardous events, and the search for a culprit in case of a damaging event associated with losses.

If the increasing demand for a higher degree of protection is put forward the design and implementation of mitigation strategies not only has to focus on values currently being at risk. In addition, possible future system states have to be considered such as changes in the process behaviour leading to altered design events or an increase in exposed values (Keiler et al., 2006; Fuchs and Keiler, 2008). Furthermore, increasingly more attention has to be paid to possible system failures, and maintenance of protection structures becomes progressively more important due to the limited lifetime of such structures. Particularly with respect to the latter, the culture of oblivion outlined above appears to be a key element to the perceived decrease of public natural hazards' awareness. Since even structures designed for the 1 in 150 years flood are expected to fail the generation of information on risk organised as a dialogue-oriented process embedded in a participatory framework that allows the constructive and open engagement and integration of various stakeholders (experts, decision-makers and well as representatives of the local population) is preferable, including specific information requirements of citizens and relying on local expertise in the risk assessment process.

Complementary to these needs, particular attention has to be focused on local structural protection measures that provide a considerable and effective reduction of vulnerability directly at the endangered objects (Holub and Hübl, 2008). Previous experiences with losses due to natural hazards and corresponding negative emotions expressed by affected people seem to be motivating for citizens to show damage mitigation behaviour (Kreibich et al., 2005; Siegrist and Gutscher, 2006). Contrariwise, a substantial number of people suffering severe losses due to natural hazards did not intend to invest private money in mitigation measures. Hence, experiencing strongly negative emotions seems to be a necessary but not in all cases sufficient condition for the implementation of local structural protection.

However, with respect to the effectiveness and efficiency, recent experiences with local structural protection suggested a considerable decrease in vulnerability (Fuchs et al., 2007a; Holub and Fuchs, 2008), hence they are an indispensable element of the natural hazard management. This is also mirrored by the current Austrian legal situation, according to the stipulated self-responsibility of citizens affected parties have to primarily compensate their losses themselves. Only in legally specified exceptions, these losses can be transferred to third parties.

To conclude, the vulnerability of buildings can be reduced significantly by local structural protection measures. Therefore, people have to be motivated to take preventive actions. An important prerequisite for implementing local structural protection is the conviction to be able to minimise personal risk and losses effectively by these measures. Hence, people must be aware of their risks, which is related to information, communication and good governance.

In order to achieve these goals, several strategies are conceivable to encourage the implementation of local structural protection by raising the risk awareness and personal responsibility of affected citizens:

(1) By regularly and continuous information, coping capacities of people affected can be enhanced and thus, the personal responsibility and sensitisation towards natural hazards, risk and mitigation measures can be increased.

(2) Specialised consulting for people affected with respect to prevention and local structural protection, including information about construction and maintenance costs of local structural measures, as well as the average height of reconstruction costs resulting from natural hazard damages in private households. Furthermore, these costs should be related to common loss adjustment and compensations paid out from insurers and the Austrian disaster fund.

(3) Specialised consulting for homeowners, land use planners, and architects with respect to possibilities of prevention and local structural protection.

(4) Specialised information and consulting following natural hazard events with respect to resistant construction design and materials.

Following these suggestions, the potential of preventive measures – currently mostly unused – which partly result from a lack of information and subsequently underdeveloped risk awareness, could be increased. This would consequently result in a decrease of losses due to natural hazards and public expenditures for loss adjustment.

2.6 Conclusion

Creating disaster-resilient communities is pillared by land use regulations, risk transfer, and information. In the previous sections, the legal framework of spatial planning has been discussed. It has been addressed that due to climate change processes, the hazard potential is subject to temporal changes, which are not yet fully acknowledged by the current spatial planning legislation in Austria due to the relatively long time interval of spatial planning activities. Furthermore, modifications in land use regulations are restricted to a minimum to ensure the required stability of the law. By exploiting all options already provided by the legislation on different administrative levels, due diligence as an obligation resulting in limitations of utilisation and culminating in prohibitions executed should be enforced. Thereby, land use regulations should include the prescription of local structural protection in order to create more disaster-resilient communities.

Disaster resilience is directly connected to risk transfer mechanisms. However, these risk transfer options should be based on economic incentives of risk-minimising behaviour. Hence, the current system of governmental aids due to the disaster fund act should be adjusted, and supplemented by a system of (mandatory) extension for property insurers in Austria by a natural hazard package. This insurance should be based on basic premiums charged commensurate with the risk in order to avoid adverse selection. Furthermore, individual precaution measures undertaken, such as the implementation of local structural protection, should result in a general insurability of buildings if natural hazard insurance is not organised compulsory, or in a considerable reduction of premiums (independently from whether or not this is in line with insurers’ business principles).

To complement such incentives information on hazard and risk for a specific location has to be delivered target-oriented to any stakeholder involved. The consequences resulting from mountain hazards are strongly related to the behaviour of the population in endangered areas, and the behaviour is closely connected to the amount of information accessible. Apart from making use of innovative communication channels and adopted information strategies, the overall policy to inform people due to good governance principles has to be strengthened.

Mitigating mountain hazards is based on the need for a sound, precautionary and sustainable dealing with natural hazard phenomena, taking into consideration both, the processes and the values at risk. In order to minimise losses, different preventive measures exist that can be classified in permanent and temporal measures on the one hand, and structural measures as well as organisational measures (i.e., a governmental framework of spatial planning and appropriate legislation) on the other hand. These different measures ideally complement each other, whereby a focus on structural measures in the starting zones of hazard processes and land use planning activities in the run-out zones is detectable. With respect to the idea of integral risk management, the interaction between prevention and precaution has to be highlighted, and respective incentives for loss-reducing actions on the local level should be provided in order to reduce the vulnerability to natural hazards in Austria (Fuchs et al., 2007a; Fuchs, 2009). However, until now the performance of local structural measures often is neglected or even ignored following the axiom that such solutions cannot be effective. Local structural measures can be classified in various ways, i.e., according to the applicability for protection against the hazard process, the location with respect to the protected object, as well as the type of construction and material used; a further differentiation is possible whether the local structure is of permanent or temporary use (Holub and Hübl, 2008). The interaction between the legal framework, the possibilities of risk transfer, and raising awareness is essential for efficient disaster risk reduction and contributes to the concept of resilience as part of proactive adaptation. Coping strategies have to be adjusted to these premises, and in particular the implementation of local protection measures has to be strengthened legally, institutionally, and economically.

3 Benefits of local structural protection to mitigate torrent-related hazards

M. Holub and S. Fuchs (2008): Benefits of local structural protection to mitigate torrent-related hazards. WIT Transactions on Information and Communication Technologies, 39, 401–411

Abstract

The increasing land-use activities in European mountain regions led to a considerable threat by natural hazards such as flash floods and debris flows in areas used for settlement purpose and economic activities. To mitigate associated losses, traditional protective measures, including check dams and retention basins, were commonly implemented by public authorities. However, due to the arising scarceness of public funds, efficient protection alternatives have to be developed to reduce future expenditures. Supplementing the concept of integral risk management, this efficiency can be obtained by local structural protection reducing the vulnerability of buildings and infrastructure facilities considerably. However, data related to the effects of local structural protection measures to reduce losses has not been quantified satisfyingly so far, and the associated decrease in vulnerability has hardly been measured until now. In this paper, results of a comparative standardised cost benefit analysis are presented. Different mitigation strategies were assessed and the benefit of local structural measures was quantified. The results suggest that local structural measures reduce the vulnerability of buildings towards natural hazards considerably, and that they therefore should be considered as either additional or even alternative mitigation measure.

3.1 Introduction

In the second half of the 20th century a noticeable socio-economic development took place in Alpine regions, which resulted in a significant aggregation of settlements and infrastructure facilities, and consequently in an accumulation in tangible assets. These areas are increasingly and repeatedly threatened by natural hazards such as flash floods, debris flows and avalanches since safe regions suitable for development are relatively sparse in mountain regions (Fuchs and Keiler, 2008). As a result, an increase in losses due to hazard processes had been observed in recent years world-wide as well as on a European level (Munich Re, 2007), even though in Alpine areas losses from avalanches and torrent processes appeared to decrease (Fuchs and Bründl, 2005; Oberndorfer et al., 2007).

Dealing with natural hazards has a long tradition in the Alps. During the last centuries, areas potentially endangered were predominantly used for extensive agricultural purpose to avoid danger. Since the outgoing 19th century, a change of these patterns of utilisation is traceable, the first authorities for the protection of natural hazards were founded, e.g. in Austria in 1884 (Länger, 2005). For more than half a century technical mitigation measures were developed and put in place. These active measures, representing the human reaction to hazard processes, appeared to be the appropriate way to cope with this challenge. Conventional structural mitigation, such as checkdams, torrential barriers and retention facilities, were supplemented by watershed management, above all forestal measures and soil-bioengineering. Since the 1960s, these conventional mitigation measures were complemented by passive protection concepts, and hazard maps were introduced aiming to reduce an exposure to hazards. The need for hazard mapping was regulated in the Austrian law related to forests in 1975 (Republik Österreich, 2003) and an associated decree in 1976 (Republik Österreich, 1976).

However, neither conventional measures, which influence both, the intensity and the frequency of events, nor passive mitigation concepts can guarantee reliability and complete safety (Schmid, 2005). Thus, a residual risk of damage to buildings and infrastructure as well as of harm to people remains (Fell, 1994; BMLFUW, 2006). Furthermore, technical mitigation concepts are cost-intensive in construction and maintenance, which is an increasing problem for public authorities as a major fund provider due to the overall budget constraints.

Local structural protection measures which are implemented directly at or adjacent to endangered objects might therefore be a valuable and serious alternative with respect to the concept of integral risk management (Holub and Hübl, 2008). However, the effect of local structural protection in reducing susceptibility of values at risk has not been quantified satisfyingly so far (Fuchs et al., 2007), even if the positive effect in reducing vulnerability seems to be obvious. At first it will be necessary to compare the advantages and disadvantages of conventional mitigation measures and local structural protection, above all the cost-efficiency. In this paper this is done for a small catchment in the Eastern Alps, Austria, with respect to flash floods with fluvial bed load transport in order to provide data related to possible mitigation concepts for the responsible political decision makers.

3.2 Method

Since mitigation measures have characteristics of public goods, above all non-excludability and non-rivalry, the private sector does not supply them in a sufficiently great enough quantity given the potential economic benefits to society. Therefore, the supply must take place via the public sector. As a result of the increasingly limited financial resources of the public sector there is a need for an efficient and sustainable policy of public expenditures for protection against natural hazards (Fuchs and McAlpin, 2005). Consequently, the costs and benefits of mitigation measures will be increasingly determined to allow for a comparison of the cost-effectiveness of different measures and an evaluation of the economic efficiency of mitigation strategies. Mitigation measures are considered economically beneficial if the utility produced by them exceeds or is equal to the associated costs. From an economic point of view, mitigation measures should not only be implemented with minimised costs (cost-efficiency), rather they should be provided on a socially optimal scale (allocative efficiency; Weck-Hannemann, 2006). In order to provide the optimal supply of protection measures, the public sector will need, among other information, evaluations of the costs and benefits of mitigation approaches. Three alternative assessment methods are available for decision making, (i) cost-effectiveness analysis, (ii) cost-efficiency analysis, and (iii) cost-benefit analysis. Even if all three methods can be applied as decision tool for public and private projects, the latter is the only method to directly assess both, costs and benefits in monetary terms (Thöni, 2006). Thus, the cost-benefit analysis seems to be an appropriate instrument to study and compare advantages and disadvantages of different mitigation scenarios.

In this paper, a standardised method for cost-benefit analysis developed by the Institute of Mountain Risk Engineering, University of Natural Resources and Applied Life Sciences in collaboration with the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management was used to assess the cost-efficiency of different mitigation concepts in a small alpine catchment (BMLFUW, 2005; Kraus et al., 2006).

3.2.1 Test site

The rural Auenbach test site is situated in a sub-catchment of the Lavant valley, located in the eastern part of Carinthia, Austria, near the border to Slovenia (Fig. 3-1). The southeast exposed valley of the test site shows a total length of 12.5 km and a total difference in elevation of 890 m. A district of the village of Prebl is situated along the valley bottom, with a total of 67 buildings, 54 of which in the categories of residential buildings and farm buildings. Due to the steep topography, the slopes are susceptible to mass movement processes, in particular shallow landslides. Within the last decades the test site was affected by periodic flood events. Impacts originating from static or dynamic flood as well as from extraordinary surface runoff, accompanied by transport of solids, endanger the stability of the buildings (Fig. 3-2). The major processes at the valley bottom include the possible intrusion of water and solids through the building openings causing damage to the interior of the buildings. These flood events resulted in conventional mitigation activities in the test site; measures such as ripraps and bank revetments were built for almost 60 years.

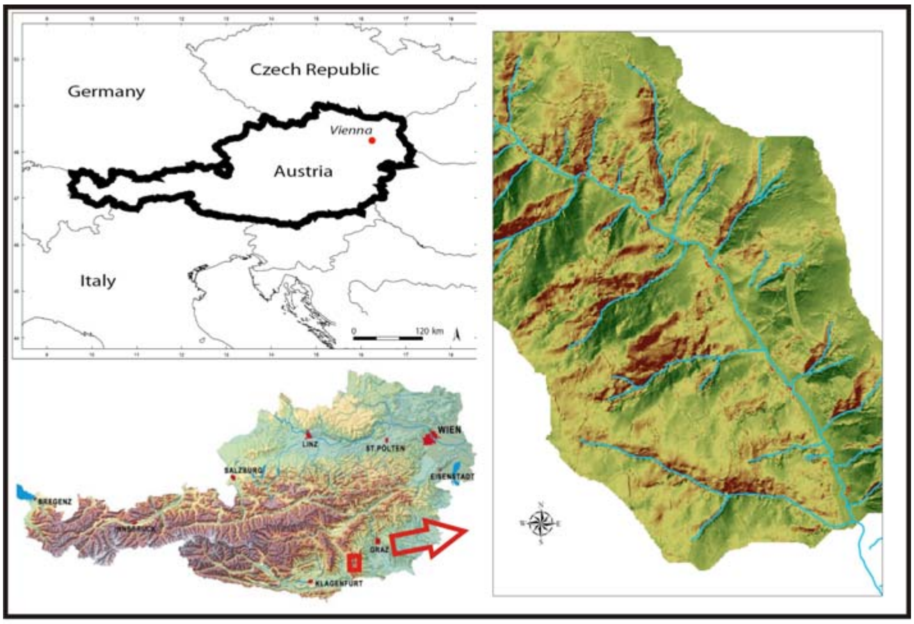


Figure 3-1. *Location of the Auenbach test site (Carinthia, Austria).*

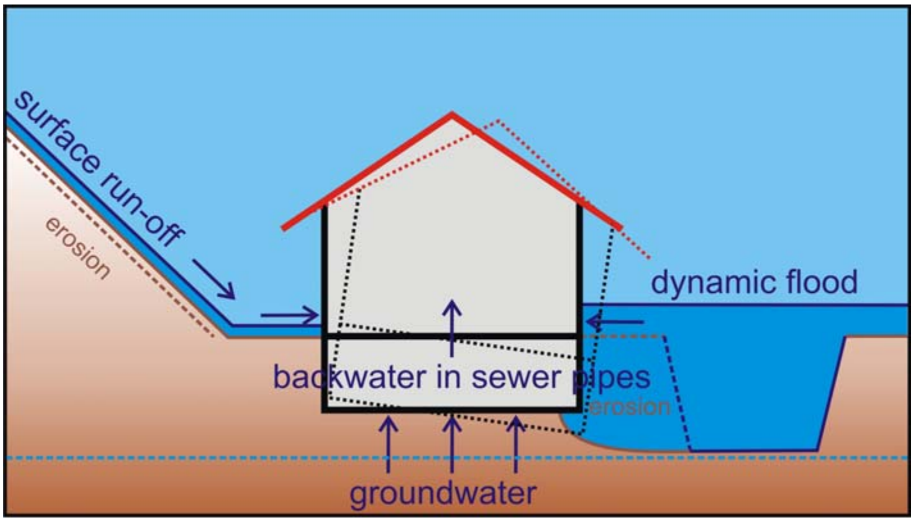


Figure 3-2. *Damage patterns due to static and dynamic flooding*

In 2005, a re-activated landslide in the upper part of the catchment resulted in intensive discussion about the capacities of the current mitigation strategies. In particular, flash floods resulting from a possible blocking of the river due to the sliding mass and a subsequent outbreak were addressed. As a result, the Austrian Torrent and Avalanche Control Service planned to implement a new torrential barrier to avert losses due to flash floods with fluvial bed load transport in the lower parts of the catchment.

3.2.2 Risk analysis

By means of hydrologic calculations and 2-dimensional hydraulic numerical modelling, the design event with a return period of 150 years was calculated for the test site. Based on these results and according to the legal regulations of hazard zoning in Austria, yellow and red hazard zones were determined. The red hazard zone is defined by the energy line > 1.5 m in height and torrential depositions > 0.7 m. The yellow hazard zone is defined by the energy line < 1.5 m and torrential depositions < 0.7 m, respectively (Republik Österreich, 1976; Holub and Hübl, 2008).

The elements at risk were analysed with respect to their spatial location and extension using GIS. The category, size and shape of the buildings was recorded from digital datasets of the communal administration and updated during a field study. A total of 49 buildings are affected by possible flash flood events, seven of which are located in the red hazard zone. In the yellow hazard zone, 42 buildings are located (see Tab. 3-1; HZ = hazard zone; SFH = single family house; MFB = main farming building; AFB = adjoining farming building; STB = stable; GAR = garage).

The evaluation of the elements at risk was carried out according to the federal guidelines (BMLFUW, 2005). Thus, a vulnerability factor of 0.1 and 0.3 was applied in the yellow and red hazard zone. The economic valuation of the exposed buildings was carried out (Kraus et al., 2006). Hence, data on the volume of the buildings were sampled and average prices of reconstruction per cubic metre according to the type and function of individual buildings were assigned (Kranewitter, 2002).

Table 3-1. *Number of buildings according to category and hazard zone.*

HZ	SFH	MFB	AFB	STB	GAR	TOTAL
Yellow < 0.7 m	17	1	7	2	7	33
Yellow > 0.7 m	3	1	2	0	2	9
Red > 1.5 m	0	0	2	2	3	7
TOTAL	20	2	11	4	12	49

3.2.3 Mitigation concepts

Two fundamentally different concepts of mitigation were compared in this study, (i) a concept of conventional mitigation based on the implementation of torrential structures and (ii) a concept of local structural protection for buildings located in the endangered areas.

The conventional concept was based on structural measures such as retaining and filtering barriers as well as retention basins in the upper part of the catchment. According to this mitigation concept, buildings within the red and yellow zone would be protected from major impacts associated with the assumed design event. Additionally, damage to infrastructure facilities such as the road network and the sewerage system, and agricultural and silvicultural areas could be averted.

The concept of local structural protection was based on the catalogue of local structural measures to protect buildings against floods (Holub and Hübl, 2008). Measures such as enhanced constructions and sealed openings were assumed to efficiently protect buildings from hazard impacts up to a height of approximately 0.7 m (Fig. 3-3 and Fig. 3-4). Consequently, they are not suitable to protect buildings in the red hazard zone. Furthermore, since local structural protection is only appropriate for the protection of buildings, damage to adjacent or adjoining infrastructure will not be reduced.

Figure 3-3. *Enhancement (raising) of light wells above flood level*

Figure 3-4. *Sealing of openings by half-sided plates by magnet technique (WHS-Hochwasserschutzsysteme, 2007)*

3.2.4 Cost-benefit analysis

A standardised method of cost-benefit analysis was applied to obtain the cost-efficiency of planned mitigation measures (BMLFUW, 2005). During the cost-benefit analysis, i) absolute cost efficiency and ii) relative cost efficiency considering several alternatives were assessed. Thus, costs and benefits were monetarily quantified. Since costs and benefits occur during different time intervals they were discounted using the interest rate of 3.5 % derived from the average rate of interest of long-lasting federal bonds. Applying empirically derived coefficients for the major transport process, the event magnitude, the defined design event and the resulting vulnerability of elements at risk, the cost-benefit analysis was adjusted to meet the protection targets.

3.2.4.1 Costs

For the conventional mitigation concept, the cost estimate resulted in a project sum of approximately € 1.3 million. Taking into account maintenance and discounting to the present-day net value, costs summed up to € 1.36 million.

Calculating the total costs for local structural measures, building properties (cellar, hillside situation, garage possibly integrated in the building) were found to have a major influence on the calculation. Garages detached to buildings, buildings in the red hazard zone and buildings in the yellow hazard zone where the deposition height and/or the flow depth exceeded 0.7 m were not taken into account since they cannot be protected by local structural measures. In Tab. 3-2, the input data used for the estimation of costs is shown. The total costs for necessary local structural measures resulted in approximately € 270,000.

