

## AVALANCHE ZONING IN FRANCE—REGULATION AND TECHNICAL BASES

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**ABSTRACT.** Avalanche zoning in France comprises two main parts:

1. A map of the probable location of avalanches was produced between 1970 and 1976, at a scale of 1 : 20 000, and covering nearly 600 000 ha. This was prepared by using a novel method based on:

- (i) the photo-interpretation of air photographs: the relief, extent of vegetation, notably forests, the structure of deposits and alluvia, the comparison of several areas, thus enabling the zones which appear to have been struck by avalanches in the past to be identified;
- (ii) information acquired from inhabitants and the study of archives;
- (iii) a detailed inspection of the ground which can reveal physical or anthropogenic signs not disclosed by photo-interpretation.

This map is only concerned with the past and gives no indication of frequencies.

2. French law places an obligation on the State to define the limits of the zone subject to natural risk before a building permit can be obtained.

Consequently, since 1974 when France ventured into zoning, plans have been made on a large scale (1 : 2 000) showing the zones exposed to avalanches. Plans are made in three colours: white presumed to be without danger, red dangerous and therefore prohibited to constructors, and blue zones, doubtful.

Blue zoning, the most difficult to establish, relies on the evaluation of specialists, supported by the classical calculation of Voellmy, as well as by some first results received from experiments in a water channel for powder-snow avalanches, or from numerical simulations for other avalanches.

The blue zone includes heavy avalanches with a time of return greater than 300 years and slightly more frequent avalanches (return time 30–50 years) but of very little importance.

According to circumstances in every blue zone, several types of measure are recommended: police measures (evacuation or regulation in the home), architectural measures of reinforcement, protective structure construction or annual checking by the authorities that natural (forest) or artificial (structures) defences are in a good state.

**Résumé.** *Le zonage des avalanches en France — règlement et fondement technicité.* Le zonage des avalanches en France comprend deux volets principaux:

1. La carte de localisation probable des avalanches rédigée entre 1970 et 1976 à l'échelle du 1 : 20 000 et couvrant près de 600 000 ha. Elle a été établie par une méthode nouvelle comprenant:

- (i) la photo-interprétation de photographies aériennes: le relief, l'extension de la végétation, notamment forestière, la structure des dépôts et alluvions, la comparaison entre diverses couvertures permettant de délimiter les zones qui semblent avoir été recouvertes par l'avalanche dans le passé;
- (ii) les informations recueillies auprès des habitants et d'après l'étude des archives;
- (iii) un examen approfondi des lieux qui peuvent révéler des traces physiques ou d'origine humaine non visibles sur photos aériennes.

Cependant, cette carte ne concerne que le passé et ne comporte pas d'indication de fréquence.

2. La loi française oblige l'Etat à délimiter les zones exposées à des risques naturels avant la délivrance des permis de construire.

C'est pourquoi, depuis 1974, la France s'est engagée dans le zonage à grande échelle (1 : 2 000) des zones exposées aux avalanches. Les plans sont établis en trois couleurs: la zone blanche est réputée sans danger, la zone rouge est dangereuse et interdite à la construction, la zone bleue est douteuse.

Le zonage en bleu, le plus difficile à établir, repose sur l'estimation des spécialistes, s'appuyant sur les calculs classiques de Voellmy comme sur les premiers résultats des expériences en canal noyé pour les avalanches de neige poudreuse ou de simulations numériques pour d'autres avalanches.

Les zones bleues comprennent des avalanches faites à périodes de retour supérieures à 300 ans et des avalanches un peu plus fréquentes (périodes de retour de 30 à 50 ans) mais de très faible importance.

Selon les cas particuliers à chaque zone bleue, plusieurs types de mesures sont recommandées: des mesures de police (évacuation ou consigne à la maison), des mesures architecturales de renforcement, l'implantation d'ouvrages protecteurs, ou le contrôle annuel par les autorités du bon état des défenses naturelles (forêts) ou artificielles (ouvrages de protection).

