AVALANCHE HAZARD MAPPING - 30 YEARS EXPERIENCE IN AUSTRIA

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ABSTRACT: Natural hazards are increasingly a limiting factor in mountainous countries in connection with the growing population and economical development. People become more and more alienated to environment conditions and are unable to recognize and control natural hazards. On the other hand the demand for safety of life and property is increasing in society and is requested to be transferred from the individuals to the authorities. In this state elaboration and presentation of natural hazards maps like avalanches, floods, debris flows, rockfall and landslides in the mountainous areas of European countries like Austria was started in the last decades. The legal basis and implementation of hazards zoning in Austria with special references to avalanches, the use of run out models, the questions of return periods, safety or risk consequences and acceptance by the people, political and economical consequences and prospective goals of avalanches hazard zoning in the future are briefly presented in the paper.

KEYWORDS: Avalanche hazard mapping, Austrian Service in Torrent and Avalanche Control, Natural hazard

1. INTRODUCTION:

Austria covers an area of 84.000 km^2 with 8 million inhabitants. The federal territory is divided in 9 Federal Provinces (Bundesländer) with a total number of 2355 communities. 70 % of the country are located within the Alps, reaches up to 3.800 m above sea level. The geological formations are varying between sediments, limestone in the peripheral areas and schist, granite, gneiss in the central part, often covered by deposits from several ice ages.

Big floods in the last century were the reason to establish a public service for torrent and avalanche control in 1884 to protect settlements and installations against this kind of natural hazards. The main work period in this field however was started after the world war second especially as a consequence of two big avalanche disasters in 1951 and 1954 when 270 people were killed within a few days.

Increasing and uncontrolled use of land as a consequence of the economical development – especially by tourism in the valleys of Western Austria – has led to further need of protection in the following decades. Therefore land use planning was necessary to prevent further extension of settlements into areas endangered by natural hazards as floods, avalanches, rockfall and landslides.

For this reason hazard zoning which is in the responsibility of the Federal Government, was started at the beginning of the seventies and regulated by Federal Laws.

Hazard maps confirmed by different administrative decisions are now considered as one of the basic data for further land use planning which have to be observed by the communities. This led to passive disaster prevention in Austria in an effective way. Hazard maps are also a base for temporary safety measures and the prioritization of permanent protective works against natural hazards.

2. LEGAL REGULATIONS

Hazard zoning was started in Austria around 1970 by the Federal Forest technical Service in Torrent and Avalanche Control and after some years of practical experience regulated officially in the new Forest Law 1975. The details regarding Hazard Zone Plans were settled in a decree by the Federal Minister of Agriculture and Forestry in 1976.

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Beyond these federal regulations executive rules concerning hazard zones are laid down in provincial laws for landuse planning. In these laws it is stated generally that areas endangered by natural hazards as floods, avalanches, debris flows, rockfalls and landslides are not allowed to be defined as development areas. The hazard zone maps have to be observed by local authorities (municipalities and rural communities) in the relevant decisions.

In addition the Ministry of Agriculture and Forestry has decided that in case of disregarding of the Hazard Zone Maps public funds for flood and avalanche control works are not available or money already used has to be reimbursed.

3. THE HAZARD ZONE PLAN

According to the decree of 1976 the Hazard Zone Plans for avalanches and torrents have to be prepared by the Federal Service in Torrent and Avalanches Control and are free of charge for the communities.

A Hazard Zone Plan is worked out normally for an area of one community and consists of a cartographic and a textual part.

3.1 The cartographic part

Includes a

a) Hazard maps (scale 1:10.000 – 1:50.000) with all relevant catchments and an overview of the whole community area.

b) Hazard Zone Maps (scale 1:1000 – 1:2000 at least), showing the results of investigated and valuated data of each hazard in the form of "Hazard Zones" on the basis of a return period of approximately 150 years for torrential floods and avalanches and 100 years for floods of rivers. The map has to include the land register and the aerial picture as background information nowadays

3.2 The textual part

consists of a description of the

a) basic data

b) arguments of valuation and

c) arguments for the hazard zoning.

4. HAZARD ZONES IN GENERAL

4.1 The Red Hazard Zone

includes areas which are endangered by torrential floods or avalanches to such an extent that their permanent use for settlements, infrastructures and transport facilities is not possible. The Red Hazard Zones include also less, but frequently endangered areas.