Table 3-2. *Overview of building properties and corresponding costs per building for the implementation of local structural protection measures (prices include 20 % tax and assembly)*

Building properties	Entrance door (€ 1,200) half sided sealing plate width 1.0 m height 1.0 m	Terrace door (€ 1,200) half sided sealing plate width 1.0 m height 1.0 m	Light wells (€ 1,000) enhancement (raising) height 1.0 m	Garage door (€ 3,000) half sided sealing plate width 2.5 m height 1.0 m	Entrance door (€ 1,800) half sided sealing plate width 1.5 m height 1.0 m	Costs [€]
with cellar	1	1	6	0	0	8,400
without cellar	1	1	0	0	0	2,400
hillside situation, integrated garage	1	0	0	1	0	4,200
stable without cellar	2				1	4,200

3.2.4.2 Benefits

The benefit was defined as prevented damage to buildings in the test site. Therefore, elements at risk had been evaluated according to the requirements of the cost-benefit analysis taking the data from the risk analysis. Since local structural measures prevent direct damage to buildings, potential additional benefits such as the protection of infrastructure facilities, agricultural and silvicultural areas were not taken into account during the analysis.

3.2.4.3 Mitigation scenarios

Three scenarios had been defined according to the requirements of the responsible decision maker, (i) conventional mitigation measures aiming to avoid future design events, (ii) local structural measures neglecting that they could not fully avoid losses due to design events, and (iii) local structural measures taking into account these possible losses on the cost side of the mitigation concept.

(1) Scenario 1: CMM
Conventional mitigation measures are implemented; protection for all elements at risk in red and yellow hazard zones (HZ).

(2) Scenario 2: LSM
Local structural protection measures; protection for objects inside the yellow hazard zone to a deposition height and/or flow depth < 0.7 m (yellow HZ); no protection for detached garages.

(3) Scenario 3: LSM+
Local structural protection measures; additional costs (equals a reduction of benefit) due to arising losses from those buildings that are not equipped with local structural protection in red and yellow hazard zones; protection for objects inside the yellow hazard zone to a deposition height and/or flow depth < 0.7 m (yellow HZ); no protection for detached garages.

In Tab. 3-3 the input data used during the cost-benefit analysis and the calculation of the benefit-cost-ratio are shown.

Table 3-3. *Input data used for the cost-benefit analysis*

	CMM	LSM	LSM+
Event factor [1]	2	2	2
Process factor [1]	1	1	1
Damage factor in yellow HZ [1]	0.1	0.1	0.1
Damage factor in red HZ [1]	0.3	0.3	0.3
Protected buildings in yellow HZ < 0.7 m [1]	33	27 (no garages)	27 (no garages)
Protected buildings in yellow HZ > 0.7 m [1]	9	0	0
Protected buildings in red HZ [1]	7	0	0
Intangible benefit [1]	1.1	1.1	1.1
Examination time period [a]	80	80	80
Interest rate [%]	3.5	3.5	3.5
Total costs, rounded [€]	1,300,000	220,000	360,000

Event factor 2: large, medium and small events are taken into account

Process factor 1: fluvial bedload transport with a magnitude up to the design event

3.3 Results

The results of the cost-benefit analysis are presented in Tab. 3-4 In general, the mitigation concepts using local structural measures (LSM and LSM+) offer a better benefit-cost-ratio of 1.67 and 1.21 than the concept based on conventional measures (CMM; 0.36).

For scenario CMM, the total benefits to be created amounted to € 1,468 million. Even if in scenario CMM the number of protected buildings was higher (49) than in scenarios LSM and LSM+ (27), the benefit-cost ratio was < 1 due to the relatively high costs associated with the planned conventional mitigation measures (discounted: € 1.36 million). As a consequence, the net present value became negative, and amounted to € -870,000. However, it has to be taken into account that scenario CMM was the only concept providing protection for all buildings in both, the red and the yellow hazard zone. Furthermore, though beyond the boundary of the studied system, additional benefits might be created by this concept since it also offers protection to values at risk located further downstream adjacent to the receiving stream.

Table 3-4. *Results from the cost-benefit analysis*

	CMM	LSM	LSM+
Protected buildings in yellow HZ < 0.7 m [1]	33	27 (no garages)	27 (no garages)
Protected buildings in yellow HZ > 0.7 m [1]	9	0	0
Protected buildings in red HZ [1]	7	0	0
Tangible benefit, rounded [€]	667,000	523,000	380,000
Intangible benefit, rounded [€]	67,000	52,000	38,000
Total costs without discounting, rounded [€]	1,612,000	273,000	273,000
Total costs with discounting, rounded [€]	1,360,000	230,000	230,000
Total benefits without discounting, rounded [€]	1,468,000	1,151,000	835,000
Total benefits with discounting, rounded [€]	491,000	385,000	279,000
Capital value, rounded [€]	-870,000	155,000	49,000
Ratio benefit-costs [1]	0.36	1.67	1.21

For scenario LSM, the total benefits to be created amounted to € 1,151 million, and the total costs to € 230,000. Thus, scenario LSM showed the best benefit-cost ratio of 1.67, even if local structural protection would only be provided up to flow depths and deposition heights of 0.7 m, and therefore no buildings situated in areas exceeding this value were protected. Consequently, it has been taken into account that all other values at risk (detached garages, buildings inside the red hazard zone and buildings in the yellow hazard zone where the deposition height and/or the flow depth exceeded 0.7 m) cannot be satisfyingly sheltered from damage.

As a result, losses might occur, which had been considered in the set of calculation for scenario LSM+. Consequently, the possible benefit was reduced by necessary reconstruction costs for buildings located in areas with flow depths and deposition heights > 0.7 m. Thus, the benefits were reduced to € 835,000 while costs of € 230,000 occurred. As a result, the benefit-cost ratio was reduced to 1.21; however, this scenario was still cost-efficient.

To conclude, if decisions regarding mitigation concepts in the test site were only based on cost-benefit analyses, scenario LSM+ (taking into account possible losses at buildings that are not protected by local structural measures) showed the best benefit-cost ratio, while the conventional mitigation concept was the least efficient.

3.4 Conclusion and discussion

Recent studies related to torrential hazards in Austria suggested a considerable decrease in vulnerability, if local structural protection is implemented (Fuchs et al., 2007). However, possible associated risk-minimising effects of local structural measures were not quantified satisfyingly so far. To close this gap, and provide insight in these effects, a standardised cost-benefit analysis was applied for an Alpine catchment, using an ex-ante perspective. Considerable different benefit-cost ratios were obtained, depending on (i) a relatively high amount of expenditures necessary for conventional mitigation and (ii) a relatively small amount of values at risk to be protected. Mitigation concepts based on local structural measures showed benefit-cost ratios > 1, even if the protective effects of local structural measures are limited to deposition heights of approximately 0.7 m. Thus, cost-benefit analyses are very case-sensitive, and results are hardly transferable to other regions. The assumptions made in this study were conservative, above all with respect to the boundaries of the system. Whether or not a test site is considered as a closed system or as an open system in terms of a sub-catchment within a river network, the concept of implementing local structural protection measures will result in different benefit-cost ratios.

However, local structural protection is a serious and promising approach in mitigating natural hazards. Comparing costs of local structural protection with those of conventional mitigation measures, a significant potential for saving future public expenditures exists since such measures usually have to be funded and implemented by the private households. To increase individual responsibility for mitigation, and to achieve a broader acceptance for such measures, information and possibly participation of affected people seems to be essential, since in general people have a high confidence in conventional technical mitigation concepts. Apart from an enhanced enforceability of necessary legal regulations such as building codes, as a side effect, such information campaigns will result in an increased risk awareness of people concerned. Accordingly, individual responsibility will be strengthened, and the society will be able to alternatively use (increasingly scarce) public funds in a more cost-efficient way.

Apart from engineering foci presented above, it has to be emphasised that local structural measures generally fit better in the landscape than traditional mitigation measures. Even if a quantification of this effect is outstanding, measures protecting individual objects usually consist from smaller structures which could either be integrated harmonically into the appearance of a building.

Considering all these aspects provides a possible ability for decision makers to take into account advantages and disadvantages of conventional and local structural protection measures. Consequently, the concept of local protection should be embedded within the framework of integral risk management strategies. However, the decision will often be a political one, as recent years had shown. Hence, further studies have to be carried out in order to assess the effects and consequences of local structural protection for a future enhancement of risk-minimising efforts with respect to buildings and infrastructure facilities.

4 Local protection against mountain hazards – state of the art and future needs

M. Holub and J. Hübl (2008): Local protection against mountain hazards – state of the art and future needs. Natural Hazards and Earth System Sciences, 8, 81-99

Abstract

During the last decades, settlement activities increased in European mountain regions. Due to the scarceness of areas suitable for development, residential estates were extended into areas endangered by natural hazards such as mass movements. These settlements generally show a considerable vulnerability to tangible assets.

Integral risk management strategies to reduce the vulnerability to tangible assets are presented for the assessment of such endangered areas. Conventional mitigation and local structural measures are discussed with respect to the necessary delimitation of endangered areas, the preparedness of people and possible financial prevention. According to different natural hazard processes (flash floods with and without bedload transport, debris flows, land slides, rock falls and avalanches) and various structural elements of buildings, a catalogue of local structural measures is presented with respect to occurring process impacts and protection objectives. Thereby, different local structural measures are classified and recommended according to a possible implementation for newly-erected buildings and for upgrading existing buildings, respectively. Based on these recommendations, future needs for a sustainable and comprehensive reduction of risk in settlement areas endangered by mass movements are outlined. Above all, this includes a prescription of building codes and the re-introduction of an obligatory final inspection of buildings.

4.1 Introduction

During the last decades, an increasing land-use activity could be observed in European mountain regions. In Austria, settlements have been expanded, leading to extensive land consumption and associated population growth. Since the 1970s, the average useable living space rose from 22 m² per person in 1972 to 38 m² in 2001 (Statistik Austria, 2004). As a major part of Austria is located in mountain areas above 1000 m a.s.l. (approx. 36 % of Austria's territory; approx. 19 % of Austria's territory is located higher than 1500 ma.s.l.), areas suitable for permanent settlement are limited (see Fig. 4-1). In the entire country, 37.2 % of the whole area is suitable for permanent settlement and associated economic activities, while in some Federal States, the values remain noticeably below one third of the area. Due to this scarcity, commercial parks and particularly vulnerable infrastructure has been extended into areas which are endangered by natural hazards such as mass movements and avalanches.

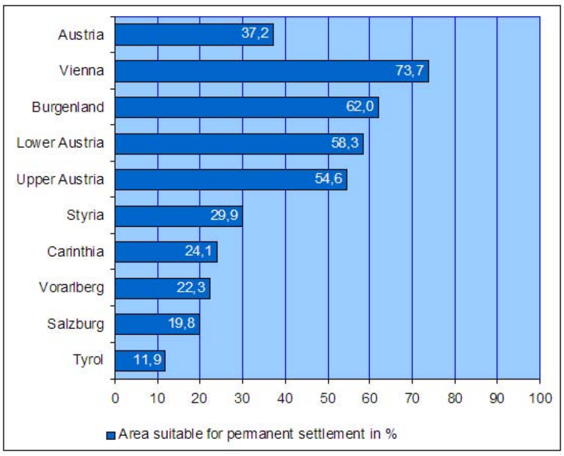


Figure 4-1. *Percentage of area suitable for permanent settlement in Austria and in the Federal States (BEV, 2004).*

Consequently, an increase in losses due to hazard processes is often claimed in recent years and can be mostly explained by an increase of property values in endangered areas (Munich Re, 2007). However, these statements have hardly been quantified. Until now, only few studies addressed the development of losses due to natural hazards in the Alps (SLF, 2000; Jóhannesson and Arnalds, 2001; Nöthiger et al., 2002; Fuchs and Bründl, 2005) and in Austria (Embleton-Hamann, 1997; Luzian, 2000; Oberndorfer et al., 2007).

In Austria, strategies to prevent or to reduce the effects of natural hazards in areas of settlements and economic activities have a long tradition. Apart from early attempts for the local protection of settlements tracing back in the Mediaeval times, official authorities were only founded in 1884 (Länger, 2003) based on a first legal regulation (Österreichisch-Ungarische Monarchie, 1884). In the second half of the 19th and in the early 20th century, protection against natural hazards was mainly organised by implementing permanent measures in the upper parts of the catchments to retain solids from erosion and in the release areas of avalanches. These measures were supplemented by silvicultural efforts to afforest high altitudes. Since the 1950s such conventional mitigation concepts – which aimed at decreasing both, the intensity and the frequency of events – were increasingly complemented by more sophisticated technical mitigation measures. Until the 1970s, mitigation concepts mainly aimed at the deflection of hazard processes into areas not used for settlements. In 1975, the Forest Act was introduced, legally prescribing fundamentals in dealing with natural hazards in Austria (Republik Österreich, 1975). Additional legal regulations for torrent and avalanche control as well as hazard mapping were implemented in 1976 (Republik Österreich, 1976).

Consecutively to the development of land-use planning in the mid-1970s, hazard maps were introduced as a passive mitigation measure to prevent the development of settlement activities in endangered areas (Länger, 2005). Hazard maps, expected to be implemented area-wide across Austria by 2010, are supplemented by building codes in areas with less hazard impact, and serve as a basis for integral risk management strategies. As a result, hazard processes are no longer solely deflected; conversely, a combination of diverse active and passive mitigation measures is applied to prevent damage to buildings, infrastructure and persons. This combination includes conventional technical structures to influence the natural process as well as local structural measures to reduce the process impact on values at risk.

However, little information is available on local structural protection measures so far, in particular with respect to different types, designs and materials used. The aim of the following sections is to partly close this gap by (i) presenting the concept of local structural protection within the framework of integral risk management and (ii) providing a catalogue of local structural measures used in Austria to protect buildings as well as infrastructure and lifelines.

4.2 Conventional mitigation within the framework of integral risk management

In the Republic of Austria, conventional mitigation of natural hazards can be traced back to the 1890s, when the French system of forest-technical torrent and avalanche control was adopted. Watershed management measures, forest-biological and soil bio-engineering measures as well as technical measures (construction material: timber and stone masonry) had been implemented. Thus, conventional mitigation concepts – which influence both, the intensity and the frequency of events – only consider technical structures within the catchment, along the channel system or track and in the deposition area. According to the approach of disposition management (reducing the probability of occurrence of natural hazards) and event management (interfering the transport process of the hazard itself), a wide range of technical measures is applicable (Hübl and Fiebiger, 2005; see Tab. 4-1).

Conventional technical measures are not only very cost-intensive in construction, moreover, they interfere with the ecology of a torrent as well as with the adjacent landscape (e.g. Bělský and Jařabáč, 2004; Mayer, 2004; Rudolf-Miklau and Patek, 2004). Additionally, because of a limited lifetime and therefore an increasing complexity of maintenance in high-mountain regions, future feasibility of technical structures is restricted due to a scarceness of financial resources provided by responsible authorities (Weinmeister, 1994). If maintenance is neglected, mitigation measures will become ineffective and can even increase the catastrophic potential of natural hazards (Aulitzky, 1970).

Table 4-1. *Technical protection measures according to their location of implementation.*

	Catchment	Channel/Track	Deposition area
Drainage	**X**		
Stabilising structures	**X**	**X**	
Consolidating structures		**X**	
Deflecting structures		**X**	**X**
Breaking structures			**X**
Filtering structures			**X**
Retaining structures			**X**
Deposition areas/basins			**X**
Channel enlargement		**X**	**X**

Since conventional technical measures do neither guarantee reliability nor complete safety (Schmid, 2005), a residual risk of damage to buildings, infrastructure and harm to people remains (Fell, 1994; BMLFUW, 2006). Even if such mitigation measures may reduce short-term losses, the long term vulnerability might increase due to an enhanced attraction of “secured” areas for settlement activities and institutional investors (Mileti and Myers, 1997).

Experiences from the last years suggested that values at risk and spatial planning should be increasingly considered within the framework of natural hazard reduction (Kanonier, 2006). To meet this goal, integral risk management strategies seem to be a valuable instrument to reduce the susceptibility of buildings and infrastructure to natural hazards and to develop strategies for a strengthened resistance.

The framework of integral risk management requires a combination of active and passive measures to reduce the impact of natural hazard processes. Thereby, active measures are applied to mitigate the process and passive measures are based on the principle of a spatial separation of values at risk from endangered areas (Hübl and Steinwendtner, 2000). However, a review of existing literature had shown that active and passive measures are not defined in a unique system until now, since these terms have different meanings depending on the different mitigation philosophies in individual countries. Not only “active” and “passive” mitigation measures are used as customary terms in dealing with natural hazards, further well-established terms such as “permanent”, “temporary”, “structural” and “non-structural” measures can be found in the literature. For a clarification, definitions widely used in European mountain areas are shown in Tab. 4-2.

Table 4-2. *Compilation of definitions with respect to diverse mitigation measures.*

Active mitigation measures	Initiation, transport or deposition of mass movements can be influenced by active mitigation measures. The change of characteristics of magnitude and frequency can be achieved either by influencing the probability of occurrence of a hazardous event (disposition management), or by manipulating the hazardous process itself (event management) (Hübl and Fiebiger, 2005). Active countermeasures should reduce the consequences of the potential hazard.
Passive mitigation measures	Passive mitigation measures are based on the principle of spatial separation of the endangered people and objects from the hazardous area (Wilhelm, 1997). A reduction of potential loss and decrease of vulnerability should be achieved by preventive measures (spatial planning, land-use) and event response (immediate actions in case of an (expected) event).
Structural mitigation measures	Structural measures include all physical measures used to mitigate natural hazards.
Non-structural mitigation measures	Non-structural mitigation measures typically concentrate on identifying hazard-prone areas and limiting their use temporarily or permanently. Further forestal measures can be seen as non-structural measures. Non-structural countermeasures are very site-specific and they greatly depend on the organizational and legal structures in each country.
Permanent mitigation measures	Permanent measures comprehend durable technical and forestal measures as well as land-use planning. Further information of population is subsumed.
Temporary mitigation measures	Temporary measures are adjusted to a certain point of time and the hazard potential of a location. These measures are executed spontaneously. Usually they complete or substitute the permanent measures with respect to an increased economic efficiency.

Following these definitions, mitigation measures are categorised applying a matrix presented in Tab. 4-3. As a result, active permanent mitigation measures, such as technical measures and forestal measures, can be distinguished from passive permanent spatial planning activities and land-use regulations. Permanent measures are supplemented by temporary measures, such as immediate support (active) and evacuation (passive). With respect to risk management strategies, a combination of active and passive measures and permanent and temporal measures is used for an optimised and cost-efficient prevention of damage (e.g. Leitgeb and Rudolf-Miklau, 2004; Fuchs et al., 2007a). Thereby, damage is – apart from definitions in social sciences, where negatively evaluated consequences or effects of an event are subjectively and normatively rated – considered as quantifiable mathematical number, e.g. in terms of monetary units (Berg, 1994).

Table 4-3. *Categories of mitigation measures.*

	Active	Passive
Permanent	Soil bio-engineering	Spatial planning and land-use
	Forestal measures	Hazard mapping
	Technical measures	Local structural measures
Temporarily	Immediate measures	Information and warning
		Exclusion zones and evacuation

Risk resulting from natural hazards is defined as a function of the probability of a hazard process and the related extent of damage (see Eq. 4-1). In accordance with the definition of (United Nations, 2004), specifications for the probability of the defined scenario (p_{Si}), the value of the object affected by this scenario (A_{Oj}), the probability of exposure of object j to scenario i (p_{Oj}, s_i), and the vulnerability of object j in dependence on scenario i (v_{Oj}, s_i) are required for the quantification of risk ($R_{i,\,j}$).

$$R_{i,j} = f\left(p_{Si}, A_{Oj}, v_{Oj,Si}, p_{Oj,Si}\right) \qquad \text{(Eq. 4-1.)}$$

By risk management strategies, population vulnerability can be reduced and the susceptibility of values at risk can be minimised considering the following fundamental issues (Habersack et al., 2004; Fuchs et al., 2007b):

(1) Spatial precaution (risk prevention)

Areas, which are permanently or at least temporarily exposed to natural hazards, are to be kept free from settlements (Roy et al., 2003; Hooijer et al., 2004). This fundamental statement is mirrored by the current legislation in Austria, where areas of permanent danger due to natural processes have to be delimited by hazard maps (Republik Österreich, 1976). During spatial planning activities, these areas should not be allotted for development. However, alternative utilisation, such as for agricultural purpose or leisure activities remain possible (Hattenberger, 2006; Kanonier, 2006). Spatial planning (competence of the Federal States), land-use planning (competence of the municipalities which act at the same time as building authority), and hazard mapping (competence of the Federation, conducted by the Austrian Forest Technical Service of Torrent and Avalanche Control; see Appendix A) are common tools. For the latter, intensity maps, synoptically hazard maps, risk maps and protection deficit maps are required as an essential basis for a sustainable management of natural hazards (Borter, 1999; Egli, 2000a).

(2) Structural precaution (risk reduction)

Damage to objects without structural precautions is evenly distributed to the building and the interior, such as furniture and content (see Tab. 4-4). The damage costs easily doubles or triples if an oil tank bursts by buoyancy and leaks oil.