ZUSAMMENFASSUNG. *Lawinenzonung in Frankreich — Vorschriften und technische Grundlagen.* Lawinenzonung in Frankreich umfasst zwei Hauptteile:

1. Kartierung wahrscheinlicher Lawinenvorkommen, durchgeführt zwischen 1970 und 1976, im Masstab 1 : 20 000 für ein Gebiet von fast 600 000 ha, nach folgender neuartiger Methode:

- (i) Interpretation von Luftbildern nach Relief, Ausdehnung der Vegetation, vor allem des Waldes, Struktur von Ablagerungen und Aufschüttungen, sowie Vergleich verschiedener Reichweiten; auf diese Weise konnten die Zonen, die in der Vergangenheit von Lawinen bestrichen wurden, festgelegt werden.
- (ii) Mitteilungen seitens der einheimischen Bevölkerung und Studium der Archive.
- (iii) Sorgfältige Besichtigung des Terrains, wobei physische oder anthropogene Anzeichen zu finden sind, die aus der Photointerpretation nicht hervorgehen.

Diese Kartierung bezieht sich nur auf die Vergangenheit und enthält keine Häufigkeitsangaben.

2. Die französische Gesetzgebung verpflichtet den Staat zur Festlegung von Grenzen für Gebiete mit natürlicher Gefährdung, bevor Baugenehmigungen erteilt werden dürfen.

Als Folge davon unternahm Frankreich seit 1974 eine grossmasstäbige (1 : 2 000) Zonierung für lawinengefährdete Gebiete. Die Pläne sind dreifarbig: weiss für vermutlich sichere Lagen, rot für gefährdete Bereiche, in denen deshalb Bauverbot herrscht, und blau für zweifelhafte Zonen.

Die blaue Zonung, die am schwierigsten vorzunehmen ist, verlässt sich auf die Einschätzung von Spezialisten, gestützt sowohl auf die klassische Berechnung nach Voellmy wie auf erste Ergebnisse aus Versuchen für Pulverschneelawinen im Wasserkanal oder auf numerische Simulationen für andere Lawinen.

Die blaue Zone erfasst schwere Lawinen mit einer Wiederholungszeit von mehr als 300 Jahren und häufigere Lawinen (Wiederholungszeit 30 bis 50 Jahre), jedoch von sehr geringer Bedeutung.

Den Umständen entsprechend sind in jeder blauen Zone verschiedene Arten von Massnahmen zu empfehlen: polizeiliche Massnahmen (Evakuierung oder Wohnbeschränkung), Baumassnahmen wie Verstärkungen, Einbau von Schutzanlagen oder jährliche, amtliche Kontrolle des Zustandes natürlicher (Wald) oder künstlicher (Verbauungen) Schutzanlagen.

LOCATED in the centre of Europe, the Alps have been inhabited, even in their remotest valleys, for several thousand years. In France, the population maximum was reached during the nineteenth century. Since the beginning of the present century, however, the French Alps have experienced accelerating depopulation as the mountain people seek easier ways of life and higher living standards elsewhere. This process of emigration has resulted in a progressive loss of local knowledge concerning the historical experience of natural hazards (*risques naturelles*).

During the past 20 or 30 years, a new population has been attracted to re-occupy the mountains. These people are principally transitory and lack mountain-hazard experience: ski-ing is their primary attraction and they form a winter-time population maximum in new settlements high above the old villages. These new settlements take the form of high-density ski resorts, or dispersed mountain cottages, usually equipped with modern conveniences. Repeated accidents would indicate that many of these buildings have been sited without regard to, or knowledge of, areas under the threat of snow avalanches and other natural hazards. Public authorities now face the responsibility of controlling this hitherto unplanned and irresponsible growth pattern. Warning of the risks involved is a minimum requirement (cf. Aulitzky, 1974).

HISTORICAL KNOWLEDGE: MAP OF THE PROBABLE LOCATION OF AVALANCHES (*carte de localisation probable des avalanches — C.L.P.A.*)

There is a pressing need to reconstitute "collective memory" based on the accumulation of group experience through time, and which is lacking for many areas because of mountain depopulation.

Since 1899 there has been a systematic attempt to assemble observations on activity in the better-known avalanche paths that occur in the proximity of inhabited settlements. This so-called "continuing avalanche enquiry" (*enquête permanente sur les avalanches*) is extremely important in the development of avalanche-hazard forecast bulletins published by Météorologie Nationale (de Crécy, 1966). This approach was recently updated to ensure compati-

bility with the international avalanche classification (de Quervain and others, 1973). It is invaluable for avalanche-frequency studies but it covers only well-known avalanche paths and not new paths, or previously unrecorded paths that may threaten ski resorts.