4.1 The Yellow Hazard Zone

covers areas with reduced danger between the Red Zone and the boundaries, where the damaging effects of the design event with a return period of approx. 150 or 100 years come to an end (criteria see below). Buildings and infrastructures are allowed to be built in the Yellow Zone but they must be protected by reinforcements and special architectural designing. People within new buildings should be safe, but outside they are endangered nevertheless. In areas which are already settled, an expert opinion has to be observed by public authorities for the permission of buildings and infrastructural installations. Limiting terms are: reinforced walls and windows, no doors and windows towards the avalanche or flood site, anchoring of the roof construction and so on.

In non settled areas natural dangers normally have to be eliminated by technical defence works before their identification as developing areas, but public funds are not available for this purpose.

As a special regulation in Austria it has been decided by the Ministry for Transport in the so called "Avalanche Decree for Cable Railways" that in ski areas at least one appropriate ski run per ski lift must be "permanently safe from avalanche danger". That means the lift and one adequate run must be situated outside of avalanche hazard zones resp. protected by permanent defence measures.

5. FURTHER DELIMITATIONS IN THE HAZARD MAPS

5.1 Brown areas

These areas are not endangered by floods or avalanche but obviously by rockfall or landslides. In this case experts for geology, soil mechanics and hydrogeology e.g. must be consulted by the competent authorities before dedication.

5.2 Blue Areas

These areas are needed and have to be reserved for protective measures in the future and also forests needing a special management to obtain their protective function.

5.3. Violet areas

These areas have special morphological protective effects, for example a natural earth dam around a settlement, therefore such an area has to be kept free from every kind of development or alteration.

6. ADMINISTRATIVE PROCEDURE

The draft of the Hazard Zone Map – elaborated and coordinated by the responsible district office of the Austrian Service - has to be submitted to the mayor of the community concerned and to be published there for public inspections during four weeks. Everybody affected by hazards zones is entitled to express his written opinion on the Hazard Zone Plan.

After this public announcement the draft of the hazard map has to be checked by a commission consisting of four persons: two competent experts and two representatives of the political level as follows:

a) Ministry of Agriculture and Forestry,
b) Federal Service for Torrent and Avalanche Control
c) provincial government and
d) community

This commission has also to consider the comments delivered by the people during the public announcement.

The commission makes its decision by simple majority of votes, in case of parity the vote of the representative of the Ministry is deciding. Finally the reviewed Hazard Zone Plan has to be approved officially by the Minister of Agriculture and Forestry and handed over to the relevant authorities (municipality and district administration). The original of the approved Hazard Zone Plan remains at the competent technical office for public inspection.

If basic elements of the hazard zones have changed, the plan has to be adapted to the new conditions.

Finally the Hazard Zone Map can be considered as a general planned expert opinion covering a defined area with a maximal administrative and political confirmation but needs further interpretation by competent experts in case of detailed application.

If there is some change in the basic situation as additional protective measures or new knowledge in methodology the Hazard Zone Plan has to be renewed.

7. AVALANCHE HAZARD ZONES

7.1 Demarcation criteria valid until 1999

Red hazard zone:

Avalanche pressure:

Return period 150 years	$\geq$ 25 kN/m²
Return period 1 – 10 years	$\geq$ 3 kN/m²
Deposition height:	$\geq$ 1 m

Yellow hazard zone:

Return period 150 years	3 – 25 kN/m²
Return period 1 – 10 years	1 – 2 kN/m²

Demarcation criterion for avalanche hazard zones was the avalanche pressure and the deposition height of avalanches. The regulation was similar to regulations in neighbouring countries like Switzerland. In Switzerland the criteria for Red hazard zones is an avalanche pressure of more than or equal to 30 kN/m² for a 300 year event.

7.2 Demarcation criteria valid since 1999

Red hazard zone:

Avalanche pressure:

Return period 1 -150 years $\geq$ 10 kN/m²

Yellow hazard zone:

Return period 1 - 150 years 1 – 10 kN/m²

The aggravation of the demarcation criteria for avalanches has been ordered by the responsible Ministry for Agriculture and Forestry after the avalanche disaster in Galtür February 1999, where 38 people died after two avalanche events. The goal was to raise additionally the safety in the Alpine areas

8. ETHODS APPLIED IN AVALANCHE HAZARD MAPPING

8.1 Historical method

At the beginning of avalanche hazard mapping in the seventies the use of avalanche runout models was limited to the analytical VOELLMY-SALM model. This model was widely used in the alpine countries but the use was restricted to the flowing part of avalanches. The possibilities to investigate into different scenarios were limited and therefore the so called "historical method" was preferred.