Table 4-4. *Distribution of damage at the building itself and at interior decoration (adopted from Egli, 2002a).*

Damage at the building itself	Damage at interior decoration
Walls, ceilings and their panelling (36 %)	Furniture (40 %)
Floor and floor covering (27 %)	Fixtures (40 %)
Heating system (27 %)	Doors and electrical equipment (20 %)
Electric wires and windows (10 %)	

Besides conventional technical mitigation measures, structural precaution is achieved by an adapted construction design and the appropriate use of an object. Structural precaution is the main application domain for local structural measures, since the individual vulnerability of buildings can be fundamentally decreased by strengthening e.g. brick walls with reinforced concrete components (Fig. 4-2), and/or the adopted interior design of the different rooms according to occupancy time and hazard potential. Fig. 4-3 provides a model for such adopted design; the sleeping room is located opposite the hazard impact whilst the bathroom is located more hazard-exposed. A well organised utilisation of the rooms can influence the vulnerability and as a result the risk considerably (Fell, 1994; Fell and Hartford, 1997).

Figure 4-2. *Brick walls reinforced by ferro-concrete components to strengthen the building’s resistance.*

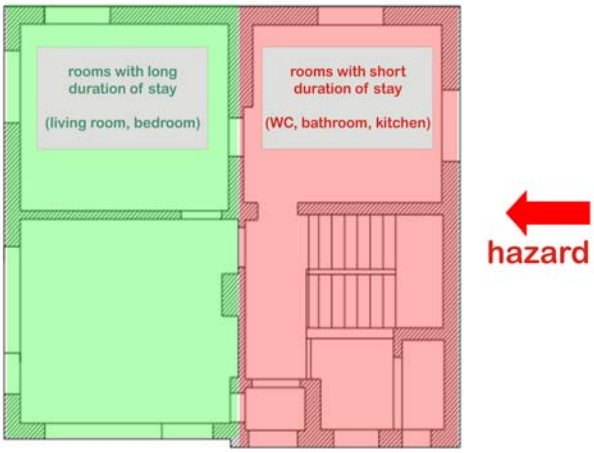


Figure 4-3. *Distribution of the different rooms according to occupancy time and the hazard potential.*

(3) Behavioural precaution (risk reduction)

In general, the triggering mechanisms of mountain hazards initiate processes with considerable high transport velocities. As a consequence, possibilities of forecasting and warning are limited due to a relatively short time period between cause and effect (see Tab. 4-5). Thus, preparedness for such events is closely linked to peoples' behaviour, in particular with respect to evacuation and sheltering (Fell and Hartford, 1997). Behavioural precaution is a risk reduction principle addressing concrete action before, during and after a hazardous event. However, top-down approaches concerning appeals and information are usually not well received; on the other hand, the responsibility for possible deficits is regularly attributed to the institutional obligations of public authorities in the aftermath of an event. If obligation to concrete precautions by the authorities is not supported by noticeable incentives, such actions can only be considered as an offer to self-motivated people (Ita and Giller, 2006). As a long term objective, shaping the opinion of people to assume personal responsibility for natural hazard mitigation should be achieved. Furthermore, there is a call for voluntary contributions to the prevention of disasters (Patek, 2003).

Table 4-5. *Velocity of mass movements and resulting advance warning time.*

Mass movement	Maximum velocity	Advance warning time
	[km/h] ([m/s])	
Flash flood	20 (5)	Seconds to minutes
Debris flow	40 (10)	Seconds to minutes
Spontaneous land slide	4 (1)	Seconds to minutes
Permanent land slide	1-1000 mm/a	Months to years
Rock fall	110-140 (30-40)	Seconds
Dense avalanche	40-140 (10-40)	Seconds to minutes
Powder avalanche	110-250 (30-70)	Seconds

(4) Institutional precaution (risk transfer)

Transferring risks to a broader community is usually achievable through products sold on the insurance market. However, any insurance to cover losses from natural hazards is optional in Austria. Apart from the inclusion of damage resulting from hail, pressure due to snow load, rock fall and sliding processes in an optional storm damage insurance, no standardised product is currently available on the national insurance market. Moreover, the terms of business of this storm damage insurance explicitly exclude coverage of damage due to avalanches, floods and inundation, debris flows, earthquakes and similar extraordinary natural events (Schieferer, 2006). As a result, each citizen is responsible for individual private financial reserves to cover losses resulting from natural hazards, which might increase the individual vulnerability. Compulsory elementary insurance is only recently debated, but could transfer the risk by shifting losses to a broader community (Ungern-Sternberg, 2004).

If the terms “structural precaution” and “personal responsibility” are combined for a mental exercise, “local structural measures” appear as the logical result. However, since local structural measures have to be regarded as personal (private) precaution, it is the individual responsibility to implement such structures. Individual responsibility ranks among the basic pillars of the civil defence system. Therefore, adequate information and an appropriate practical implementation in the private sector are particularly important to achieve a higher level of personal precaution (Ita and Giller, 2006).

4.3 Local protection measures – fundamentals and effects

The principles of planning and implementation of local structural measures to reduce vulnerability against natural hazards are neither highly sophisticated nor very innovative. However, the performance of local structural measures often is neglected or even ignored following the proverb that cheap solutions cannot be effective. Generally, local structural measures are “the afterthought of a tragedy rather than a forethought of prevention” and are “developed based on individual experiences more than scientific knowledge” (IBHS, 2005). Besides, in relation to the potential damage caused by natural hazards, the construction of local structural measures seems to be reasonable, in particular if renewal or reconstruction is planned (FEMA, 1998).

4.3.1 Fundamentals

Some basic principles should be considered for the implementation of local structural measures:

(1) Knowledge of the interactions between all the possible hazard processes within the area concerned is required.

It is insufficient to refer only on the most probable transport process, rather than to consider all possible hazard processes and the inherent interactions and interdependencies (multi-hazard- and multi-risk-approach, respectively).

(2) Spatial measures should be preferred to structural measures.

The most effective way to avert the impact of natural hazards to damage potential is to keep the affected areas clear of values at risk. Therefore, non-structural mitigation measures – such as land-use planning activities – should take priority over other mitigation concepts. Moreover, the implementation of local structural measures usually involves – occasionally considerable – costs. Consequently, the upgrading of existing objects with such measures might be rather unprofitable with respect to the required high expenditures. Even if cost-benefit ratios of local structural measures suggest an economic efficiency, the implementation might fail since the construction costs occur in the present while the possible benefits arise in the future. Although economically considered by discount rates, this does not encourage private initiatives for the implementation of local structural protection measures (Ita and Giller, 2006).

(3) Permanent measures should be preferred to mobile equipment.

As mountain hazard processes are usually characterised by high transport velocities, lead time for reaction (if early warning systems are installed) might be very short. Thus, mobile mitigation measures cannot provide the same safety level than fix installed protective systems since they need a certain amount of time for installation. In particular, the required installation time can increase considerably if the elements of the mobile protective system are not disposable directly at the endangered object and/or the operator is not regularly trained in setting up the system.

(4) Damage to third parties is not acceptable; hence, local structural protection must not cause negative impacts to adjacent or downstream riparian owners' values at risk.

Following disastrous losses, persons concerned are typically willing to implement local structural measures. As a result, these measures are often installed in individual responsibility neglecting any integrated concept performed by the authorities in charge. In doing so, uncoordinated mitigation results within the area affected by the hazard process, and possible future losses are shifted further downwards the catchment (e.g. massive concrete walls which deflect the runoff and the sediments to the adjacent property).

To conclude, the apparent objectives of local structural measures include the limitation of loss potential, damage to third parties, and damage to the environment (Egli, 2002a). Knowledge on the hazard processes and the related impacts, the feasibility of individual local structural measures as well as the effect of the combination of individual measures are essential for the effectiveness of local protection measures.

4.3.2 Effects

It seems to be obvious that local structural measures reduce the vulnerability of buildings considerably. However, since data related to the effects of process impacts towards buildings are rare, and in particular a possible reduction of impacts due to local structural measures has not been quantified satisfyingly so far, the decrease of vulnerability has hardly been measured until now (Kreibich et al., 2005; Grothmann and Reusswig, 2006).

Nevertheless, with respect to inundations and flooding, local structural measures are found to be effective in decreasing vulnerability, in particular if flood levels are below two metres (Egli, 2002a, 2002b) and if static flood intensities are small, respectively (Kreibich et al., 2005). With respect to dynamic flooding, Kimmerle (2002) had proven that buildings with local protection measures suffered less damage than unprotected ones, and concluded that particular combinations of different local structural measures are effective in sheltering values at risk from impacts due to torrential floods. Design and performance are the most important issues considering the efficiency of local structural measures. Consequently, strategies of reducing losses show different levels of effectiveness with respect to different types of measures (see Tab. 4-6).

Table 4-6. *The effect of different strategies to avoid water intrusion into buildings (adopted from Egli, 2002a, 2002b).*

Local structural measure	Efficiency
Deflection of floods	60-80 %
Elevated construction	almost 100 %
Sealing of the building’s openings	50-85 %
Sealing of the building’s openings in combination with deflection	almost 100 %
Water resistant interior design	10-35 %
Adopted use of the building	30-40 %

These findings support the results presented in Fuchs et al. (2007b) on the effects on vulnerability depending on whether or not bedload penetrated a building located on a torrent fan. In particular with respect to low and medium debris flow intensities, local structural measures such as deflection walls and coverings of building openings seem to be an appropriate tool to decrease vulnerability.

Local structural protection can be either performed as enclosing structure or as structure directly connected to the building. Measures surrounding the object at risk seem to be more effective since they prevent immediate impacts on the building shell, while structures directly implemented at the building shell are generally less space-consuming. However, a combination of measures is anticipated to increase the level of safety. Apart from engineering foci presented above, it has to be emphasised that local structural measures generally fit better in the landscape than traditional mitigation measures. Even if a quantification of this effect is outstanding, measures protecting individual objects usually consist from smaller structures which could either be integrated harmonically into the building’s appearance or which are generally not visible to untrained eyes.

4.4 Catalogue of local structural measures

The following catalogue of local structural measures used in European alpine regions represents an overview of existing and well-established protective techniques, and aims at increasing the resistance of buildings planned and constructed in the future. Consequently, the catalogue might be a valuable tool to decrease the susceptibility to loss resulting from natural hazards – in particular for consultants and practitioners. Taking the classification of local structural measures into account, some fundamentals should be considered before implementing the necessary structural adaptation.

4.4.1 Classification of local structural measures

Local structural measures can be distinguished and classified in various ways, i.e., according to the applicability for protection against the hazard process, the location with respect to the protected object, as well as the type of construction and material used; a further differentiation is possible whether the local structure is of permanently or temporarily use, see Tab. 4-7.

Table 4-7. *Classification of local structural measures.*

Criteria	Classes	Description
Transport process	(Flash) flood – debris flow, land slide – rock fall – avalanche	Different transport processes represent different impacts.
Effective period	Permanent – temporarily	Local structural protection can be either installed as a permanent device or can consist out of mobile modules which are installed only for a certain time after an early warning.
Location of local structural measures	Directly connected to the building – enclosing the building	Local structural protection can be either performed as enclosing structure or as structure directly connected to the building.
Construction type	New building – upgrade of an	Different local structural measures show different fea-

	existing building	sibility due to the construction of new buildings or renovation of existing ones.
Construction materials	Soil – timber – steel – brick (masonry) – concrete – reinforced concrete	Considering the transport process and its impact, different construction materials show different performances.

Considering the possible impacts of natural hazards, different construction materials show different performance and resistance. In Fig. 4-4, a list of conventional construction materials regularly used in the building industry is presented, and their suitability for resisting various process impacts is shown. If the hazardous processes endangering an object at risk are assessed, these tables can be used to determine relevant impacts on the objects. Moreover, the main protection objectives and the possible local structural measures are described.

🔴 = low resistance 🟡 = average resistance 🟢 = high resistance	***Resistance to***			
	Avalanche	Debris flow	Rock fall	Water (Flood)
Construction material respectively embodiment				
Loose fill material - soil	🟢	🔴	🟡	🟡
Stone masonry	🟡	🟡	🟡	🟢
Masonry	🟡	🟡	🟡	🟢
Concrete	🟢	🟡	🟢	🟢
Reinforced concrete	🟢	🟢	🟢	🟢
Timber *)	🟢	🟢	🟢	🟡
Stone	🟡	🟡	🟡	🟢
Steel	🟢	🟢	🟢	🟢
Wall				
Lime sand brick	🟡	🔴	🔴	🟢
Fired solid brick	🟡	🟡	🟡	🟢
Vertically perforated brick	🟡	🟡	🟡	🟡
Clinker	🟡	🟡	🟡	🟢
Concrete	🟢	🟢	🟢	🟢
Aerated concrete (gas concrete)	🔴	🟡	🟡	🟡
Timber *)	🟡	🟡	🟡	🟡
Timber block construction	🟢	🟢	🟢	🟡
Timber framing - prefabricated house	🔴	🔴	🔴	🟡
Reinforced concrete elements - prefabr. house	🟡	🟡	🟡	🟢
Glass brick	🟡	🟡	🟡	🟢
Window				
Timber *)	🟢	🟢	🟡	🟡
Plastics	🟡	🟡	🟡	🟢 🟡
Aluminium	🟢	🟢	🟢	🟢
Galvanised steel	🟢	🟢	🟢	🟢
Windowsill				
Marble	🟢	🟡	🟡	🔴
Other natural stone	🟢	🟡	🟡	🟢
Timber *)	🟢	🟡	🟡	🟡
Coated aluminium and metal	🟢	🟢	🟢	🟢
Sandstone	🟢	🟡	🟡	🔴
Schist	🟢	🟡	🟡	🟡
Door				
Wooden doorframe / timber set	🟡	🟡	🟡	🔴
Metallic door frame	🟢	🟢	🟢	🟢
Wooden door *)	🟢	🟢	🟢	🔴
Metallic door (high quality steel)	🟢	🟢	🟢	🟢
Stair				
Concrete	🟢	🟢	🟢	🟢
Solid wood	🟡	🟡	🟡	🟡
Galvanised steel construction	🟡	🟡	🟡	🟢
Massive stair in natural stone	🟡	🟡	🟡	🟢

*) The evaluation bases on a massive and robust construction design. The construction design influences the resistance considerably.

Figure 4-4. *Resistance of conventional construction materials to natural hazards (modified from Strauss, 2006, pers. comm.).*

4.4.2 Catalogue of local structural measures – static and dynamic floods, and fluvial transport of bedload

Impacts originating from static or dynamic flood as well as from extraordinary surface runoff, accompanied by transport of solids, endanger the stability of the building (see Fig. 4-5). The major processes include groundwater buoyancy and erosion processes, apart from the possible intrusion of water and solids through the building openings and the sewage system, the latter causing damage to the interior of the buildings. Several local structural measures are possible, as shown in Fig. 4-6. Considering the catalogue of local structural measures to protect buildings against floods, widely-used examples of protection measures, such as elevated constructions and sealed openings, are presented in Figs. 4-7 to 4-10. For the erection of new buildings, the terrain can be elevated above the flood level, which results in an overall decrease in retention area from an integrated spatial point of view (Fig. 4-7). If structural re-calculation is possible, the ground floor can be built on stilts and elevated above flood level (Fig. 4-8). The upgrade of existing buildings often requires slightly different measures, such as the enhancement of light wells (Fig. 4-9) and basement stairs (Fig. 4-10) above flood level.

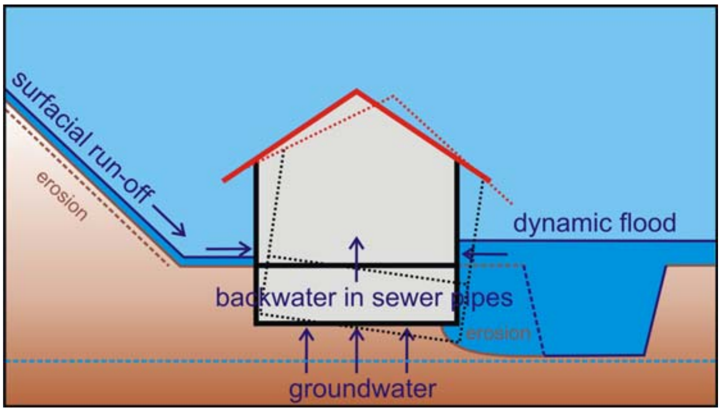


Figure 4-5. *Damage patterns due to static and dynamic floods.*

Relevant impact	Objective	Local structural measure	New building	Upgrade building
Leakage into the object	Safe deflection of flood discharge	Garden design without disacharge impeding elements	🟩	🟩
		Formation of flood plains	🟩	🟨
		Drainage of surfacial water	🟩	🟩
		Interrupted enclosures with deflecting effect	🟩	🟨
		Landscape design rising towards the object	🟩	🟥
		Design and shape of the building (ground plan)	🟩	🟥
	Elevated construction	Elevated construction	🟩	🟥
	Waterproofed construction	Nonreturn valves in sewer pipes	🟩	🟩
	Sealing of openings	Position of openings regarding the flow direction	🟩	🟨
		Cellar light wells made of concrete instead of synthetic material	🟩	🟥
		Cellar light wells raised above flood level	🟩	🟩
		Cellar light wells sealed with glass bricks	🟩	🟩
		Cellar light wells sealed with steel top covers	🟩	🟩
		Ventilation wells raised above flood level	🟩	🟩
		External cellar stairs with platform	🟩	🟩
		Metallic window/door frame	🟩	🟨
		Windows and doors attached from outside	🟩	🟨
		Window/door frame placed in steel frame from outside, which is fixed in wall	🟩	🟨
	Prevention of damage to swellable materials	Window sash out of aluminium or synthetic material	🟩	🟨
		Waterproofed materials for finishings	🟩	🟨
	Prevention of damage to heating system and oil tank	Anchorage of oil tank (buoyancy, tilting)	🟩	🟩
	Prevention of damage to interior decoration and house automation	House automation on the second floor	🟩	🟨
		Sealing of pipe lead-throughs	🟩	🟩
Endangering the stability of the exposed object	Prevention of damage to outwalls	Static reinforcement of impact wall	🟩	🟥
		Steel-concrete pedestal for pillars of roofs and balcony	🟩	🟨
	Prevention of excavation and erosion of foundation	Foundation sufficiently deep	🟩	🟥
		Bedplate instead of strip foundation	🟩	🟥
		Prevention against scouring the foundation	🟩	🟥
	Prevention of deposition of sediments on intermediate ceilings and soil covered buildings	Reinforced components (steel concrete) for the ceiling	🟩	🟥
		Reduced span width of ceiling components	🟩	🟥
		Ceiling supported by pillars	🟩	🙂
		Concept of internal and external use of the object	🟩	🟩
		Combination of protection measures	🟩	🟩
		Pre-fabricated mobile protection measures against floods	🟩	🟩
		Emergency systems (sandbags, shelves, sealing compound)	🟩	🟩
		Constructive easily feasible		🟩
		Constructive hardly feasible		🟨
		Constructive not feasible		🟥

Figure 4-6. *Local structural measures for new buildings as well as for an upgrade of existing objects with respect to possible impacts of floods.*

Figure 4-7. *New building: Object built on altered (elevated) terrain (courtesy of: die.wildbach, 2005).*

Figure 4-8. *New building: Object built on stilts (courtesy of: Fuchs, 2007).*

Figure 4-9. *New building and upgrade: Enhancement (raising) of light wells above flood level.*

Figure 4-10. *New building and upgrade: Enhancement (raising) of basement stairs above flood level.*

4.4.3 Catalogue of local structural measures – debris flow

Due to pressure and friction, debris flows can induce high forces to buildings. Impacts originating from the dynamic or static load of debris flow material and transported solids such as boulders endanger the stability of the building (Fig. 4-11), apart from the possible intrusion of debris flow material through the building openings which might cause damage to the interior of the building. As shown in Fig. 4-12, several local structural measures are possible. Considering the catalogue of local structural measures to protect buildings against debris flows, selected examples of protection measures such as deflection walls and splitting wedges are presented in Figs. 4-13 and 4-14.