The most important contribution to avalanche-zoning developments in the French Alps was made between 1970 and 1976. This work resulted in the publication of maps at a scale of 1 : 20 000 known as "maps of the probable location of avalanches". The areas covered included 600 000 ha in the Alps and Pyrénées. Two approaches were employed.

#### *Photo-interpretation*

Air photographs were studied stereoscopically so that avalanche paths that have been active during the last 100 or 200 years could be identified (Cazabat, 1972). Starting zones are indicated by topographic features: steepness of slopes, convex profiles, occurrence of cliffs, aspect, and so on. Avalanche tracks are usually conspicuous, especially when they cut through a forested area. Even when a century or more has elapsed since the occurrence of a significant avalanche event, variations in species composition and age structure are reliable diagnostic elements for the interpreter. Determination of the extent of the run-out zone is frequently more difficult. However, avalanche debris can often be identified, or a comparison of sequential air-photograph coverage will reveal progressive landscape modification such as to facilitate mapping of approximate run-out limits.

#### *Field investigation*

The air-photograph interpreter, accompanied by an avalanche specialist, can then undertake the second phase of the mapping; this will involve interviewing the local inhabitants. This method involves assembling local witnesses so that they confront one another, thus testing the accuracy of their recollections against each other or against any historical documentation. The field team will also map all landscape features of avalanches that may not have been observed during the photo-interpretation phase (Martinelli, 1974). These features will include:

- i. Areas of major snow accumulation: excessive thicknesses of snow along mountain lee crests or indications of snow deposits, such as avalanche debris remaining into the summer, and vegetation patterns.
- ii. Physical features such as waterlogged areas, badly kept pastures, or pastures being invaded by low shrubs; deformed or broken trees, and so on.
- iii. Sometimes there are anthropogenic indicators such as peculiarities in the shape, size, and orientation of fields as recorded on the cadastral register; the presence of a cross or an *ex voto* in a field, or even the remains of an old avalanche-deflecting structure originally built to protect a house which has since disappeared.

Data collected in this manner, after they have been submitted to verification by local witnesses, are recorded on the map. This compilation constitutes the second part of the map.

#### *Map showing the probable location of avalanches: advantages and disadvantages*

The two sets of data, air-photograph data and that derived from field work, are then superimposed on the same map, with differentiation being achieved by using an orange colour for the former and a pink colour for the latter. This becomes the map showing "the probable location of avalanches", which is printed and distributed to various civic authorities responsible for public safety and land-use planning. The mayor of the relevant parish must ratify the map.

In each case where written evidence or verbal witnesses are available, a card is filed recording the avalanche-path situation and its features. The card is also used to record information on the time of each recorded avalanche event, the major damage incurred, and the name of the observer.

The main advantage of this type of map is that it can be prepared quickly and economically (two teams of two men can cover about 100 000 ha during one summer of field investigation at a cost of about 15 F/ha or 1.21 U.S.\$/acre). Such maps are adequate to facilitate land-use decision-making on a broad scale, such as the siting of a new road, ski resort, or town. On the other hand, this approach does not enable assessment of avalanche frequency nor possible future occurrence. Therefore, it is not satisfactory as a basis for issuing licences for specific buildings.

#### “AVALANCHE-ZONE PLANS” (*plans des zones exposées aux avalanches — P.Z.E.A.*)

Article R.III.3 of the French “*code de l’urbanisme*” (town-planning code) stipulates that building restrictions may be applied to areas subject to natural hazards such as avalanches, and that these areas must be delimited by prefect decree. To meet such a legal requirement, a ministerial circular, dated 5 December 1974, was issued for organization of the preparation of avalanche-zone plans. These documents are drawn up at the request of the parish or prefect, and cover only those areas where town planning is in progress or is envisaged. The scale used is the same as that of the town plans (i.e. 1 : 2 000 or 1 : 5 000).

#### *Typical features of avalanche-zone plans*

They are comparable to their Swiss and Austrian counterparts in that they are multi-coloured:

*Red zone*: definitely dangerous and no construction permitted.

*White zone*: considered as most likely to be safe.

*Blue zone*: an intermediate area of uncertain safety.

To achieve this tripartite zoning, specialists must inspect every avalanche path and undertake a thorough enquiry. Generally, the “red zone” will correspond to the orange and pink areas of the maps of “the probable location of avalanches”, since it can be assumed that avalanches have occurred there in the past.