"Historical method" means that all data of historical events have to be collected and evaluated.

This data could be:

- written reports in old newspapers or chronicles in churches, schools or historical archives.
- Results of interviews with experienced local persons as hunters, foresters or farmers
- "hazard indicators" or "silent witnesses" along the avalanche track or in the run out area as indicators to former events. This could for example be the pattern of vegetation along the avalanche track or the distribution of avalanche debris in the run out area.

The main problems are:

Neither the reports in chronicles and the results of interviews nor the interpretation of hazard indicators gives information with high enough accuracy about return periods, run out distances or avalanche pressure.

In some areas no chronicles are available because of little interest in former times. Many settlement areas in our country are not older than thirty to fifty years and therefore no information – except perhaps hazard indicators – exists about natural hazards before settlement.

8.2 Runout models

Additionally the results of theoretical calculations and models have to be taken into account and compared with the above mentioned observations in well known and defined avalanche paths.

The applied methods result in a better delimitation of hazard zones in avalanches with well known parameters and enable some kind of calibration with "nearest neighbours". Of course, this proceeding is easier in areas with long settlement history and with vegetation as trees and shrubs where avalanche events are visible for a long time. In avalanche areas with less known data the use of models for calculating the run out distance becomes more important than in the cases described above.

In Austria the application of the analytical "Swiss Model" (Salm, Burkard, Gubler) for the calculation of the run out distances of dense flow avalanches has a long tradition, but recently some numerical models are in use:

Topographical landscape model (LIED,BAKKEHOI,WEILER,HOPF 1995)

This model was developed in Norway (LIED, BAKKEHOI, 1980). Goal was to develop a model that can be used without choosing any parameters. Only topographic factors have been identified that are most important for the run out. The model has been adapted to the Austrian Alps by Lied, Bakkehoi, Weiler Hopf (1995) and is applied only to run out estimation in longitudinally concave avalanche paths. The application is easy with little equipment and the results are satisfying for a first rough approach and in cases, where only the run out distance is questionable and avalanche pressure, velocity or lateral spreading is not important. The disadvantage of the model is fact that important features of starting areas as aspect, width, surface and shape are not taken into consideration in the model. That means – theoretically – an avalanche from a 20 m wide starting area has the same run out distance as an avalanche from a 200 m wide area. Therefore a high degree of expert knowledge in application is necessary l

One-dimensional numerical dense snow avalanche dynamic model AVAL-1D (CHRISTEN, BARTELT, GRUBER, ISSLER 1999)

The model was developed in Switzerland and it follows the classical analytical Voellmy-Salm model which has been applied in the setting Salm, Burkhard, Gubler (1990) for several years in Austria. Flow velocity and height are calculated for every point on the avalanche track. The choice of two friction parameters (dry friction μ and turbulent friction ξ) and the estimation of the fracture height and fracture area (avalanche mass) require some experience in using the model. It is recommended by the authors to use both models (the analytical and the numerical) for a comprehensive consideration. It is taken into account that the numerical model delivers higher – more realistic – velocities and in difference to the analytical model a non - linear decrease of avalanche velocity and pressure in the run out area.

Two-dimensional numerical dense-snow avalanche dynamic model ELBA (VOLK, KLEEMAYR 1999)

The avalanche simulation model ELBA has been developed at the University of Natural Resources and Applied Life Sciences in Vienna and it is mainly designed for the application in risk analysis. The basic constitutive equations have been derived from the Voellmy approach and modified for the 2-dimensional implementation. The program is a stand alone software with standard interfaces to ARC/Info and ArcView GIS Software. The choice of the avalanche mass and a dry friction parameter μ is necessary. The normally in the Voellmy model used turbulent friction is integrated in the model and derived from the roughness in the landscape model.

The model is calibrated on approx.150 avalanches (Volk, Kleemayr 1999). Because of the two dimensionality the simulation of lateral spreading is possible. The experience with this model in practical application is good, the handling of the computer program is easy and the visualisation of the results is very good because of the combination with ARC View GIS Software. First of all the model is applied to determine run out directions and run out distances.