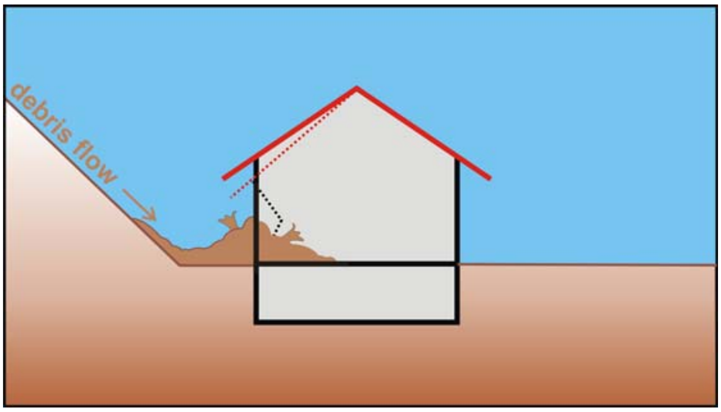


Figure 4-11. *Damage patterns due to debris flows.*

Relevant impact	Objective	Local structural measure	New building	Upgrade building
Endangering the stability of the exposed object	Prevention of general damages	Elevated construction	🟩	🟥
		Wedge-shaped floor plan	🟩	🟥
	Prevention of damage to outwalls (measures at and around the building)	Retention dam	🟩	🟨
		Deflection dam/wall	🟩	🟨
		Splitting wedge for buildings and pylons	🟩	🟨
		Strengthening of exposed walls (reinforced concrete)	🟩	🟥
		Reinforced facing formwork	🟩	🟩
		Stand-alone pillars out of reinforced concrete	🟩	🟨
	Prevention of damage on intermediate ceilings	Strengthening of intermediate ceilings	🟩	🟥
Intrusion of debris material	Prevention of damage due to mechanical demolition and contamination	No openings in exposed walls	🟩	🟨
		Small windows (located far above ground level)	🟩	🟨
		Impact protection for windows (massive shutter)	🟩	🟩
		Concept of internal and external use of the object	🟩	🟩
		Combination of protection measures	🟩	🟩
		Constructive easily feasible		🟩
		Constructive hardly feasible		🟨
		Constructive not feasible		🟥

Figure 4-12. *Local structural measures for new buildings as well as for an upgrade of existing objects with respect to possible impacts of debris flows.*

Figure 4-13. *New building and upgrade: Deflection wall and dam.*

Figure 4-14. *New building (and upgrade): Deflection wall and splitting wedge.*

4.4.4 Catalogue of local structural measures – land slide

Impacts originating from the dynamic or static load of sliding material endanger the stability of the building (see Fig. 4-15), in particular with respect to translational slumps. Several local structural measures can be implemented, the most popular are described in Fig. 4-16. Considering the catalogue of local structural measures to protect buildings against land slides, selected examples of protection measures such as soil bio-engineering and soil-nailing are presented in Figs. 4-17 to 4-18. Moreover, the stabilisation of sliding masses is strongly supported by an efficient drainage system installed in the subsurface layers (Fig. 4-19).

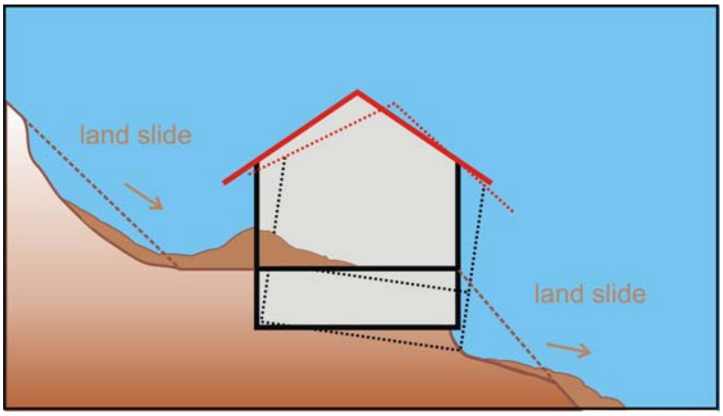


Figure 4-15. *Damage patterns due to land slides.*

Relevant impact	Objective	Local structural measure	New building	Upgrade building
Endangering the stability of the exposed object	Prevention of general damages	Stabalising sliding masses (supporting elements, vegetation)	🟩	🟩
		Drainage of sliding masses	🟩	🟩
	Prevention of damage to outwalls	Strengthening of exposed walls (reinforced concrete)	🟩	🟥
		Reinforced facing formwork	🟩	🟩
	Prevention of damage on intermediate ceilings	Strengthening of intermediate ceilings	🟩	🟥
	Subsidence, tilting, translational displacement	Static separation of structural levels	🟩	🟥
		Static separation of outbuilding	🟩	🟥
		Strengthened bedplate with cellar out of reinforced concrete	🟩	🟥
		Deflection of load to stagnant ground	🟩	🟥
		Non-stop reinforcement from bedplate to wall	🟩	🟥
		Lightweight constructions out of timber	🟩	🟥
Intrusion of sliding solids	Prevention of damage due to mechanical demolition and contamination	No openings in exposed walls	🟩	🟨
		Small windows (located far above ground level)	🟩	🟨
		Impact protection for windows (massive shutter)	🟩	🟩
		Concept of internal and external use of the object	🟩	🟩
		Combination of protection measures	🟩	🟩
		Constructive easily feasible		🟩
		Constructive hardly feasible		🟨
		Constructive not feasible		🟥

Figure 4-16. *Local structural measures for new buildings as well as for an upgrade of existing objects with respect to possible impacts of land slides.*

Figure 4-17. *New building and upgrade: Soil bio-engineering measures to stabilise unsteady slopes (courtesy of: Rankka, 2005).*

Figure 4-18. *New building and upgrade: Soil nailing measures to stabilise unsteady slopes (courtesy of: Rankka, 2005).*

Figure 4-19. *Enclosing structures: Drainage system to stabilise the sliding layers of the slope.*

4.4.5 Catalogue of local structural measures – rock fall

Impacts originating from the dynamic load of rolling, bouncing or falling rocks obviously jeopardise the stability of the building as well as the interior of the building (Fig. 4-20). Several local structural measures are possible, the most promising are described in Fig. 4-21. Considering the catalogue of local structural measures to protect buildings against rock fall processes, selected examples of protection measures include earth-filled dams on the hillside of objects to dissipate the kinetic energy (Fig. 4-22) and strengthened outer walls without any windows (Fig. 4-23). While earth-filled dams are relatively space consuming, they are considerably efficient in particular if they are combined with net barriers (Fig. 4-24).

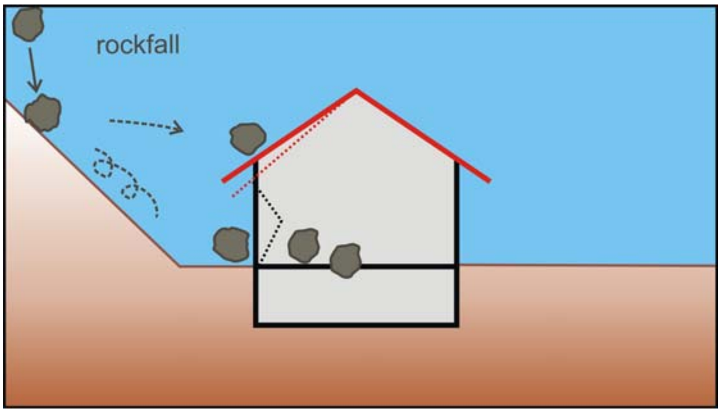


Figure 4-20. *Damage patterns due to rock falls.*

Relevant impact	Objective	Local structural measure	New building	Upgrade building
Endangering the stability of the exposed object	Prevention of general damages	No buildings directly at the toe of a slope	🟩	🟥
		Integration of building into the surface (roof terrace)	🟩	🟥
		Keeping down surface of exposed walls (ground plan)	🟩	🟥
		No cables and pipes on exposed walls	🟩	🟨
		Save location of exterior areas (terrace, play ground)	🟩	🟨
		Stabilising the source of rockfall	🟩	🟩
		Periodical clearing of loose material	🟩	🟩
		Net barriers at the rockfall track	🟩	🟩
		Retention dam/wall	🟩	🟩
		Low value front building	🟩	🟨
	Prevention of damage to outwalls	Strengthening of exposed walls (reinforced concrete)	🟩	🟥
		Reinforced facing formwork	🟩	🟩
		Energy absorbing facing fromwork (e.g. logs)	🟩	🟩
		Earth filled dam at exposed wall	🟩	🟩
		No openings in exposed walls	🟩	🟨
		Small windows (located far above ground level)	🟩	🟨
		Impact protection for windows (massive shutter)	🟩	🟩
		Windows turned away from direction of impact	🟩	🟥
	Prevention of damage on intermediate ceilings	Strengthening of intermediate ceilings	🟩	🟥
	Prevention of damage to the roof	Strengthening of roof structure	🟩	🟨
		Earth filling of flat roofs	🟩	🟩
		No roof-lights	🟩	🟨
		Concept of internal and external use of the object	🟩	🟩
		Combination of protection measures	🟩	🟩
		Constructive easily feasible		🟩
		Constructive hardly feasible		🟨
		Constructive not feasible		🟥

Figure 4-21. *Local structural measures for new buildings as well as for an upgrade of existing objects with respect to possible impacts of rock falls.*

Figure 4-22. *New building and upgrade: Earth-filled dam for energy dissipation of falling rocks.*

Figure 4-23. *New building: Strengthened front wall without windows.*

Figure 4-24. *Enclosing structures: Net barrier to protect buildings against rock fall.*

4.4.6 Catalogue of local structural measures – avalanche

Avalanches with their dense and powder fraction can affect buildings with high pressures and pulls to walls and roofs. Impacts originating from the dynamic or static load of snow and transported solids jeopardise the stability of the building (Fig. 4-25). An additional frequently observed impact is the intrusion of snow through the building openings which result in remarkable damage to the interior of the buildings. Local structural measures are widely used in European mountain regions, the most promising are described in Fig. 4-26. Considering the catalogue of local structural measures to protect buildings against avalanches, selected examples of protection measures such as deflection dams and splitting facilities (Fig. 4-27), and roof terraces to integrate the building into the surface of the slope are presented (Fig. 4-28). Earth-filled dams have a long tradition tracing back to Mediaeval times and are very efficient, while porched walls (Fig. 4-29) and reinforced shutters (Fig. 4-30) are only used since the 1960s.

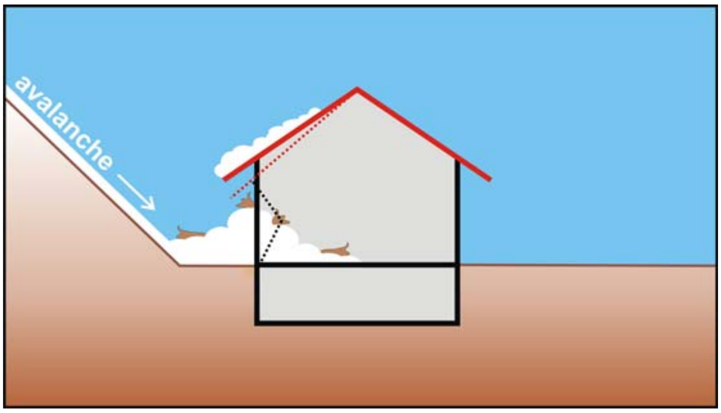


Figure 4-25. *Damage patterns due to avalanches.*

Relevant impact	Objective	Local structural measure	New building	Upgrade building
Endangering the stability of the exposed object	Prevention of general damages	Arrangement of buildings in a line (parallel to flow direction)	🟩	🟥
		Integration of building into the surface (roof terrace)	🟩	🟥
		Keeping down absolute height of building (exposed surface)	🟩	🟥
		Wedge-shaped floor plan	🟩	🟥
	Prevention of damage to outwalls (measures at and around the building)	Measures against snow gliding (ground pegs)	🟩	🟩
		Retention dam	🟩	🟨
		Deflection dam/wall	🟩	🟨
		Low value front building	🟩	🟨
		Splitting wedge for buildings and pylons	🟩	🟨
		Earth filled dam at exposed wall	🟩	🟨
		Strengthening of exposed walls (reinforced concrete)	🟩	🟥
		Reinforced facing formwork	🟩	🟩
	Prevention of damage to the roof	Strengthening of roof structure	🟩	🟨
		Stand-alone pillars out of reinforced concrete	🟩	🟨
		Short eaves respective fixed roofs (pull)	🟩	🟨
	Prevention of damage on intermediate ceilings and snow covered buildings	Strengthening of intermediate ceilings	🟩	🟥
Intrusion of snow	Prevention of damage due to mechanical demolition	No openings in exposed walls	🟩	🟨
		Protection of entrance by a front building	🟩	🟨
		Small windows (located far above ground level)	🟩	🟨
		Windows turned away from direction of impact	🟩	🟥
		Window/door frames mounted on metallic frame (no polyurethane foam)	🟩	🟨
		Avalanche resistant windows with rugged fittings	🟩	🟩
		Attaching doors and windows from the outside	🟩	🟨
		Impact protection for windows (massive shutter)	🟩	🟩
		Mounting the shutters on the wall (not on the frame)	🟩	🟩
		Countersinking of shutters in wall (shearing effect)	🟩	🟨
		Concept of internal and external use of the object	🟩	🟩
		Combination of protection measures	🟩	🟩
		Constructive easily feasible		🟩
		Constructive hardly feasible		🟨
		Constructive not feasible		🟥

Figure 4-26. *Local structural measures for new buildings as well as for an upgrade of existing objects with respect to possible impacts of avalanches.*

Figure 4-27. *New building and upgrade: Earth-filled dams as deflection and splitting facilities.*

Figure 4-28. *New building: Roof terrace to integrate the building into the surface of the slope.*

Figure 4-29. *New building: Protection of windows by porched walls.*

Figure 4-30. *New building and upgrade: Window shutters to prevent intrusion of snow.*

4.5 Conclusion

Effective local structural measures are the result of systematic hazard analyses and aim at the reduction of vulnerability of values at risk located in the accumulation areas of hazard processes. The importance of local structural measures is related to the concept of conventional mitigation on the one hand and the implementation of land-use planning on the other hand. Consequently, the concept of local protection should be embedded within the framework of integral risk management strategies.

Considering different mass movement processes and their impacts on the built environment, multiple solutions for the protection of new buildings and the upgrade of existing inventory exist. Planned early, expenditures for the implementation of local structural measures are comparatively low related to the total cost of the planned construction.

Recent studies related to torrential hazards in Austria (Fuchs et al., 2007b) and Switzerland (Romang, 2004) suggested a considerable decrease in vulnerability, if local structural protection is implemented. However, until now it is hardly possible to quantify the risk-minimising effects of local structural measures. Hence, further studies have to be carried out in order to assess these effects and their consequences for future enhancement of risk minimising efforts with respect to buildings and infrastructure facilities.

Apart from these overall goals, there are specific needs for an improvement of the level of information for affected people, legal regulations and risk transfer mechanisms in Austria as well as other European mountain regions. These needs would not only result in an increased risk awareness of people concerned, but also in an enhanced enforceability of necessary legal regulations, above all building codes. As a result, the individual responsibility could be strengthened and the society will be enabled to alternatively use (increasingly scarce) public funds in a more cost-efficient way.

4.5.1 Information

It has been widely accepted that people who experienced natural hazards and their impacts are willing and able to reduce their individual susceptibility considerable (e.g., Smith, 1981; Wind et al., 1999). However, since half-life of knowledge is very short, information about natural hazards and their damage potential to exposed values at risk should be repeatedly provided by communities, e.g. by regular informative meetings at community level. Such meetings should also include technical information on underlying assumptions made during the risk assessment procedure, such as the concept of probability, ranges and uncertainties associated with design events, and residual risk. Furthermore, the potential of local structural measures should be clearly stressed, as well as their comparatively low costs with respect to potential losses. This list is not exhaustive; above all, people have to know where to obtain professional help in planning local structural measures.

4.5.2 Legislation

According to a decision of the supreme court of the Republic of Austria, hazard maps feature the character of a qualified expertise rather than a legal basis for land-use planning activities (Hattenberger, 2006; Kanonier, 2006), and thus have no obligating effect for builders and homeowners concerning imposed restrictions (building codes). Hence, hazard maps should become an obligatory part of land-use planning activities by using standardised (legal) procedures and terms to minimise the scope of interpretation of restrictions due to these maps (Schremmer et al., 2005). However, these requirements might not be consistent to the strongly federal organisation of Austria’s governmental structure. In each individual federal state, different building acts exist, which makes a national standardisation of legal prescriptions difficult. Furthermore, hazard mapping is a national affair, while building laws are a matter of federal states (Hattenberger, 2006). Compulsory building codes implemented on the national level for objects in exposed areas should be the minimum standard to be achieved in the future. With respect to a reduction of risk, exceptional building permits in red hazard zones have to be considerably reduced. Compulsory building permits should be prescribed even for small construction projects, and should be accompanied by a compulsory final technical acceptance of completed buildings to receive the permission of use.

4.5.3 Risk transfer

It has been outlined in Section 2 that natural hazards are not yet subject to compulsory insurance in Austria. Nevertheless, concepts of obligatory insurance evolved in other countries affected by natural hazards, and succeeded in a considerable risk reduction (Ungern-Sternberg, 2004; Fleischhauer et al., 2006). Apart from the ongoing discussion on a possible implementation of such an insurance in Austria (Fuchs, 2007, pers. comm.), reduced premiums for implemented local structural measures could be a possible incentive to increase acceptability of individual precaution. Furthermore, a positive consideration of both, local structural measures and private insurances in case of necessary compensations by the catastrophe fund would be desirable (The current situation in Austria acts the opposite way: Compensations paid out by privately effected insurances are subtracted from grant aids by the catastrophe fund; Prettenthaler and Vetters, 2005). In order to foster such incentives, local structural measures would also be promoted if reduced bank credits for construction were available.

Appendix A – Hazard zone mapping in Austria

In Austria, the methodology for delimiting hazard zones is regulated by a national legal act (Republik Österreich, 1975) and an associated decree (Republik Österreich, 1976). The implementation of these regulations is assigned to the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) and administrated by the governmental departments of the Austrian Service for Torrent and Avalanche Control (die.wildbach) and the Federal Water Engineering Administration.

The Forest Act (§ 8b) of 1975 prescribes the delimitation of hazard zones in catchment areas susceptible to natural hazards such as torrential floods or avalanches (Forest Act § 99) and areas reserved for mitigation measures. In § 11, the compilation of hazard maps and the involvement of communes and population are regularised. The contents and designs of these maps are specified by the decree associated to the Forest Act (Republik Österreich, 1976). According to § 5 (2) of the Decree on Hazard Zoning, all available data and information on natural hazards as well as interactions between individual hazard processes have to be considered during the compilation of hazard maps. Furthermore, interferences with the human environment, such as infrastructure facilities and settlements have to be taken into account.

Hazard maps are usually based on the area of an individual community, and should be compiled in a reproducible manner to allow for validation during the approval process by the Federal Ministry of Agriculture, Forestry, Environment and Water Management.

Hazard maps are based on a design event with a return period of 150 years, and an event occurring more frequent with a return period of 10 years (Republik Österreich, 1976). In § 6 of the

Decree on Hazard Zoning, the criteria for delimitation of hazard zones is prescribed. According to these prescriptions, red hazard zones indicate those areas where the permanent utilisation for settlement and traffic purposes is not possible or only possible with extraordinary efforts for mitigation measures. Yellow hazard zones indicate those areas where a permanent utilisation for settlement and traffic purposes is impaired by hazard processes. Furthermore, specific other areas have to be displayed in the hazard maps: (1) Blue colours mark areas to be provided for future mitigation measures, (2) brown colours indicate areas affected by land slides and rock fall and (3) purple colours indicate areas that can be used as protection due to their natural properties, such as protection forests or natural retention basins.

5 Mountain hazards: reducing vulnerability by adapted building design

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Abstract

Despite the long tradition of technical mitigation on a catchment scale in European mountain regions, losses due to mountain hazards are still considerably high in number and monetary loss. Therefore, the concept of technical mitigation had been supplemented by land-use planning and, more recently, local structural protection. Local structural protection includes measures directly implemented at or adjacent to endangered objects, and has proven to be particularly cost-effective with respect to integral risk management strategies. However, the effect of local structural protection in reducing the vulnerability of elements at risk, and the associated consequences with respect to a reduction of structural vulnerability have not been quantified so far. Moreover, there is a particular gap in quantifying the expenditures necessary for local structural protection measures. Therefore, a prototype of residential building adapted to mountain hazards is presented in this study. This prototype is equipped with various constructional elements to resist the incurring impact forces, i.e., of fluvial sediment transport and of snow avalanches. According to possible design loads emerging from these hazard processes, the constructive design necessary is presented, and the amount of additional costs required for such an adaptation is presented. By comparing these costs with quantitative loss data it is shown that adapted building design is particularly effective to reduce the consequences of low-magnitude, high-frequency events in mountain regions.

5.1 Introduction

In the recent years, increasing numbers of natural hazards and associated losses have shown to the European Commission and the Member States of the European Union the paramount importance of the natural hazards issue for the protection of the environment and the citizens (Barredo, 2007). There is a strong scientific evidence of an increase in mean precipitation, and magnitude and frequency of extreme precipitation events, which implies that extreme flood events might become more frequent (Christensen and Christensen, 2003; Kundzewicz et al., 2005; Solomon et al., 2007; Keiler et al., 2010). In parallel, exposure to floods might increase across Europe as well as flood vulnerability due to population and wealth moving into flood-prone areas. Such issues have already been reported due to a global increase in population and the associated shift in economic activities (e.g., O'Keefe et al., 1976; Susman et al., 1983). Thus, even without taking climate change into account an increase of flood disasters in Europe might be foreseeable (Mitchell, 2003). However, alternative sources reporting on quantifying studies both on flood hazards at a continental level (US and Europe) as well as at a regional level suggested a trend in the opposite direction. Firstly, as discussed in Smith and Petley (2009) and confirming earlier reports within the development context by Guha-Sapir and Below (2002) as well as within the global effort to reduce losses (White, 1994), the key point is to be aware of the levels of uncertainty attached to loss data. Secondly, even if flood damages continued to increase despite extensive flood management efforts since 1900, particularly when measured in constant currency units, the trend is not as obvious once normalized. If the flood data related to the US are presented in terms of damage per unit wealth, a slight and statistically insignificant downward trend is observed (Loucks and Stedinger, 2007), which suggests that floods might have a lessening or neutral impact on the overall personal wealth of citizens in the US over the course of the past decades. Some other studies have focused on regions with similar economic susceptibility than the US, such as Canada (Etkin et al., 2003) and Europe (Becker and Grünewald, 2003; Mudelsee et al., 2003; Barredo, 2007). Since floods were a substantial hazard in Europe over the past centuries some inventories exist on the temporal distribution of such events. However, there is no comprehensive or standardized individual database for such losses in Europe. Hence, available information is relatively sparse (Mitchell, 2003). Mudelsee et al. (2003) concluded from a hydro-meteorological point of view by an analysis of flood magnitudes that there is no evidence from the observations for recent upward trends in the occurrence of large flood events in central Europe. Similarly, Barredo (2009) concluded by using available information from databases such as EM-DAT and NATHAN, that no clear positive trend in flood losses in Europe exists if they are normalized by eliminating the socio-economic influence of growing exposure in areas affected.