The “blue zone” is much more problematical. Personal evaluation by the author of the zone plan is of prime importance. However, this is supplemented by calculations using Voellmy’s formulae. Research is also undertaken into “model” avalanche flow by mathematical techniques (Pochat and Carry, 1978; Brugnot and Pochat, in press) for flowing avalanches and by the use of physical models in water channels for powder-snow avalanches (Hopfinger and Tochon-Danguy, 1977; Hopfinger and Beghin, 1978). These approaches are of great assistance in approximating blue-zone boundaries. Nevertheless, the problem of estimating maximum possible snow depth in the starting zone still remains. Similarly, the problem of establishing the return period of such a climax event remains unresolved. Thus the actual degree of hazard cannot be determined quantitatively.

Study of the card indexes of the “continuing avalanche enquiry” (“*enquête permanente sur les avalanches*”) will also be of assistance, in addition to the current research in numerical avalanche forecasting (Bois and Obled, 1973; Bois and others, [1975]; Bovis, 1977). Finally, it is necessary to decide on the frequency of occurrence between red- and blue-zone designation. In France two principles are taken into account:

- i. Extremely rare avalanches with a return period of the same magnitude as that of post-glacial climatic fluctuations (i.e. about 300 years) may be very severe. Yet, the long

return period hardly warrants total prohibition of construction. Thus a blue-zone designation is made and security of inhabitants is achieved through a judicial decision to order evacuation by the civic authorities. Such may be ordered, for instance, during exceptional meteorological conditions, such as very heavy snow-fall, and circumstances that can easily be identified.

- ii. Small avalanches with a return period greater than 30 or 40 years are also regarded as falling within blue-zone delimitation. In this case, structural constraints on buildings can be used to ensure adequate protection.

#### *Legal consequences of avalanche-zone plans*

For the red zone no building permits will ever be issued, while construction in the white zone is not restricted from the point of view of protection against natural hazards.

In certain circumstances, building licences may be refused for blue-zone applications. If a licence is issued, it may be dependent on certain conditions determined by specialists. These include:

*Structural conditions.* Walls of buildings facing the path of an oncoming avalanche shall have no windows or, if windows are allowed, they shall have fixed frames only with strengthened glass such as to withstand pressures of 1 000, 2 000, or 3 000 daN m<sup>-2</sup> for one or two floor levels. These stipulations presume the use of concrete for both main and dividing walls.

Roofs must not protrude beyond the top of the wall that faces the direction from which the avalanche may come, nor can the pitch exceed 45°. In some cases, deflecting structures may be required for individual buildings.

*Town-plan conditions.* Limitations can be placed on building density. This is related to a land-occupation coefficient (*“coefficient d’occupation des sols”*) which is the ratio of total floor space of completed building to initial area of land. Similarly, building alignments may be controlled, according to the slope line and the spacing between alignments of buildings. Thus, the up-slope house on one alignment may be specially protected and the space between alignments determined so that the design avalanche can pass between buildings. In this way, avalanche protection for one group of buildings will be undertaken so as not to increase the risk of an adjacent group.

*Conditions imposed by local authorities.* There is the possibility of evacuation of houses during periods of determined high avalanche risk. For this purpose, blue-zone designation is very important. Also, the mayor of a community has the obligation each autumn to require a detailed forest inspection where such forests provide blue-zone protection. Thus, if the forest has disappeared, or has been damaged by fire or disease, the mayor can forbid winter-time occupation of the blue-zone buildings until appropriate responses have been made. These could include, for instance, erection of snow fences in the avalanche starting zones above the damaged forest. Similarly, the mayor is responsible for autumn inspection of snow fences that protect blue-zone structures.

#### CONCLUSION

At the present time in France there are about 50 mountain communities equipped with avalanche-zone plans; this is about half of the expressed needs. The requirement for additional zone plans is probably growing because of the general agreement that zoning is the best and least expensive form of avalanche-hazard protection and reduction. Such plans are subject to revision as knowledge about avalanche behaviour increases, or as local conditions change. However, it has been necessary to take these immediate preliminary steps rather than to wait for perfection, because of the rapid growth in pressure from town planning in relation

to the continued growth in winter recreation. The mountains remain vast and inviting but the amount of safe land at high elevations is probably much less than originally envisaged by the ski-resort developers. Extensive areas still remain in France, as in other countries, for conquest by the skier. We hope our modest experience in avalanche-hazard zoning will be useful to other countries.

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