Three-dimensional powder snow – dense snow model SAMOS (Snow Avalanche Modelling and Simulation, (SAMPL, ZWINGER, KLUWICK 1999, HAGEN, HEUMADER 2000)

The computer program SAMOS was developed by AVL in cooperation with the Austrian Service in Torrent and Avalanche Control, the Austrian Institute for Avalanche and Torrent Research and the University of Technology in Vienna. The model is able to describe the formation of powder snow avalanches from the dense flow part of dry avalanches and hence is able to capture the whole range of mixed dry avalanches from pure dense flow to pure powder snow avalanches. The handling is because of the complexity of the model much more expensive than the previously mentioned models. It is the most advanced model and SAMOS is the only model which is able to simulate the behaviour of both the powder and the dense flow part of an avalanche. Therefore it is applied to solve special questions as for example the height of the powder avalanche cloud or the direction and the impact of a powder avalanche which is separated from the dense flow because of morphological conditions in the avalanche track or the run out area. The model is the most important one because big disastrous avalanches are usually dry snow avalanches with a powder part and a dense flow part.

9. CRITICAL REMARKS

9.1. Can we rely on the used models?

This question can not be replied in one sentence. There are avalanches as above mentioned which are most suitable for calculation because of their clear determination of the starting area, avalanche mass and track conditions. In such cases the models are crucial completion and support for the accuracy of the determination of the Hazard Zone. They also enable to compare results with neighbouring avalanches under similar conditions. In this way the used models can be regarded as transfer methods to support the expert opinion in a quantitative way. On the one hand the models deliver a frame of possible events (statistical models) and on the other hand a deeper understanding and knowledge about avalanche dynamics.

Summarizing it can be stated from the Austrian point of view, that the delimitation of avalanche hazard zones should be the result of the experience of experts, historical records, statistical investigations and the use of different run out models. This comprehensive method takes into account that the avalanches as natural phenomenon can change their character and spreading in a way that cannot be forecasted and calculated only by formulas and theoretical approaches.

9.2 <u>Can we calculate return periods?</u>

It is not possible to calculate return periods in such long recurrence intervals because lack of adequate observation periods. In alpine countries like Austria the estimation of return periods might be easier than in other countries because of the long settlement history with corresponding chronicles about avalanche disasters like 1689, 1793, 1916, 1951, 1954, 1984 and 1999. Therefore the 150 year return period as required in the Austrian regulations is rather a theoretical approach.

A crutch is the calculation of the return periods of avalanches by using the 150 year return period of the three day snowfall. On one hand we know that a 150 year three day snowfall leads not mandatorily to a 150 year avalanche, on the other hand – this is what we have experienced in the Feb. 1999 – little snowfall over al longer period than three days may also generate big avalanches.

9.3 The consequences of the aggravation of the delimitation criterions in avalanche hazard zoning

The aggravation of the avalanche zoning criteria from 25 kN/m² to 10 kN/m² led to a high enlargement of red avalanche areas. In a first step all avalanche zones were enlarged to an extent of two - third of the yellow areas. This was a rough estimation of enlargement considering a linear decrease of avalanche forces in the run out.

In a second step, all avalanche hazard maps have to be recalculated with the above mentioned models and delimitated on the basis of the new regulations.

The basic equation for the avalanche velocity is

$$v(m/s) = \sqrt{P(kN/m^2)/\rho(t/m^3)}$$

P (kN/m²) Avalanche pressure

ρ (t/m³) 0,3 t for dense flow

ρ (kg/m³) 0,01 t for powder flow

If one compares the old and the new border of the red hazard zone on basis of this formula one can see, that the difference in avalanche velocity is fairly low in the dense flow (approx 4 m/s), but fairly high in the powder snow part (approx. 20 m/s).

This show, that the delimitation of the powder part of avalanches gets more significance in the new regulations. It leads to considerable problems in delimitation of zones because the models for powder snow avalanches are not yet as well developed as

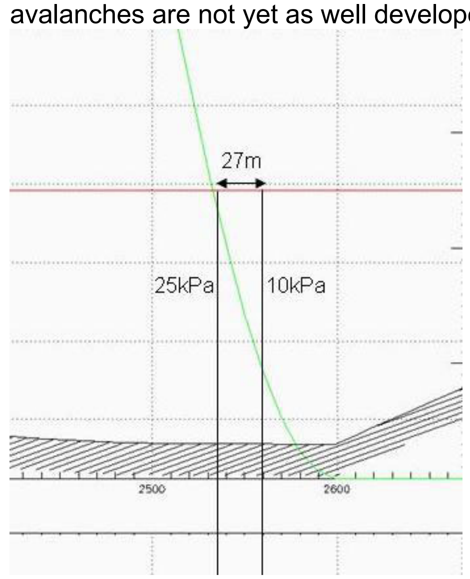

Fig. 1: Difference in run out distance between 25 kN/m² and 10 kN/m² border; Calculation of dense flow avalanche with the Swiss model AVAL-1D

those for dense flow avalanches. In practice only one model is suitable for powder snow avalanches in Austria and this is the mentioned SAMOS – model.