Nevertheless, these circumstances have produced a reaction in the European Commission, and a Directive on the assessment and management of flood risks addressed to the Member States was issued (Commission of the European Communities, 2007) as one of the three components of the European action programme on flood risk management (Commission of the European Communities, 2004). Within this directive, it has been officially acknowledged for the first time that flood events (defined in its broadest sense including torrent processes) are natural phenomena which cannot be prevented. Such events have the potential to severely compromise economic development and undermine the economic activities of the community due to an increase of human activities in floodplains and the reduction of the natural water retention by land use activities. As a result, an increase in the likelihood and adverse impacts of flood events is expected. Therefore, concentrated action is needed at the European level to avoid severe impacts on human life and property.

5.2 Mountain hazards

Besides many national and European efforts to reduce natural hazard impact on society, considerable damage has still occurred in the recent years in European mountain regions. Thereby, greater availability of information of natural hazard occurrence both on a scientific basis and also due to broader media coverage resulted in an increase of hazard awareness on a societal level, in particular due to a perceived increase in property damage and fatalities. The increased public awareness has often been misconstrued as an indication for increased frequency and magnitude of events which will trigger the potential increase in losses. It is still under debate, however, to which extent recent increases in damage ratios can be related to changing process behaviour and thus increased magnitude and frequency, and to which extent these developments are a result from increased utilization of areas prone to hazardous events for human settlement, economic activities and infrastructure corridors. Therefore, both of these possibilities need further research efforts in order to allow for an economically efficient and socially acceptable way of dealing with natural hazards, in particular with respect to the densely populated mountain regions of Europe.

During the last decades, an increase in land-use activity could be observed in European mountain regions. Taking the Republic of Austria as an example, settlements have been expanded, leading to extensive land consumption and associated population growth. Since 1970s, the average useable living space increased from 22 m^2 per person in 1972 to 38 m^2 in 2001 (Statistik Austria, 2004). As a major part of Austria is located in mountain areas above 1,000 m a.s.l. (this is approximately 36 % of Austria's territory, and approximately 19 % of Austria's territory is located higher than 1,500 m a.s.l.), areas suitable for permanent settlement are limited. In the entire country, 37.2% of the land area is suitable for permanent settlement and associated economic activities, while in some Federal states, the values remain noticeably below. Due to this scarcity, land use activities have repeatedly been extended into areas which are endangered by natural hazards such as mass movements, torrent processes, and avalanches. As a consequence, property values prone to these processes increased accordingly.

Accordingly, an increase in losses due to hazard processes has often been claimed in the recent years as a result of the occurrence of harmful events. However, such statements were hardly quantifiable so far, only few studies addressed the development of natural hazard events and associated losses in alpine countries. These studies were mostly focused on distinct events or reference periods, not on assessing the topic from a broader point of view by compiling a comprehensive database, such as e.g., SLF (2000), Nöthiger et al. (2002), Fuchs and Bründl (2005), and Hilker et al. (2009) for Switzerland, and Embleton-Hamann (1997), Fliri (1998), Luzian (2002), and Fuchs (2009) for Austria.

Though, with respect to the concept of integral risk management (Fell et al., 2008), such information is required in order to be able to plan and implement sustainable mitigation strategies. Sustainable mitigation strategies, as outlined by Holub and Fuchs (2009) in more detail, have to be pillared on a complementary multiplicity of risk treatment options acting upon the maxim of cost-efficiency in relation to the targeted expenditures and the aspired decrease in risk. Given the significance of these expenditures, risk-based appraisal of the costs and benefits (in terms of risk reduction) of major capital works is now customary in many alpine countries (Haering et al., 2002; BMLFUW 2005, 2006).

5.3 Vulnerability

Following the axiom that natural hazard risk is a function of hazard and consequences (Varnes, 1984; Fell et al., 2008), the ability to determine vulnerability is an essential step for reducing these consequences and therefore natural hazard risk. The approach of structural vulnerability is focusing on impact intensity and structural susceptibility of elements at risk, ranging from 0 (no damage) to 1 (complete destruction). From this technical point of view, as a general rule vulnerability assessment is based on the evaluation of parameters and factors such as building types, construction materials and techniques, state of maintenance, and presence of protection structures (Fell et al., 2008). For this reason, vulnerability values describe the susceptibility of elements at risk facing different process types with different spatial and temporal distributions of process intensities (e.g., flow depths, accumulation heights, flow velocities and pressures, Fuchs et al., 2007a, b; Holub and Fuchs, 2008).

If vulnerability is considered as a functional relationship between process magnitude or intensity, the resulting impact on structural elements at risk, and exposed values, vulnerability is related to the susceptibility of physical structures and is defined as the expected degree of loss resulting from the impact of a certain (design) event on the elements at risk. With respect to the hazardous processes, empirical parameters such as magnitude and frequency have to be evaluated based on probability theory. Thereby the magnitude-frequency concept plays a key role. When the activity of different hazard processes is compared on a given timescale some processes appear to operate continuously while others operate only when specific conditions occur.

By applying the concept of structural vulnerability, from an engineering point of view, considerable areas in European mountain regions are vulnerable to hazard processes (Fuchs, 2009). Even though the theory of vulnerability has been subject to extensive research and numerous practical applications over the past decades, considerable gaps still exist with respect to standardized functional relationships between impacting forces due to occurring hazard processes and the structural damage caused (Fuchs et al., 2007b; Papathoma-Köhle et al., 2011). For a major part these gaps result from the overall lack of data, in particular concerning: (1) losses caused by mountain hazards as a result of existing empirical classifications of damages, and (2) measurements of impact forces that caused these losses. Recently, promising approaches for a quantification of vulnerability have been made by Wilhelm (1997), Borter (1999), Barbolini et al. (2004) and Keiler et al. (2006) with respect to avalanches and rock fall processes, respectively. However, sound suggestions for landslides and torrent processes are still largely unavailable, even if these processes caused major losses in the Alps in the recent years (Fuchs et al., 2007a; Fuchs, 2009; Totschnig et al., 2011). Although such empirical relationships become increasingly important in determining the vulnerability of structural elements at risk, the results only mirror the average expected systems behaviour (expected destruction due to impacting forces) for a specific setting, e.g., the entire area of a torrent fan presumably affected by a defined 1 in 150 year event.

In addition, the analysis of empirical data had shown that the vulnerability of buildings affected by medium hazard intensities (e.g., 1.00-1.50 m deposition height for torrent processes) is highly dependent on whether or not the entrained material harms the interior of the building (i.e., by an intrusion of material through openings such as doors, wells and windows, Fuchs, 2009). These findings support previous work carried out by Romang et al. (2003). Consequently, local protection measures such as deflection walls and specially designed closure structures for at-grade openings definitely play a major role in reducing the vulnerability of buildings, particularly with respect to low and medium process intensities (Fuchs et al., 2007b).

Local structural protection measures which are implemented directly at or adjacent to endangered objects might therefore be a valuable and serious alternative with respect to reducing vulnerability within the concept of integral risk management (e.g., Johnson et al., 2005). However, the effect of local structural protection in reducing susceptibility of values at risk has not been quantified satisfyingly so far (Holub and Hübl, 2008), even if the positive effect in reducing vulnerability seems to be obvious. Local structural protection additionally seems to be economically efficient, as recently shown by Holub and Fuchs (2008) with respect to torrent hazards. To decrease the vulnerability of a building it is generally aimed at a combination of adapted construction design and appropriate interior use. Such an appropriate interior design is defined as a room layout which is modified according to possible hazard impacts. This modification is mainly based on the idea of allocating rooms according to e.g., occupancy time of the inhabitants in order to reduce possible threats and losses (Fig. 5-1). Adapted construction design, in contrast, is rather based on structural enforcements, and therefore targeted at a strengthening of the building envelope by local structural protection.

Local structural protection, namely constructive preventive measures, can be either performed as enclosing structure or as structure directly connected to the building. Such enclosing structures are defined as measures surrounding elements at risk but which are not connected to them. These seem to be very effective since they prevent direct hazard impacts on the building envelope, while structures directly connected to the building envelope in principal generate an increased resistance of the construction; furthermore, they are less land-consuming. However, a combination of both alternatives is anticipated to decrease the level of vulnerability (Holub and Hübl, 2008).

Local structural protection measures can be distinguished and classified according to their applicability for protection against hazard processes, their location with respect to the element at risk, as well as their construction type and material used. A further differentiation is according to the permanent or temporal implementation, such as permanent concrete walls or mobile flood protection. Considering the possible impacts of natural hazards, different construction materials show different performance and resistance. Consequently, a process-specific risk assessment, carried out at the earliest possible conceptual design stage and focusing on impact forces, vulnerability as well as damage patterns, will result in an appropriate protection concept (FEMA, 1998; Holub and Hübl, 2008; Renfroe and Smith, 2010). Therefore, information on both, hazard impacts and corresponding loads on the building envelope is necessary.

Figure. 5-1. *Distribution of the different rooms according to occupancy time and hazard potential (Holub and Hübl, 2008)*

Taking these findings as a basis, we will present a prototype of residential building typical for European mountain regions and adapted to mountain hazard processes. In particular, this prototype is equipped with various constructional elements which are able to resist the impact forces of hazardous events, i.e., fluvial sediment transport related to torrents, and snow avalanches. Therefore, we will start with a brief overview on studied hazard processes. Thereafter, we focus on (1) possible loads emerging from these hazardous processes and impacting the building envelope (2) the constructive design necessary to resist the loads, and (3) the amount of additional costs necessary for such an adaptation.

5.4 Hazard processes

Within this paper two major hazard categories occurring in mountain areas worldwide but also on the European level are considered: fluvial sediment transport related to torrents, and snow avalanches.

The term torrent refers to steep rivers within a mountain environment and is defined as a constantly or temporarily flowing watercourse within small catchment areas and characterized by changing perennial or intermittent discharge and flow conditions (ONR, 2009). Torrent events include a process group with a variety of different characteristics including discharge composed from pure water runoff, discharge with variable sediment concentration and debris flows (Costa, 1984). Fluvial sediment transport is characterized by a lower sediment concentration than debris floods and debris flows (< 40 % by weight Costa, 1988).

Fluvial sediment transport and related torrent processes cause static or dynamic impacts originating from flow conditions and the respective amount of transported solids. With respect to scale, process impacts may include surface as well as channel runoff, accompanied by erosion and deposition phenomena of different magnitude (Fuchs et al., 2008). The major process patterns result in possible intrusion of water and solids through the building openings and the sewage system, causing damage to the interior of the buildings, apart from possible buoyancy as well as erosion processes resulting in subsidence or even tilting, endangering the stability of the building (Fig. 5-2).

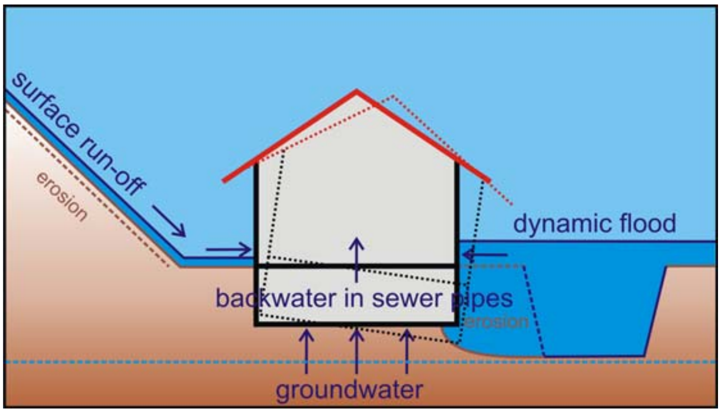

Figure 5-2. *Damage patterns due to torrent processes (Holub and Hübl, 2008)*

Snow avalanches are fast-moving mass movements within a mountain environment and are defined as gravity driven snow masses, moving along a certain track downwards slopes with a dislocation distance > 50 m (McClung and Schaerer, 1993). According to the mechanisms of flow, snow avalanches are regularly distinguished into dense flow avalanches, which may contain additional solids such as rock fragments and logs, and powder avalanches (Keylock, 1997; Bründl et al., 2010). Elements at risk located in the deposition area are influenced by two major processes, the air pressure plume in front of a powder avalanche and the snow in motion that exerts high impact pressure on objects located in the runout path (Sovilla et al., 2008).

Avalanches with their dense and powder snow part may affect buildings due to incurring high pressure loads and suction effects to the walls and the roof. Impacts originating from the dynamic or static load of snow and transported solids jeopardize the stability of the building (Fig. 5-3). Furthermore, snow and solid intrusion through the building openings may occur which will lead to considerable damage inside the buildings.

In the following section, the loads resulting from fluvial sediment transport related to torrents, as well as loads resulting from snow avalanches are presented. Additionally insights in the general building design criteria are provided.

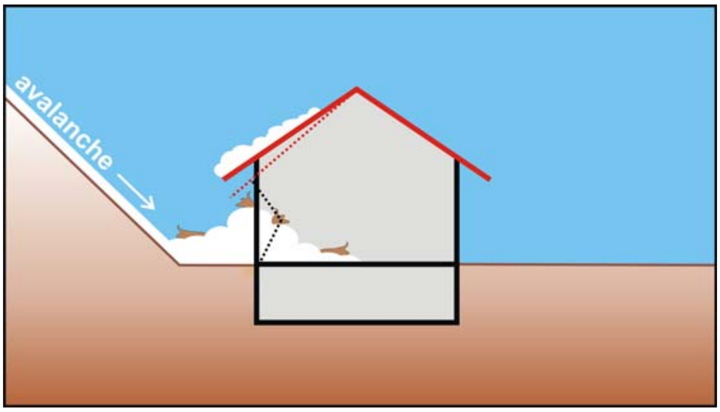

Figure 5-3. *Damage patterns due to snow avalanches (Holub and Hübl, 2008)*

5.5 Loads on the building envelope

In general, building design criteria have to rely on the following set of design loads, (1) in order to take into account the dead load of the structure (weight of all materials of construction incorporated into the building), (2) to take into account the maximum possible live load (result of the occupancy of a structure), (3) load assumptions resulting from the impact of wind storm, and (4) the assumed static snow load with respect to the design criteria of the truss. Furthermore, (5) the design loads resulting from fluvial sediment transport, and (6) the design loads for snow avalanches (dense part and powder part) were calculated.

5.5.1 Dead load of the structure

To take into account the dead load of the structure under consideration, the characteristic tare weights were taken from the respective Austrian building code ÖNORM B 1991-1-1 (ON, 2003, 2006a). This building code provides design guidance and actions for the structural design of buildings and civil engineering works including geotechnical aspects for the densities of construction materials and stored materials, for the self-weight of construction works, and for imposed loads for buildings.

5.5.2 Live load

The live load of the floor slab (first and second floor) were calculated by applying ÖNORM B 1991-1-1 (ON, 2006a) with n_1 = 2.0 kN/m² for the category of residential buildings, n_2 = 1.5 kN/m² for the walkable attic story, and n_3 = 3.0 kN/m² for the staircase.

5.5.3 Impact of windstorm

The impact of windstorm on the structure was calculated by applying ÖNORM EN 1991-1-4 and the national specifications ÖNORM B 1991-1-4 (ON 2005a, 2006b). The basic peak gust pressure was calculated with $q_{b,0}$ = 0.46 kN/m² resulting from the local wind conditions in mountain valleys of Austria.

To calculate the design loads, the walls and the roof were classified into sections A to J (see Fig. 5-4), and different pressure coefficients cp were assigned. With respect to the roof, the design loads 1–4 have to be calculated separately by the addition of either DL1 and DL2, DL1 + DL4, DL2 + DL3 or DL3 + DL4. The flow direction of the wind storm was assumed to affect the building from the valley-side.

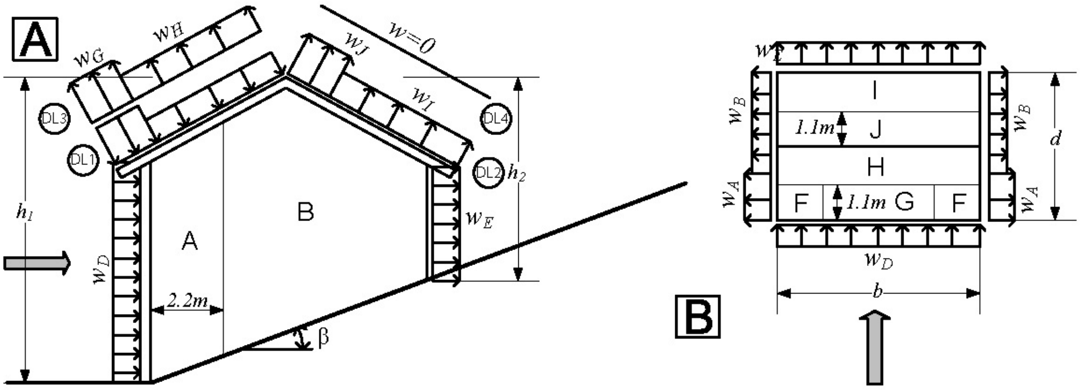

Figure 5-4. Structural system for windstorm impacting a building, DL1 = load factor 1, DL2 = load factor 2, DL3 = load factor 3, DL4 = load factor 4, $w_{A...J}$ = wind load, β = inclination of the slope, $h_{1,2}$ = building height 1 and 2, d = building width parallel to the flow direction, b = building width normal to the flow direction. The grey arrow indicates the flow direction, A = lateral view, B = top view.

In analogy to the windstorm loads, design loads for the powder part of snow avalanches were calculated, while the flow direction of the powder part was assumed to affect the building from the hillside.

In Tab. 5-1, the assigned pressure coefficients are shown for both, wind storm and powder avalanches (ON 2005b). The pressure coefficients $C_{pe,10}$ are related to the probability of occurrence of a 1 in 10 years event and the exposure to a gable roof.

Table 5-1. *Coefficients ($C_{pe,10}$) for the assignment of wind storm and powder avalanches loads impacting gable roofs according to ON (2006a, b), h_1, h_2, b and d refer to the building dimensions outlined in Fig. 5-4.*

		Impact windstorm		Impact powder avalanche	
		h_1/b=0.8 and d/b=0.7		h_2/b=0.5 and d/b=0.7	
		min	max	min	max
Wall area	A	-1.04		-1.0	
	B	-0.74		-0.7	
	D	0.8		0.8	
	E	-0.37		-0.35	
Roof area	F = G	-0.5	0.7	-0.5	0.7
	H	-0.3	0.7	-0.3	0.7
	I	-0.4	0	-0.4	0
	J	-0.5	0	-0.5	0

5.5.4 Snow load

The static snow loads and their distribution were calculated by applying ÖNORM EN 1991-1-3 and the national specifications ÖNORM B 1991-1-3 (ON, 2005b, 2006b). In dependence on the location above sea level and a specific meteorological zonation, the characteristic snow load was calculated with s_k = 2.10 kN/m², representing the averaged local snow conditions in Austria.

The snow load on a gable roof was calculated by using Eq. 5-1, the design coefficient μ_A is dependent on the inclination of the roof and was averaged with 0.8 for an inclination of $\alpha = 30°$. Hence, the resulting snow load s_A equals 1.68 kN/m², while in a second set of calculations, the design load DL1 was modified to include the effect of snowdrift as shown in Fig. 5-5. Design load DL2 assumed a snow drift on the valley side of the roof, and for DL3 snow drift effects on the hillside were taken into account. The resulting snow loads were modified accordingly.

$$s_A = \mu_A \cdot s_k \quad [\text{kN/m}^2] \qquad \text{(Eq. 5-1.)}$$

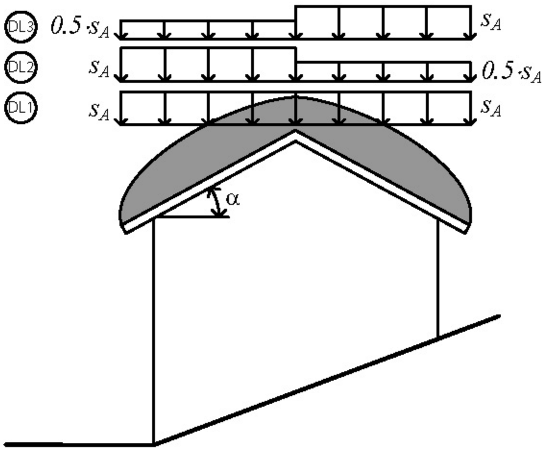

Figure 5-5. *Structural system for snow impacting a building, DL1 = load factor 1, DL2 = load factor 2, DL3 = load factor 3,* s_A *= snow load, α = inclination of the roof.*

5.5.5 Additional loads resulting from natural hazard impact

The building envelope is affected by additional forces resulting from the impact of natural hazard processes such as fluvial sediment transport and snow avalanches. The general impact pressure of flowing masses on obstacles is based on hydrodynamic approaches following Eq. 5-2 Thereby, forces resulting from the impact are considered as stationary and therefore time-independent, and flow velocities are considered as being constant over the flow depth.

The impact of transported solids, such as woody debris and larger boulders, is considered separately due to the higher pressure which affects the building envelope locally in selected areas.

$$p = C \cdot 0.5 \cdot \rho \cdot v^2 \cdot (\sin\alpha)^2 \quad [\mathrm{kN/m^2}] \qquad \text{(Eq. 5-2.)}$$

where, ρ is the density of the fluid, v is the velocity of the fluid, C is the drag coefficient of the circumfluent obstacle, dependent on the type of process, the rheology of process and the geometry of the obstacle (design coefficient).

The angle α is the inclination between the impacted wall (of the building envelope) and the flow direction of the hazard process. If the impacted wall is directed parallel to the flow path, an angle of α = 20° is used as an approximation instead to mirror the occurring forces accordingly. The impact pressure is directed normal to the impacted walls.

If any flowing masses impact an obstacle the additional resistance will increase the flow depth due the backwater effects. This increase in flow depth is approximated by Eq. 5-3 for fluvial sediment transport and Eq. 5-4 for snow avalanches.

$$h_{Stau} = \frac{v_{fl}^2}{2 \cdot g} \quad [\mathrm{m}] \qquad \text{(Eq. 5-3.)}$$

$$h_{Stau} = \frac{v_L^2}{2 \cdot g \cdot \lambda} \quad [\mathrm{m}] \qquad \text{(Eq. 5-4.)}$$

where, v_{fl} is the velocity of the flowing mass, v_L is the velocity of the snow mass, g is the acceleration of gravity, λ is the stowage height coefficient (dependent from flow characteristics of the fluid; dimensionless)

If areas are impacted with an angle α ≠ 90°, a friction tension (shear stress) $q_{fl,\,R}$ (fluvial sediment transport) and $S_{L,\,R}$ (snow avalanches) additionally to the normal force has to be considered (Eq. 5-5 for fluvial sediment transport and Eq. 5-6 for snow avalanches). Thereby, the friction coefficient μ is dependent on the roughness of the impacted wall.

$$q_{fl,R} = \rho_{fl} \cdot g \cdot h_{fl} \cdot \tan\beta \quad [\mathrm{kN/m^2}] \qquad \text{(Eq. 5-5.)}$$

where, ρ_{fl} is the density of fluid, g is the acceleration of gravity, h_{fl} is the flow depth, tan β is the inclination between the impacted wall (of the building envelope) and the flow direction of the hazard process.

$$s_{L,R} = \mu \cdot s_{LF,\alpha} \quad [\mathrm{kN/m^2}] \qquad \text{(Eq. 5-6.)}$$

where, μ is the frictional loss coefficient, $s_{LF,\alpha}$ to be calculated according to Tab. 5-2.

In Tab. 5-2, the overall equations used to calculate the impact pressure of fluvial sediment transport and snow avalanches are provided.

Table 5-2. *Equations used to calculate the impact pressure of fluvial sediment transport and snow avalanches.*

Process	Pressure	Variable	
Fluvial process	$p_{fl,dyn} = c_d \cdot 0.5 \cdot \rho_{fl} \cdot v^2 \cdot (\sin\alpha)^2$ $p_{fl,stat} = \rho_{fl} \cdot g \cdot h_{fl}$ $p_{fl} = p_{fl,stat} + p_{fl,dyn}$	c_d	Drag coefficient
Powder avalanche	$s_{LS} = c_p \cdot c_{LS}(z) \cdot 0.5 \cdot \rho_{LS} \cdot v_{LS}^2 = c_p \cdot s_{LS}(z)$	$c_{LS}(z)$	Powder avalanche coefficient (Issler, 1999)
		c_p	Pressure coefficient
Dense flow avalanche[1)]	$s_{LF,\alpha} = c_d \cdot 0.5 \cdot \rho_{LF} \cdot v_{LF}^2 \cdot (\sin\alpha)^2$	c_d	Drag coefficient

[1)] Surfaces are impacted in normal direction

5.5.5.1 Fluvial sediment transport

Design loads were based on the assumption that a building adjacent to a torrent is affected by flooding with moderate sediment load, and parameters characterizing the fluvial sediment transport are shown in Tab. 5-3.

Fluvial sediment transport results in a pressure on the luvward side (p_{fl}). The impact pressure on the walls parallel to the flow direction (K) were calculated as an area being impacted with an angle of 20° ($p_{fl20,K}$), and an additional frictional tension $p_{fl,K}$ is assumed at these walls (Fig. 5-6). Additionally, woody material transport was assumed at the exposed building wall (q_{efl}), and was considered with a maximum pressure within an area of 0.5 m x 0.5 m.

The design load resulting from DL 1 is presented in Fig. 5-6; and the resulting impact pressures where calculated by applying Eq. 3 and 5 based on the equations provided in Tab. 5-2 and the parameters shown in Tab. 5-3, and are presented in Tab. 5-4.

Table 5-3. *Parameters necessary to calculate the impacts resulting from fluvial sediment transport.*

Parameter		Value	Source
Flow height	h_{fl}	1.0 m	Assumption
Density	ρ_{fl}	1,300 kg/m^3	(Bergmeister et al., 2008; ONR, 2009)
Velocity	v_{fl}	4.0 m/s	(ONR, 2009)
Design coefficient (rectangle)	c_d	1.50	(Egli, 1999)
Design coefficient (splitting wedge)	c_d	1.25	(Egli, 1999)

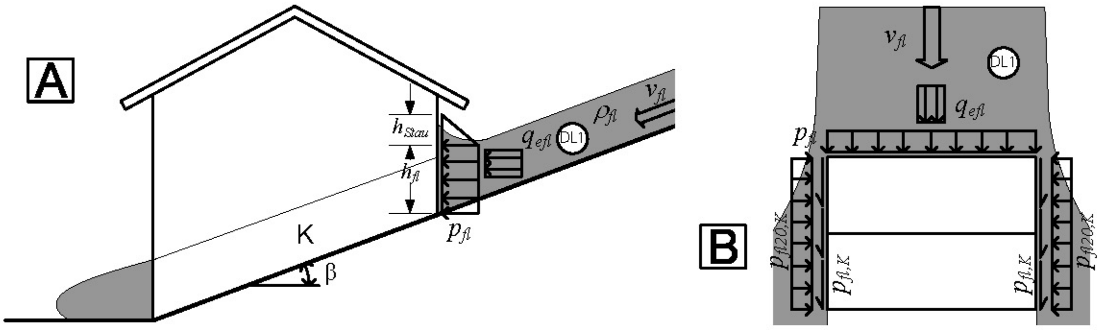

Figure 5-6. *Structural system for fluvial sediment transport impacting a building, DL1 = load factor 1, p_{fl} = pressure on the luvward side, $p_{fl,K}$ = frictional tension, $p_{fl20,K}$ = frictional tension assuming an impact angle of 20°, q_{efl} = impact pressure due to woody material transport, v_{fl} = flow velocity, ρ= density of the fluid, h_{fl} = flow height, h_{Stau} = backwater effects due to Eq. 5-3. A = lateral view, B = top view.*

***Table 5-4.** Impact pressures resulting from the impact of fluvial sediment transport on a building, values are provided in kN/m^2.*

Loads on the walls							
p_{fl}	15.6	$p_{fl,20,K}$	1.82	q_{efl}	288	$p_{fl,K}$	4.64
h_{Stau} = 0.8 m							

5.5.5.2 Snow avalanche

Design loads were based on the assumption of a mixed-type snow avalanche hitting an obstacle, composed from a (dense) flow part and a superimposed powder part (Bründl et al., 2010). The parameters necessary for the calculation of design load are summarized in Tab. 5-5.

The flow part of an avalanche causes a pressure on the luvward side of the obstacle (s_{LF}). The impact pressure on the walls parallel to the flow direction (K) were calculated as an area being impacted with an angle of 20° ($s_{LF20, K}$), and an additional frictional tension $s_{LR,K}$ is assumed at these walls. Additionally, potentially transported material (e.g., boulders, logs) was assumed at the process ward building wall (q_{eLF}), and was considered with a maximum pressure within an area of 0.5 m x 0.5 m (Fig. 5-7).

The design loads resulting from DL1 (dense flow part) and DL2 (powder part) are presented in Fig. 5-7; and the resulting impact pressures were calculated by applying Eq. 4 and 6 based on the equations shown in Tab. 5-2 and the parameters shown in Tab. 5-5, and are presented in Tab. 5-6. Loads incurring in the roof area ($s_{LS,G}$–$s_{LS,J}$) were calculated by applying values from Tab. 5-2 following principles outlined in ÖNORM EN 1991-1-4 (ON, 2005a).

***Table 5-5.** Parameters necessary for the calculation of design loads for mixed-type snow avalanches.*

Avalanche type	Parameter		Value	Source
Dense flow part	Flow depth	h_{LF}	1.5 m	Assumption
	Snowpack depth	h_A	0.5 m	Assumption
	Density	ρ_{LF}	300 kg/m^3	(ASTRA, 2007; ONR, 2007)
	Velocity	v_{LF}	20 m/s	(Bozhinskiy and Losev, 1998)
	Drag coefficient (rectangle)	c_d	2.0	(Egli, 1999)
	Drag coefficient (splitting wedge)	c_d	1.5	(Egli, 1999)
	Dimensionless coefficient due to flow characteristics	λ	1.5	(Egli, 1999)
	Friction coefficient	q	0.3	(Egli, 1999)
Powder part	Flow depth	h_{LS}	Exceeding obstacle height	Assumption

	Density	ρ_{LS}	20 kg/m³	(ON, 2006c; ONR, 2007)
	Velocity	v_{LS}	40 m/s	(Bozhinskiy and Losev, 1998)
	Powder avalanche coefficient	$c_{LS}(z)$	2	(Issler, 1999)

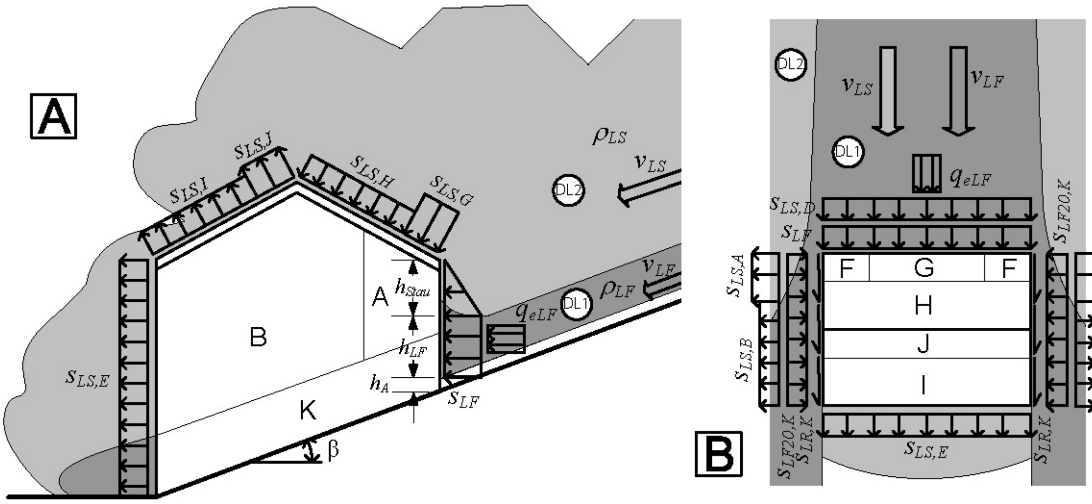

Figure 5-7. *Structural system for snow avalanches impacting a building, DL1 = load factor 1 (flow part) and DL 2 = load factor 2 (powder part), Flow part:* S_{LF} *= pressure on the luvward side,* $S_{LR,K}$ *= frictional tension,* $S_{LF20,K}$ *= frictional tension assuming an impact angle of 20°,* q_{eLF} *= impact pressure due to woody material transport,* v_{LF} *= flow velocity,* ρ_{LF}*= density of the fluid,* h_{LF} *= flow height,* h_{Stau} *= backwater effects due to Eq. 5-4.,* h_A *= height of the initial snow cover, Powder part:* $S_{LA\ldots J}$ *= load on the respective Section A…J,* v_{LS} *= flow velocity,* ρ_{LS}*= density of the fluid, A = lateral view, B = top view.*

Table 5-6. *Impact pressures resulting from the impact of a mixed-type avalanche on a building, values are provided in kN/m*^{2}*.*

Loads on the walls				Loads on the roof		
					min	max
s_{LF}	120	$s_{LS,A}$	-32	$s_{LS,F}$	-16	22.4
$s_{LF,20,K}$	14	$s_{LS,A}$	-32	$s_{LS,G}$	-16	22.4
q_{eF}	400	$s_{LS,B}$	-22.4	$s_{LS,H}$	-9.6	22.4
$s_{LR,K}$	4.2	$s_{LS,D}$	25.6	$s_{LS,I}$	-12.8	0
$s_{LS(z)}$	32	$s_{LS,E}$	-11.2	$s_{LS,J}$	-16	0
h_{Stau} = 13 m						

5.6 Prototype

Taking into account the loads on the building envelope outlined in the previous section, a prototype for a contemporary reinforced building was developed. This prototype represents a typical alpine residential building in the European Alps. Due to topographical constraints, residential buildings in mountain areas of Europe are commonly constructed in a hillside situation. The characteristic building includes a basement as well as first floor (ground floor) and second floor (upper floor). The average effective floor space equals 70 m², which amounts to approximately 210 m² in total (see Fig. 5-8). Supporting walls consist of masonry while the baseplate and the ceilings are constructed from reinforced concrete, respectively. Timber is used for the roof truss, as well as the frame connectors for windows and doors. The roof truss is covered by copper sheet; the roof area is of projecting type in order to better protect the outside walls. Due to the hillside situation, the basement serves usually as a quasi-first floor towards the valley. At the hillside, light wells are installed to allow for a utilization of the basement.

The possible loads due to hazardous events outlined in the previous section will result in several shortcomings of these typical residential buildings with respect to the design of their envelope:

(1) Due to the process characteristics of fluvial sediment transport and snow avalanches, openings generally weaken the static resistance and stability of any wall. Moreover, they are a probable location for intrusion of material such as debris, water, and snow masses, above all due to the inherent material weakness of doors and windows.

(2) If the material has been deposited in the interior of the building, an additional static load on ceilings and walls will occur.

(3) With respect to torrent processes erosion initiated by surface runoff alongside the walls and as a result from possible shifts in the channel bed may lead to a scouring of the baseplate.

(4) An overstrain of the sewage system associated with extraordinary flood discharge may cause back water effects in the sewage pipes of the building and, as a result, cause flooding from inside.

(5) With respect to snow avalanches, a projecting roof is considered susceptible to damage due to the occurring pressure gust and suction effects which result from the velocity of the powder part of the avalanche.

As a consequence, a necessary mitigation concept has to be developed taking into account these shortcomings. This concept, referred to as local structural protection, has necessarily to be adjusted to the appearing loads.

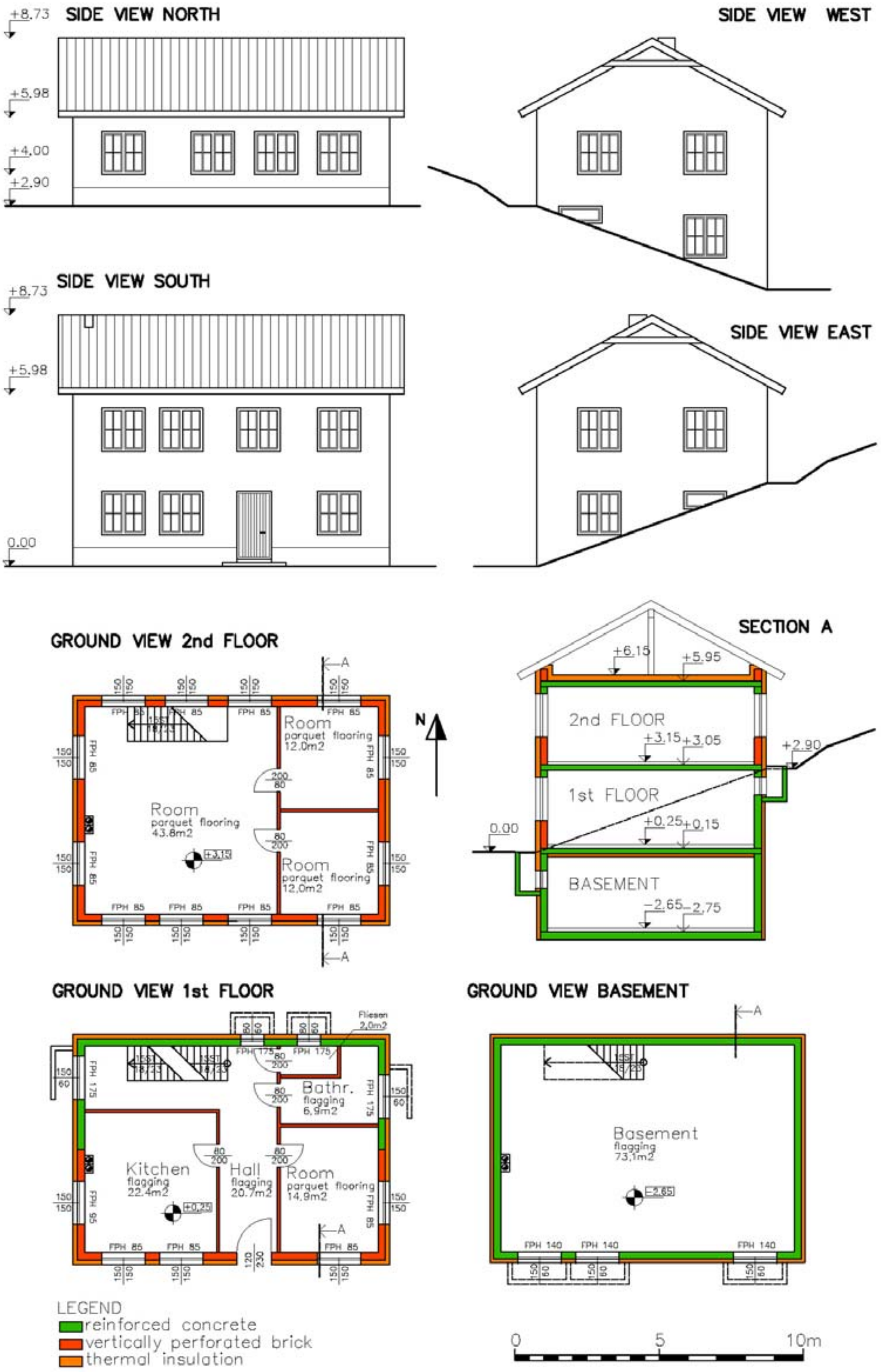

Figure 5-8. Prototype building representing a typical alpine residential building.

Mitigation by local structural protection measures can be distinguished and classified in various ways, i.e., according to the applicability for protection against the hazard process, the location with respect to the protected object, as well as the type of construction and construction materials used (Holub and Hübl, 2008). Furthermore, local structural protection can be performed either in terms of a structural reinforcement of an existing building envelope, or in terms of a construction design comprehensively adapted to possible loads of a new construction. Thereby, constructive measures can either be physically connected to the building envelope (e.g., a reinforced window shutter), or the envelope as a whole could be adopted (e.g., by removing any window openings at the exposed building side). Furthermore, a construction directly adjacent to the building envelope could be performed (e.g., an avalanche splitting wedge not connected to the building envelope). However, the overall aim is to develop a cost-efficient and protection-effective solution (Holub and Fuchs, 2008) that simultaneously fulfils the requirements of a formal aesthetic standard.

5.6.1 Structural reinforcement of the building

The structural reinforcement of any building in terms of increased protection against the impact of natural hazard processes (i.e., fluvial sediment transport and snow avalanches) can be achieved by different constructive approaches. In this section, possible adaptations will be presented with respect to reinforcement of the foundation, the structural levels (first and second floor), the roof construction, as well as with respect to additional design elements such as building openings, or mobile protection elements (see Tab. 5-7 and Fig. 5-9).

A major protective effect regarding possible settlements of the entire building, which may occur due to erosion originating from torrent processes, includes the construction of a base plate instead of a strip foundation; a measure that is obviously suitable to increase the overall stability.