10. POLITICAL AND ECONOMICAL CONSEQUENCES OF ZONING

10.1 <u>Land use planning</u>

The limited living space for permanent use in the mountainous areas of Austria (e.g. in the Federal Province of Tyrol only 12% of the whole territory with one third of the Austrian tourism) and an increasing pressure to use land for settlement purposes has led to the political decision to introduce hazard zoning in Austria in 1975. As already mentioned, the border between yellow and red hazard zones of avalanche was fixed with the 25 kN/m² pressure line and later changed to the 10 kN/m² line.

Some areas were used for settlement purposes even before hazard mapping was introduced and a lot of infrastructure is therefore situated in the later delimitated hazard zones.

Although avalanche hazard mapping has existed since 1975 the value of settlement infrastructure and the number of people in hazardous areas in the alpine valleys during hazardous periods has extremely increased in the last few decades because of the high development of winter tourism. Not only the number of inhabitants in the Federal Province of Tyrol is twice as high as hundred years before, the number of tourist is twenty times as high as in the fifties of the last century. Due to the lack of hazard-free areas settlement, tourism and traffic infrastructure has been developed also in avalanche threatened areas that has been delimited as yellow avalanche hazard zones before.

The main political consequences for land use planning are already stated in chapter "Legal Regulations". In this way after more than 30 years of hazard zoning the Hazard Zone Maps are considered in the land use plans of the most of the endangered communities in Austria and the knowledge about natural hazards is widespread in the population. The restrictions concerning land use in the Red and Yellow Hazard Zones are normally accepted by the people, especially as everybody can express his opinion within the administrative procedure.

Compensations for areas dedicated as hazard zones cannot be claimed by people resp. have never been paid in Austria. On the other hand, the people have become aware of the existing natural hazards and at the same time the demands for protective measures have increased as never before. Additional pressure for protective measures arose after the change of the avalanche hazard zone criteria in 1999.

The primary goal of hazard mapping – to reduce the long term investigations in protective measures – is only partly achieved in areas which had already been settled before hazard mapping. High pressure to erect protective measures is produced by the affected people because of higher awareness of natural hazards by visualization of those in the hazard maps.

The goal to direct future settlement towards safe areas and to keep endangered areas free of additional settlement is fully achieved.

10.2 Hazard zoning and protective measures

The implementation of permanent protective measures is one of the consequences of hazard zoning. Therefore assistance of governmental institutions for natural hazard control is frequently requested by the communities for these works and public funds from the federal and provincial governments are requested on a large scale. In Austria approx. € 25 million for avalanche protective works and more than € 30 million for erosion and torrent control measures are spent at present per year.

These technical works have to be adapted to the same parameters as used in the zoning. In Austria public money is only available for projects to protect existing settlements and installations and not to enable new developments. The reduction of hazard zones as a consequence of protective works therefore is limited to these areas and depends on type, function, maintenance and lifespan of these constructions. Especially supporting structures in the starting zone of avalanches have to be considered carefully and the reduction of hazard zones after the implementation of protective measures seems to be more difficult than the first assessment of them had indicated because of the economical, social and political consequences.

11. FUTURE GOALS

According to the described methods, legal conditions and administrative regulation hazards zoning seems to have reached a relative high level of performance and acceptance by society in Austria. Nevertheless this situation is only representing knowledge and experience at the moment and the subject needs further treatment in a dynamic process in the future such as:

- Continuous adaptation resp. verification of the hazard maps in case of the occurrence of extraordinary natural disasters, if basic elements in the nature have changed and after the implementation of defence works.

- Elaboration of “Evacuation Plans” by the communities on the basis of the avalanche hazard maps to ensure, that people are not endangered outside their houses in case of high avalanche danger.
- Long-term management of mountainous forests to ensure their protective effects and to prevent the development of new hazard sources.
- Improvement of calculation models in international research programs.
- Adaptation of national legislative and administrative regulations (e.g. ”Avalanche Decree” for cabled railways) to an international standard at least within the European Union.

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