Furthermore, the basement should be waterproofed by a sealed type of construction obtained by the use of waterproofed concrete, including the sealing of penetration such as pipes and infrastructure facilities. Light shafts implemented should exceed the expected possible flood level in order to prevent the intrusion of liquids and solids into the interior. Moreover, a backflow flap installed in the sewage system effectively prevents the effects of possible capacity overload of the drainage.

The first floor is particularly susceptible to any type of external impact resulting from torrent processes and snow avalanches, i.e., the additional dynamic as well as static pressure towards the outer walls caused by the medium, and pressure peaks originating from transported solid particles (woody debris, boulders). Therefore, process-side outer walls should be either retrofitted in case of existing structures (e.g., by an additional concrete shell) or constructed from reinforced concrete instead of brick masonry in case of a new construction.

Table 5-7. *Possible local structural mitigation measures for a reinforcement of the building, the effectiveness is indicated by x = very effective, (x) = effective and - = not effective; and the suitability for the upgrading of existing buildings is indicated similarly.*

Local structural protection measure	Type of measure	Effective for		Suitable for	
		Avalanche	Flood	Upgrade	New building
Foundation	Base plate foundation	(x)	x	-	x
Basement	Waterproofed concrete	-	x	-	x
	Enhancement (raising) of light shafts above flood level (flow depth) and sealing of all wall penetrations	(x)	x	x	x
	Backflow flaps in sewage pipes	-	x	(x)	x
First (and second) floor	Reinforcement of the supporting structure (walls, ceilings …)	x	x	(x)	x
Roof	Reinforcement of the roof, avoidance of eaves	x	-	(x)	x
Building openings	Decrease of the amount and area of windows and implementation of avalanche safe windows and/or heavy shutters	x	(x)	x	x
	Implementation of temporarily preventive measures such as mobile stop logs at (at least) the openings exposed towards processes (windows, doors, gates)	(x)	x	x	x

With respect to the roof construction, eaves should be avoided to increase the resistance of the structure against pull resulting from avalanche processes. Furthermore, an overall strengthening is recommended to resist heavy snow loads; however, this is regularly prescribed in the local building codes.

As an overarching framework, any building openings should be avoided on the process-oriented (impacted) building walls. If this is not possible due to architectural or esthetical constraints, the building openings have to be reduced in number and size, and any openings at ground surface level should be eliminated. If necessary, specially reinforced multilayer window glass, window frames and fittings are available to protect against the considerable impact pressure of hazard processes, i.e., snow avalanches. A combination with window shutters mounted at the exterior of the wall instead within the window frame complements these suggestions.

Additionally, mobile elements may protect building openings from the intrusion of material; however, such elements necessarily have to be stored nearby an endangered object in order to guarantee availability during an event.

__Figure 5-9.__ Prototype building representing a typical reinforced alpine residential building.

5.6.2 Constructive measures adjacent to the building

Apart from a structural reinforcement, the protection of any building exposed to natural hazards can be supplemented by constructive measures adjacent to these elements at risk. Besides, such measures are also appropriate to exposed constructions where either a structural reinforcement is not possible (e.g., due to financial limitations or restrictions due to monument conservation) or only possible with extraordinary efforts. In this section, a respective measure is presented in detail by taking avalanche splitting wedges and combinations between deflection dams and walls as an example (see Tab. 5-8).

A splitting wedge has a triangular shape and is generally located at the process-oriented side of a building exposed. While the vertex is directed towards the run-out area, the sides are designed in such a way that the gravitational mass movement directed downslope (e.g., a snow avalanche) is split and deflected into an area which is to be kept free of elements at risk. As a result, damage to the exposed building will be prevented. The main criterion for an effective operation of such a structure is a stable anchoring and an adequate height of the construction in order to avoid an overtopping. Furthermore, the width of a splitting wedge has to be dimensioned large enough in order to avoid any erosional as well as shearing forces to the side walls of the building to be protected. Splitting wedges are considerable effective in deflecting dense-flow avalanches and are frequently designed as a combination of heavy rip raps and earth-filled dams. As an alternative, reinforced concrete may be used for construction, while is such cases splitting wedges may also be constructed in direct connection to the exposed object (Fig. 5-10).

Table 5-8. *Possible local structural mitigation measures adjacent to the building, the effectiveness is indicated by x = very effective, (x) = effective and - = not effective; and the suitability for the upgrading of existing buildings is indicated similarly.*

Local structural protection measure	Effective for		Suitable for	
	Avalanche	Flood	Upgrade	New building
Splitting wedge (hill side exposure)	x	(x)	x	x
Deflection walls and dams	x	(x)	x	x

A deflection wall is designed following the same principles of protection, and is repeatedly used to protect an entire building ensemble from the impact of medium-magnitude events (Fig. 5-11). However, since the overall height is occasionally smaller than the height of a splitting wedge, the endangered objects may not entirely be protected and a residual exposure may remain.

Figure 5-10. *Splitting wedge directly connected to the exposed object (Davos Frauenkirch, Switzerland).*

Figure 5-11. *A deflection wall used to protect an entire building ensemble from the impact of medium-magnitude events (Galtür Tschafein, Austria)*

5.7 Expenses necessary for local structural protection

Within this section, a prototype of residential building adapted to mountain hazard processes is presented based on the design needs outlined above. This prototype is based on the modern residential building typical for the European Alps and is equipped with various constructional elements which are able to resist the impact forces of hazardous events, i.e., fluvial sediment transport, and snow avalanches. The amount of construction costs are opposed to the additional expenditures necessary for an adapted design. The price basis is related to the average standard construction prices in Austria, which equals approximately the price indices in European mountain regions. The sets of calculation are based on net prices and neglected the sales tax; therefore, the results are in principle applicable to other countries with different taxation systems.

Due to the design loads necessary for the implementation of different local structural protection measures, the average construction costs are above the costs for unprotected buildings. Nevertheless, the ratios differ for individual measures as shown in Tab. 5-9. While the additional expenditures for the construction of a structural slab amount to an increase of one-third, and the implementation of avalanche-proof windows result in an increase of two thirds (calculated in terms of the individual costs needed for this respective measure), the reduction of eaves leads to a decrease in construction costs of approximately 16 %. In total, the design adaptation of the prototype building under consideration leads to an increase in construction costs of 8 %, compared to an unprotected standard building.

In addition, expenses for a necessary splitting wedge were calculated as an example for an enclosing protection structure not physically connected to the building (Fig. 5-12).

Table 5-9. *Relative increase in construction costs if local structural mitigation is implemented.*

Measure	Increase in construction costs compared to the respective standard version [%]
Reinforcement of the hillside outer wall	+17
Reinforcement of the structural slab	+30
Reinforcement of the truss	+10
Reduction of eaves (decrease in roof area)	-16
Avalanche-proof window and window shutter	+67
Above flood-level light shafts	+23
Total costs of the prototype reinforced building	+ 8

The calculation included the necessary expenses for concrete including armoring, earth fill, interlocking, and landscaping. The major advantage of a splitting wedge, compared to the conventional local structural protection, is the feasibility of retrofitting to an already existing building without any necessary structural intervention. However, splitting wedges require space, and are therefore not appropriate to every location. The expenditures necessary for a splitting wedge protecting the typical alpine residential building in the European Alps amounted to approximately € 72,000, and are therefore more than four times as much as the total expenditures for local structural protection measures outlined above (35 % of the average construction costs for a standard non-reinforced building in Alpine areas).

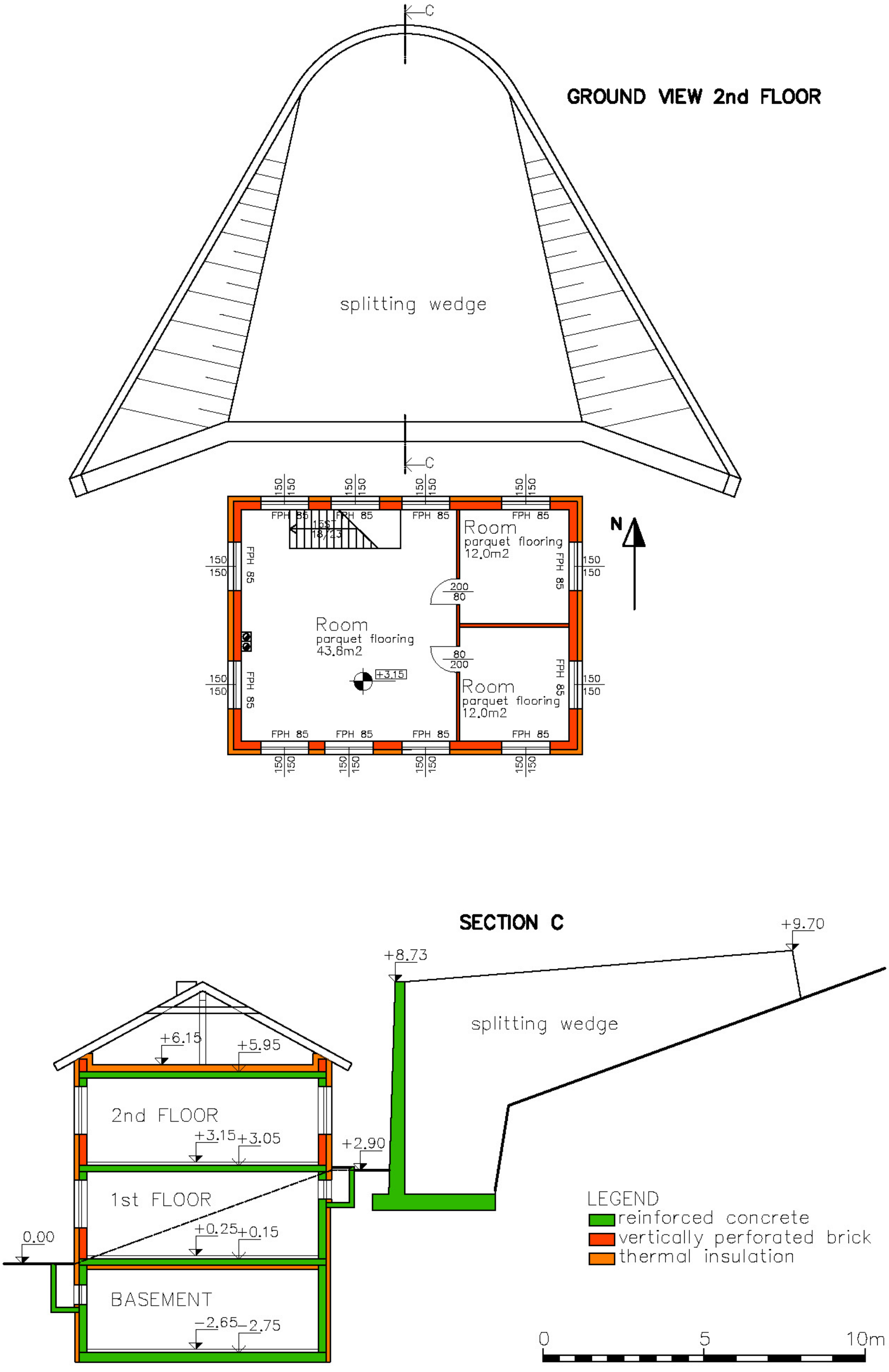

Figure 5-12. *Splitting wedge to protect a building against the impact of snow avalanches.*

5.8 Conclusion

Losses due to natural hazards in European mountain regions were considerably high, even though an increase in absolute figures cannot necessarily be proven for the period since 1950 (Fuchs and Bründl, 2005; Fuchs, 2009). In parallel, the arising discussion related to possible impacts of climate change on the magnitude and frequency of mountain hazards (Keiler et al., 2010) resulted in a rising scientific debate on the spatiotemporal evolution of elements at risk exposed (e.g., Hufschmid et al., 2005; Fuchs and Bründl, 2005; Keiler et al., 2006). As a consequence it may be postulated that risk awareness of the general public and administrative bodies responsible for hazard protection has risen (Commission of the European Communities, 2007). Accordingly, the traditional engineering approach of mitigating hazard processes directly in the release areas of individual catchments, e.g., by designing snow rakes in avalanche starting zones and retention barriers in torrent channels, were supplemented by technical structures in the run-out areas, e.g., retention basins (Holub and Fuchs, 2009). However, it had been shown that such structures have to be supplemented by passive mitigation concepts such as hazard mapping to reduce an exposure of elements at risk to hazards, a hypothesis that is rooted in very influential earlier works from the practitioners side (e.g., de Crécy, 1980; Frutiger, 1980; Hackett and Santeford, 1980; Hestnes and Lied, 1980; Ives and Plam, 1980).

Nevertheless, neither conventional structural measures, which influence both, the magnitude and frequency of events, nor passive mitigation concepts can guarantee reliability and complete safety. Therefore, the concept of local structural protection was developed (Egli, 1999; Holub and Hübl, 2008). This concept has been proven to be very cost-efficient (Holub and Fuchs, 2008); above all, since the required expenditures do not necessarily have to taken over by the general public. However, until now only little information was available on the absolute height of investments needed for such measures on the local scale.

Taking these findings as a basis, a prototype of residential building typical for European mountain regions has been presented. Based on possible design loads, this prototype was further equipped with different local structural protection measures in order to resist the impact forces of torrent hazards and snow avalanches. The underlying structural modifications were calculated based on information from the Austrian construction industry and the insurance business. As a result, it had been shown that the adaptation of the standard building would result in an increase in construction costs of below 10 %.

In absolute number, the increase in construction cost due to the implementation of structural mitigation outlined above amounts to approximately € 17,000. If this amount is compared to available data related to direct losses resulting from torrent events and snow avalanches, the savings potential becomes obvious.

The average direct loss per torrent event in Austria equals € 170,000, regardless of whether or not one building or a group of buildings suffered damage (in 2010 values, Fuchs, 2009); whereas in the years with a considerable number of high-magnitude and low-frequency torrent events, the average loss, of buildings being affected, at the individual building level equals € 85,000. In parallel an analysis of losses due to mountain hazards in Eastern Switzerland resulted in an approximated damage of € 6,000 (including the so-called frequency damages resulting from low-magnitude but high-frequency events, Fuchs and Bründl, 2005). A similar order of magnitude resulted from an analysis of the 2005 flood events in Austria, where the average damage per claimant was € 21,000 on average (Habersack et al., 2004). With respect to snow avalanches, the average loss per claimant amounted to € 17,500 in Eastern Switzerland (Fuchs and Bründl, 2005).

Comparing the results of our study with such data clearly proved the potential for local structural protection; depending on the data set, an investment of approximately € 17,000 is at least able to prevent the effects of low-magnitude but high-frequency torrent processes (amounting to € 8,000 on average, Oberndorfer et al., 2007). With respect to higher-magnitude torrent events, it has to be assumed that at least a considerable portion of the average of € 85,000 per damaged building will be prevented, and a respective decrease in loss has to be assumed. With respect to snow avalanches, the investment in local structural protection equals the average loss, which in turn implies that such average loss can be effectively prevented by local structural protection.

Within the overall context of managing natural hazard risk, local structural protection aims at reducing the structural vulnerability of buildings exposed due to a reduction of design loads on the building envelope and due to a prevention of material intrusion through building openings protected. As a result, the resilience towards low-magnitude and high-frequency events can be enhanced, leading to less economic vulnerability of values at risk exposed (Fuchs, 2009). An increased economic resilience, in turn, will put a lesser burden on the public funds necessary, since due to missing overarching insurance systems in Austria the competence of compensating losses that incurred due to natural hazards is allocated on the level of federal states (Holub and Fuchs, 2009).

Nevertheless, in some decision contexts one approach to reduce vulnerability is likely to be more effective than another, whereas in other decision contexts a combination may also be appropriate. To give an example, for some buildings located in avalanche run-out areas local structural mitigation (e.g., splitting wedges) to be born by the home owner will be the most promising (and cost-effective) measure to reduce damage, while for other buildings and given another topographic setting the provision of risk sharing mechanisms by obligatory insurance solutions will be most efficient. Often a combination of both will be more successful in reducing the individual and collective risk than only one mitigation alternative (Fuchs et al., 2007c). Effective planning for and response to hazards requires that the vulnerability associated with specific social and decision processes be understood in parallel with understandings of probabilities of occurrence leading to physical vulnerability. Thus, judgements can be made about the appropriate balance between different management options. Apart from such academic concerns, methods to reduce vulnerability to natural hazards may include innovative approaches of risk sharing, as discussed in Holub and Fuchs (2009). Thereby, legislation, loss compensation and risk transfer are accompanied by the overall aim to increase risk awareness and to implement a sustainable and long-term land use planning.

6 Conclusion

Natural hazards and their effects on the society – specified as disasters if the effects exceed a certain threshold – evoke numerous challenges. Since the late 1980s the international community meets these challenges with different international frameworks of actions in order to reduce the adverse effects of hazardous events to society (United Nations General Assembly, 1989, 2000; UN, 2005). In spite of these international efforts, world-wide trends show an increasing number of natural hazard events and increasing losses to housing and local infrastructure. On the regional level, recent natural hazard events in the European Alps (e.g., floods 2005; Keiler et al., 2010) also resulted in considerable economic direct and indirect losses, as shown by Hübl et al. (2011) for the Austrian Alps and Hilker et al. (2009) for the Swiss Alps. Nevertheless, information on loss trends has to be evaluated carefully as loss data are besides altering hazard pattern due to climate change influenced by socio-economic changes (increasing standard of living, real per capita wealth) and management efforts since the 1900s. Despite applying natural hazard and risk management strategies (Hübl et al., 2009) and stimulating the research by the international framework of action, our society is still challenged by damaging events with different frequencies and magnitudes. Thus, management efforts will continuously remain demanding, and should include the hazard assessment, the assessment of possible effects of the hazards on elements at risk exposed, as well as the assessment of vulnerability.

It was shown in Chapter 2 that in Austria, a long tradition exists in dealing with mountain hazards, in particular with respect to the analysis of hazard potential, the related assessment of design events and the planning and implementation of constructive mitigation, forest-biological mitigation, and mitigation by spatial planning. As a supplement to these concepts, local structural protection was introduced as – on the one hand – a well established means to locally reduce the impact of a hazard process to individual buildings, such as earth mounds and stone walls originating from the Mediaeval Age, and – on the other hand – an innovative measure with a with a full panoply of possibilities, including the temporal sealing of building openings or the static separation of different storeys of a building by means of hydraulic rams.

Since only a limited amount of studies was available so far with respect to the characterisation of local structural protection, in particular with respect to different types, designs and materials used, there was a particular gap on economic aspects of such measures. Therefore, in Chapter 3, general aspects of costs and benefits associated with local structural protection were addressed; and it was shown that local structural mitigation in principal is a very cost-effective possibility to reduce the impact of mountain hazards on the building envelope, and to prevent material intrusion through building openings.

According to these findings, a catalogue of local structural measures was presented in Chapter 4 with respect to occurring process impacts and protection objectives. Thereby, different local structural measures were classified and recommended according to a possible implementation for new buildings and for upgrading existing buildings, respectively. Based on these recommendations, future needs for a sustainable and comprehensive reduction of risk in settlement areas endangered by mass movements were outlined.

Local structural protection can be either performed as enclosing structure or as structure directly connected to the building. Measures surrounding the object at risk seem to be more effective since they prevent immediate impacts on the building shell, while structures directly implemented at the building shell are generally less space-consuming. In Chapter 5, the effects of local structural protection in reducing the susceptibility of elements at risk, and the associated consequences with respect to a reduction of structural vulnerability were quantified for a prototype of residential building adapted to mountain hazards. This prototype was equipped with various constructional elements to resist the incurring impact forces, i.e., of fluvial sediment transport and of snow avalanches. According to possible design loads emerging from these hazard processes, the constructive design necessary was presented, and the amount of additional costs required for such an adaptation was quantified. By comparing these costs with quantitative loss data it was shown that adapted building design is particularly effective to reduce the consequences of low-magnitude high-frequency events in mountain regions.

In the following section, some general conclusions to answer the initially formulated hypotheses are drawn based on the issues outlined in Chapters 2 to 5.

6.1 Legislation, risk transfer and awareness building

It was proposed that the legal situation in Austria with respect to hazard and risk assessment and mitigation does not sufficiently take into account mitigation measures other than technical mitigation and land-use. Therefore, it was concluded that local structural protection may not be mirrored accordingly, consequently, the respective awareness seems to be not built, and incentives for the implementation of such measures seem to be outstanding.

Embedded in the overall concept of integral risk management, mitigating mountain hazards is pillared by legislation, risk transfer, and information as a means to raise public awareness. It had been shown that the legal framework of dealing with such hazards in Austria is not yet fully acknowledging temporal dynamics in process pattern and process trajectories, leading to temporal as well as spatial risk peaks. In particular the current spatial planning legislation in Austria does not mirror accordingly these issues, mainly due to the relatively long time interval of land-use planning activities which result in regulations that are relatively static over time. Furthermore, it had been argued that modifications in land use regulations are restricted to a minimum to ensure the required stability of the law, but they should include the prescription of local structural protection in order to create more disaster-resilient communities.

Disaster-resilient communities in general need risk transfer mechanisms in order to reduce the societal effects of disaster losses. It had been shown that these risk transfer mechanisms should be based on economic incentives of risk-minimising behaviour. By taking the current system of governmental aids due to the disaster fund act as an example, shortcomings concerning a risk-minimising behaviour were highlighted. As a result of these shortcomings, suggestions for an adjustment of the current compensation scheme in Austria were made, and a system of (mandatory) extension for property insurers in Austria by a natural hazard package was discussed. Such insurance should be based on premiums charged commensurate with the risk in order to avoid adverse selection. Furthermore, individual precaution measures undertaken, such as the implementation of local structural protection, should be acknowledged and should therefore result in reduced premiums.

To complement such incentives information on hazard and risk for a specific location has to be delivered target-oriented to the stakeholder involved, e.g., by means of tailored risk maps such as prescribed in the *Directive on the Assessment and Management of Flood Risks*. The consequences resulting from mountain hazards are strongly related to the behaviour of the population in endangered areas, and the behaviour is closely connected to the amount of information accessible. Therefore, apart from adopted information strategies, the overall policy to inform the population due to good governance principles has to be strengthened, an issue that re-emerged only recently as risk governance paradigm.

It was concluded that an interaction between the legal framework, the possibilities of risk transfer, and increased risk awareness is essential for efficient disaster risk reduction. Coping strategies in Austria should be adjusted to these premises, and in particular the implementation of local protection measures has to be strengthened legally, institutionally, and economically.

6.2 Benefits of local structural protection

It had initially been hypothesised that local structural protection is generally very effective in comparison to conventional technical mitigation, in particular with respect to high-frequency low-magnitude events. However, this effect has not been sufficiently addressed so far, especially according to the potential of local structural protection to supplement conventional approaches in order to reduce small and medium-size losses.

Apart from land-use planning, mitigating mountain hazards is based on a combination of different preventive measures (cf. Tab. 1-1). These can be classified in permanent and temporal measures on the one hand, and structural measures as well as organisational measures on the other hand. Consequently, different measures ideally complement each other, whereby a focus on structural measures in the starting zones of hazard processes and land use planning activities in the run-out zones is detectable in Austria. Until now, the performance of local structural measures – and in particular their benefits arising from an economic point of view – had often be neglected or even ignored so far. To overcome this gap, a study was undertaken aiming at the quantification of costs and benefits of local structural protection in comparison to possible conventional technical mitigation.

A standardised cost-benefit analysis was applied within a catchment using an ex-ante perspective. As mitigation alternatives a set of measures was assumed to be implemented; (a) a concept of conventional mitigation based on the implementation of torrential structures, and (b) a concept of local structural protection for buildings located in endangered areas. By comparing costs and benefits of these two alternatives, considerable different benefit-cost ratios were obtained, depending on a relatively high amount of investments necessary for conventional mitigation and a relatively small amount of values at risk to be protected. Nevertheless, local structural measures showed benefit-cost ratios > 1, even if the protective effects of local structural measures are limited to a certain threshold of process magnitudes, i.e., a deposition height of approximately 0.7 m for torrent processes. Thus, it had been shown that cost-benefit analyses are very case-sensitive, and results are hardly transferable between different test sites.

However, local structural protection had proven to be a serious approach in mitigating mountain hazards. Comparing costs of local structural protection with those of conventional mitigation measures, a significant potential for saving future public expenditures exists, not only because such measures usually have to be funded and implemented by the private households, but also due to the overall less amount of investments necessary for local structural protection. Consequently, the concept of local protection should be embedded within the framework of possible management strategies. However, the decision will often be a political one, as shown in recent years when the height of public investments was somehow correlating with the public performance of (local) politicians in communities experiencing losses from mountain hazards (e.g., the 1999 avalanche events and the 2005 flood events in the Austrian Alps). Therefore, further studies have to be carried out in order to promote local structural protection as a cost-efficient alternative or supplement to conventional technical mitigation, and to support the implementation of respective protection strategies with respect to buildings and infrastructure exposed.

6.3 Local structural protection: the state of the art

It was supposed that while for some hazards, information on possible local structural protection is available, such information is not available so far for the entire variety of mountain hazards. Hence, it had to be assessed which range of local structural mitigation is available and suitable for reducing the effects of mountain hazards on the building envelope, and which measures could be implemented during new developments or in order to retrofit already existing buildings.

The ability to manage the challenge of promoting local structural protection was addressed extensively by discussing the state of the art with respect to local structural protection measures. Starting with early attempts of local structural protection in settlements of Austria, some of them even tracing back to the Mediaeval Age, an overview on the history of mitigation concepts was given. This history was not only driven by changes in the cultural dimension of hazard prevention, but also by the development of new construction materials and techniques that resulted in increasingly sophisticated design principles of such measures. For multiple types of mountain hazards possible measures were listed and categorised according to organisational, technical, and structural issues. Moreover, different construction materials and techniques were assessed according to their ability to resist different impact patterns of different hazard types. The multiplicity of solutions for the protection of both, new buildings and the existing inventory was addressed. Since effective local structural measures are the result of systematic hazard analyses and aim at the reduction of vulnerability of elements at risk exposed, the importance of local structural measures was related to the concept of conventional mitigation on the one hand and the implementation of land-use planning on the other hand.

The presented catalogue of local structural measures included an overview on possible types of measures and may therefore become a valuable tool to decrease the exposition of elements at risk exposed and consequently their susceptibility to the impact of mountain hazards.

6.4 Local structural protection: adapted building design

Compared to conventional mitigation, it has been repeatedly but vaguely assumed that local structural protection is particularly cost-effective if mean annual losses resulting from mountain hazards are opposed. Nevertheless, this assumption has not been proven so far with respect to mountain hazards.

Taking the findings outlined above as a starting point, a prototype of a residential building with an adapted building design has been presented. Based on possible design loads, this prototype was equipped with different local structural protection measures in order to resist the impact forces of torrent hazards and snow avalanches; both of these hazard types had proven to occur most frequently in Austria and therefore they caused the majority of losses during the last decades. The structural modifications necessary were quantified based on information from the Austrian construction industry and the insurance business. It had been shown that the adaptation of the standard building would result in an increase in construction costs of below 10 %. In absolute number, the increase in construction cost due to the implementation of structural mitigation outlined above amounted to approximately € 17,000. If this amount was compared to available data related to direct losses resulting from torrent events and snow avalanches, the savings potential became obvious.

Comparing these results with loss data the potential for local structural protection was clearly proven. Depending on the data set, an investment of approximately € 17,000 will at least be able to prevent the effects of low-magnitude but high-frequency torrent processes (amounting to € 8,000 on average). As a result, the resilience towards low-magnitude and high-frequency events can be enhanced by local structural protection. With respect to higher-magnitude torrent events, it has to be assumed that at least a considerable portion of the average of € 85,000 per damaged building will be prevented, and a respective decrease in loss has to be assumed. With respect to snow avalanches, the investment in local structural protection equals the average loss, which in turn implies that such average loss can be effectively prevented by local structural protection.

6.5 Discussion

Within the overall context of managing natural hazard risk, local structural protection aims at reducing the structural vulnerability of buildings exposed due to a reduction of design loads on the building envelope and due to a prevention of material intrusion through building openings protected. It had been shown in this thesis that local structural protection is an effective and cost-efficient measure, and that it is suitable to strengthen both, newly constructed buildings as well as existing buildings that have to be retrofitted. As a result, the resilience towards low-magnitude and high-frequency events can be enhanced, leading to less economic vulnerability of values at risk exposed (Holub et al., in press). An increased economic resilience, in turn, will decrease the public funds necessary, since due to missing overarching insurance systems in Austria the competence of compensating losses that incurred due to natural hazards is allocated on the level of federal states (Holub and Fuchs, 2009).

Thereby, in some decision contexts one approach to reduce vulnerability is likely to be more effective than another, whereas in other decision contexts a combination may also be appropriate. To give an example, for some buildings located in avalanche run-out areas local structural mitigation (e.g., splitting wedges) to be born by the homeowner will be the most promising (and cost-efficient) measure to reduce loss, while for other buildings and given another topographic setting the provision of risk sharing mechanisms by insurance solutions may be most efficient (Holub and Fuchs, 2009). Often a combination of both will be more successful in reducing the individual and collective risk than only one mitigation alternative (Holub et al., 2011), and a portfolio of (cost-efficient) measures can be combined into a bundle to address a considerable part of the identified risk if the economic benefits outweigh the incurring costs.

In general, the concept of local structural protection is suitable for any application, and can therefore be implemented for both, similar process types in different environmental settings and similar constructions to reduce the effects of different process types (Fig. 6-1 and 6-2).

Figure 6-1. *Elevated buildings for protection against water related hazards; spring tides at USA (left), torrent processes at Austria (middle) and permafrost-induced ground movement at Russia (right). Source: left and middle by S. Fuchs; right from http://bopohex.wordpress.com*

Figure 6-2. *Strengthening of objects against flood at Netherlands (left), debris flow at Taiwan (middle) and dense avalanches at Austria (right). Source: middle by S. Fuchs*

Within the framework of risk management the optimum level of protection is usually achieved by combining different preventive strategies such as conventional technical mitigation, local structural protection, spatial planning, and organisational measures. It has been discussed in this thesis that local structural protection has therefore a high potential within the concept of risk management, in particular when these measures are combined with land-use regulations. As such, the safety problem should not be addressed by individual measures alone. When the full variety of possible mitigation alternatives is addressed, the threat can be minimised by either active or passive measures, as extensively discussed in Chapter 1. While by active measures, the probability of occurrence, or, more precise, the exceedance probability, will be reduced, passive measures are targeted at a reduction of the effects on the elements at risk exposed. Consequently, local structural protection may also result in a fundamental decrease in risk towards a tolerable level.

Tolerable risk is, by definition, never fully accepted but mirrors a level of exposure that a society is prepared to live with because there are net benefits in doing so, as long as the risk is monitored and controlled and action is taken to reduce it. Acceptable risk represents a level of exposure that a given community is prepared to accept without imposing risk reduction measures (Crozier, 2005). Hence, risk should be kept as low as reasonable practicable, which is referred to as the ALARP-principle. Consequently, the aim of risk management is not to eliminate hazards but to reduce threats to an acceptable level which is compatible with other socio-economic demands of the society (Renn, 2008a, b). However, the definition of the level of tolerable or acceptable risk, and therefore a threshold of reasonability, is substantially driven by economic valuation in alpine countries (for related discussion, see Fuchs and McAlpin, 2005; Holub and Fuchs, 2008). If the net benefit of a measure to reduce risk is equal or higher than the cost, risk reduction is implemented. Hence, an economic basis is adopted to support societal and political decision making on the acceptability of natural hazard risk in the Alps.

However, it has – and from a multidisciplinary point of view justifiably so – been claimed by different authors that the technical concept of risk management focuses too narrowly on the probability of events and the magnitude of specific consequences (Kasperson et al., 1988). The usual multiplication of hazard, values at risk, and vulnerability results in expected values similar for low-consequence/high probability risk and high-consequence/low-probability risk. As a result, it may only be preferable to use technical risk analyses for a relative comparison between a set of alternatives or different temporal evolution and spatial trajectories, rather than to argue by using the results with respect to an absolute level of risk to be accepted within any affected community. This was comprehensively discussed by Kasperson et al. (1988), and in an extended form by Pidgeon et al. (2003). Risk acceptance, though, is inherently linked to the individual and public perception of risk. Public perceptions, however, are the product of intuitive biases and economic interests and reflect cultural values more generally (Kasperson et al., 1988). Therefore, the need to use risk analysis to design public policies on the one hand, and the inability of the current risk concepts to anticipate and explain the nature of public response to risk on the other hand provides a certain dilemma in natural hazard risk management. Nevertheless, a deeper understanding of individual factors contributing to the level of risk individuals or the society are exposed will enable responsible stakeholders to increasingly acknowledge public perceptions in mitigating natural hazards by taking a holistic perspective. Insofar, natural hazard risk assessment and management has experienced extensive development during the last decades. Drawing from many fields, the interdisciplinary risk assessment field became institutionalised in European mountain regions by initiatives such as the *International Research Society INTERPRAEVENT* and the establishment of the *Alpine Convention*, as well as by the implementation of respective European regulations on the national level, such as the *Directive on the Assessment and Management of Flood Risks*.

6.6 Outlook

Since the optimal solution with respect to risk reduction is usually a combination of alternatives, implementing preventive measures could be supplemented by insurance solutions to reduce loss frequency and severity. Insurance is a means to provide compensation for financial losses, while sometimes it is better to prevent losses. Rarer and more costly events, such as low-frequency and high-magnitude mountain hazards, should particularly be transferred to insurance companies (Swiss Re, 2011). It had been shown that the economic vulnerability can be reduced considerably if – additionally to local structural protection – alternative mechanisms of loss compensation and risk transfer would be introduced in hazard-prone regions. However, both theoretical and empirical research had shown that the market for risk transfer tends to work imperfectly or even fail completely with respect to hazards (compare Kunreuther and Pauly, 2004; Holub et al., 2011).

The main obstacle in this context is the principle of adverse selection, since only those being located in hazard-prone areas and therefore suffer from frequent losses tend to contract insurance policies. As a consequence of adverse selection, the underlying principle of every insurance, namely, the diversification and spreading of risk, is not met. As a result, until now, insurance companies provide only policies with very limited coverage, high premiums, and high deductibles (Holub et al., 2011; see also Chapter 2).

Hence, firstly, risk awareness and personal responsibility of people exposed to mountain hazards has to be increased, and supported by standardised and state-of-the-art planning and implementation procedures (including local structural protection) on a superior level. This could be achieved by prescribing certain structural measures during the implementation of land-use regulations on a municipal level, as well as the issuing of overall guidelines, such as e.g. in terms of a regulation for building codes, a national (e.g., Ö-Norm) or even European standard (e.g., Eurocodes).

Secondly, such a shift in dealing with mountain hazards should simultaneously be accompanied by the introduction of an innovative system of risk transfer to overcome adverse selection. Such a system has to be pillared by either private insurers, reinsurance, and governmental stop-loss coverage (Schieferer, 2006; Holub and Fuchs, 2009; Kron and Ellenrieder, 2009) or by mandatory governmental insurers.

The general framework of such challenges was comprehensively addressed within this PhD thesis both, from a theoretical point of view as well as from an applied perspective, focusing on local structural protection measures. However, the implementation of such concepts into practice is not a scientific issue; instead, it is driven by public demand, economic necessities, and political intention, all of which need an increased awareness-building on mountain hazard and risk.

7 Summary

If the media coverage on natural hazards is observed it seems that the damages resulting from natural disasters show an increasing trend in both the number of events and the height of losses. In parallel such a trend is regularly reported by the leading primary insurers. However, when this trend is kept in perspective, from a scientific point of view an increasing trend in the frequency of losses is disputable. Nevertheless, from the development of land-use during recent decades it has to be deduced that the individual exposure of private households and the exposure of communal assets has significantly increased, therefore, the potential height of losses simultaneously is highly dynamic.

The occurrence of potential natural hazards is significantly influenced by the prevalent environmental settings and therefore cannot be anthropogenically influenced. In contrast, the height of losses is dependent on the land-use and is dependent on the exposure of elements at risk such as buildings in an avalanche run-out area. In order to reduce the adverse effects of natural hazards, active and passive as well as permanent and temporary measures are suitable. Experiences from the past suggest that in particular mitigation measures with a protective effect for entire communities and regions are no more economically feasible. As a result, the responsibility to provide protection slightly moved from the public authorities to the individual citizen affected. This trend towards self-responsibility is mirrored by the idea of risk management, where risk transfer – the shift of monetary consequences resulting from natural hazards towards third parties (e.g., insurers) – and technical and constructive preventive measures such as local structural protection play a major role.

Local structural protection is based on the strategy to reduce the vulnerability of individual buildings towards natural hazard processes. A reduction in vulnerability can be achieved by a selection of suitable construction materials, by a hazard-adjusted type of construction and by the design and adequate utilisation of an object exposed; and should be combined with passive mitigation measures such as land use-planning.

Firstly, this thesis is focusing on the hazard awareness of the population, and on available mechanisms of risk transfer and of loss compensation in Austria. Secondly, possibilities and limitations of local structural protection will be discussed and evaluated, and opposed to the costs and benefits of conventional mitigation measures in a catchment. Thirdly, different construction materials will be evaluated in terms of their ability to resist the impacts of natural hazards. Furthermore, the application spectrum and protective power of different types of local structural protection will be highlighted focusing on new and existing buildings exposed to mountain hazards (fluvial sediment transport, debris flows, landslides, rock fall and snow avalanches). Fourthly, the additional costs necessary for the implementation of local structural protection are quantified by taking a prototype building in the Austrian Alps as an example. These expenses are finally compared to average damage costs reported in the literature, and it is shown that local structural protection is cost efficient and can significantly reduce the exposure of individual objects exposed to mountain hazards, and as a result potential future losses.

8 Zusammenfassung

Verfolgt man die Medienberichterstattung über Naturgefahren, so fällt auf, dass Schäden aus Naturgefahren innerhalb der letzten Jahre sowohl in ihrer Häufigkeit als auch in ihrer Höhe weltweit einen zunehmenden Trend aufweisen. Dieser Eindruck wird regelmäßig von den Erstversicherer mit ihren Schadenserfahrungen belegt. Betrachtet man diese Situation allerdings genauer, so ist festzuhalten, dass eine Zunahme von Schadereignissen hinsichtlich ihrer Häufigkeit wissenschaftlich kontrovers diskutiert wird. Aus der Entwicklung des Siedlungsraumes innerhalb der letzten Dekaden lässt sich jedoch klar ableiten dass die individuelle Schadensempfindlichkeit der Privathaushalte, und somit die potentielle Schadenshöhe, ebenso signifikant zugenommen hat wie jene der Kommunen mit ihrer umfassenden Infrastruktur.

Das Auftreten von Naturgefahrenereignissen wird maßgeblich von den herrschenden Umweltbedingungen gesteuert und ist somit durch menschliches Zutun in der Regel kaum beeinflussbar. Die Schadenshöhe hingegen ist abhängig von der Landnutzung sowie in weiterer Folge der Exposition gefährdeter Objekte. Zur Reduktion potentieller Schäden kommen aktive und passive sowie permanente und temporäre Maßnahmen zur Anwendung. Die Erfahrung der Vergangenheit zeigt jedoch, dass insbesondere Schutzmaßnahmen mit Flächenwirkung, die gesamte Kommunen oder Talschaften schützen können, zunehmend schwieriger zu finanzieren sind. Resultierend aus dieser Entwicklung verlagert sich die Verantwortung zum Schutz vor Naturgefahren verstärkt von der öffentlichen Hand auf den einzelnen betroffenen Bürger. Im Sinne des Risikomanagements wird von Eigenvorsorge gesprochen, die durch Risikotransfer, also der Abwälzung monetärer Folgen aus Naturgefahrenschäden auf Dritte (zum Beispiel Versicherungen) erfolgen kann, aber auch auf technischen und baulichen Präventionsmaßnahmen, wie zum Beispiel dem lokalen Objektschutz, basieren. Der lokale Objektschutz orientiert sich dabei an der Strategie, die Vulnerabilität des einzelnen Objektes zu reduzieren. Dies lässt sich vor allem durch die Wahl geeigneter Baustoffe, einer gefahrenangepassten Bauweise und Ausgestaltung des Objektes sowie dessen risikogerechter Nutzung bewerkstelligen, sollte aber stets in Kombination mit passiven Maßnahmen wie zum Beispiel der Raumplanung in Einklang stehen und ganzheitlich betrachtet werden.

Die vorliegende Arbeit beleuchtet zunächst die Situation in Österreich hinsichtlich des Bewusstseins der Bevölkerung gegenüber Naturgefahren, des Risikotransfers sowie der derzeit verfügbaren Instrumente zur Schadenskompensation. Anhand eines konkreten Schutzprojektes werden die Möglichkeiten und Grenzen des technischen Objektschutzes ebenso wie dessen Kosten und Nutzen konventionellen Verbauungsmaßnahmen im Einzugsgebiet gegenübergestellt und evaluiert. In weiterer Folge werden verschiedene Baustoffe auf ihre Eignung bzw. Widerstandsfähigkeit gegenüber Naturgefahrenprozessen hin beurteilt. Aufgeschlüsselt nach den im Alpenraum vorherrschenden alpinen Naturgefahren (Hochwasser mit Geschiebetransport, Mure, Rutschung, Steinschlag und Lawine) werden alsdann die verschiedenen Anwendungs- und Schutzmöglichkeiten des technischen Objektschutzes sowohl für Neubauten als auch zur Nachrüstung bestehender Objekte aufgezeigt. Schließlich werden die Mehrkosten für die Ausstattung eines typischen Einfamilienhauses des österreichischen Alpenraumes den in der Literatur angegebenen durchschnittlichen Schadenskosten aus Naturgefahren-Ereignissen gegenübergestellt.

Resultierend aus den oben angeführten Untersuchungen kann gesagt werden, dass technischer Objektschutz hervorragend in der Lage ist, die Schadensempfindlichkeit von Einzelobjekten signifikant zu reduzieren und sich die dafür notwendigen monetären Ressourcen, speziell bei rechtzeitiger Planung, in Relation zu den Gesamtbaukosten eines Objektes in einem sehr kostengünstigen Rahmen bewegen.

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