

INTRODUCTION AND INFLUENCE OF (LARGE) EXISTING BUILDINGS ON AVALANCHE HAZARD ZONING: CASE STUDY OF FLAINE

Philippe Berthet-Rambaud^{1*}, Fanny Bourjaillat¹

¹Engineerisk, avalanche consultants, Ste-Helene-du-Lac, France

ABSTRACT: Flaine is a French ski resort developed ex-nihilo since the 60s. In spite of avalanche slopes just above, the different settlements were possible thanks to an extensive permanent protection network including kilometers of snow bridges and nets. In the meantime, the French regulations about hazards zoning and land planning was progressively structured. Currently, it does not take into account existing protections like supporting structures to influence zoning and to allow new buildings in possibly protected areas. In this context, this study analyses the influence and possible indirect protective effect of existing buildings on surrounding areas. The corresponding results are presented starting with the procedure to assess the “dam capacity” of each building regarding both resistance and geometry, even if not specifically “avalanche designed”. Therefore, two approaches are proposed to introduce them in RAMMS software either as perfect obstacles or modified roughness. Modeling results are finally compared to a reference historical scenario to confirm the strong indirect protection in the current situation.

KEYWORDS: hazard assessment, obstacle influence, buildings resistance.

1. INTRODUCTION

Anticipating possible destruction or modification in the future, avalanche hazard zoning usually (at least in France) does not take into account the influence of existing buildings downhill of/in the transit zone or uphill of the reference deposit zone. Of course, this simplifies the assessment procedure but at the same time, these buildings have an obvious influence either positive (indirect protection) or negative (change in the avalanche impact direction, additional impactors in the flow).

The French CLPA (“Carte de Localisation des Phénomènes Avalancheux” – Avalanche Map (Bonney et al. 2010)) inventories some examples of this influence as shown on Fig.1.

According to that, analyzing this real interaction could then be useful to possibly reconsider the hazard intensity at a detailed level (new building project scale), especially in very constrained mountain settlements to reasonably open new spaces for developments. Of course, this analysis cannot be only qualitative and needs a clear assessment procedure taking into account (at least) both snow-avalanches characteristics, existing buildings capabilities (geometry and resistance).



Fig. 1: CLPA extract at St Hilaire du Touvet which clearly shows the testimony of the 1970 “Cabane du Berger” avalanche, stopped against an existing building.

This paper proposes a general assessment procedure then applied to the real case of Flaine, a ski resort developed ex-nihilo since the 60s. It notably presents the particularity to be classified regarding its architecture made of several floors reinforced concrete buildings distributed in staggered rows (Fig.2) with a certain homogeneity and density. This situation allows to safely focus the procedure

* Corresponding author address:

Philippe Berthet-Rambaud, CEO, Engineerisk, Ste Helene du Lac. France; tel: +33 623 7504 44
philippe.berthet-rambaud@engineerisk.com

on this type of large and tall buildings, excluding small or individual houses. Additionally, it has to be noted that these existing buildings (except the most recent) were not specifically "avalanche designed" as proved by many windows facing avalanche prone slopes. At that time, this development was possible thanks to an extensive permanent protection network including kilometers of active protections which are now considered as insufficiently reliable by the regulation regarding hazard zoning.



Fig. 2: Two rows of buildings at Flaine with possible avalanches coming from the north – top of the picture.

2. KEY-PARAMETERS

The originality of the proposed methodology is to consider existing buildings not regarding their own safety (and some of them are clearly not self-protected ... which is another problem) but for their capabilities to be a "sufficient obstacle" able to influence an approaching avalanche. The fact that this obstacle is occupied and the possible consequences on its residents are voluntarily out of the current scope. This notion of a "sufficient obstacle" is central in order to fix a limited set of assumptions to reach a "systematic" processing avoiding the "case by case" approach, conceptually possible but operationally illusory due to lack of input data (especially about building structures details).

The first geometric criteria is the relative size between the building and the avalanche in the same way a drag coefficient is dependent on the size of

the obstacle. In a first approach, this size (of the building) - speed (of the avalanche) ratio is decisive. A dense flow will be more easily influenced (and so by a smaller obstacle) as it is itself slow and small. Conversely, large mixed avalanches that develop potentially larger dimensions than those of multi-floor buildings and including dynamic turbulent phenomena will be of little influence. Additionally, the relative orientation also plays a role (Fig.3)



Fig. 3: Example of deviation of the dense flow avalanche of Cialancier at St Etienne de Tinnée (06/12/2008 - Source: RTM 06).

The second type is mechanical criteria. Indeed, if a building can potentially influence an avalanche and protect areas downstream by its geometry, it is still necessary for it to resist "enough". This concept of "sufficiency" is crucial as it "just" has to be a "sufficient" obstacle.

Firstly, let's consider only the supporting structure as windows and doors may fail rapidly in comparison to the bearing structure. This supporting structure has to present both a minimal porosity and a sufficient resistance. Both aspects depend on the type of construction, building material and finally design:

- The juxtaposition of bearing walls common in residential buildings to compartmentalize small apartments allows an avalanche that would "enter" to meet successively several obstacles. On the contrary, industrial buildings or small structures where there may be only an outer bearing frame would be more easily crossed.
- The accumulation at the front of the avalanche of building elements already destroyed from the first impacted sections will create a kind of jam phenomenon to

constrain and slow the inside progression (Fig.4).

- To resist, the supporting structure materials and deployment must also have sufficient mechanical strength capabilities: for example, if the wood has an interesting intrinsic resistance, it is generally associated with small building designs by assembly that do not offer sufficient guarantees. Idem for the metal cladding if used as the sole filler.



Fig. 4: Jam at the avalanche front penetrating a building (source: Arni Jonson).

The complexity of the building (obstacle) - avalanche interaction depends on many parameters and would require all the nuances related to both the characteristics of the avalanche and the details of the affected building to analyze each case. In order to develop a systematic procedure applicable to Flaine, the current work is voluntarily limited to several floors reinforced concrete large buildings subjected to dense avalanche flows.

3. INTRODUCTION OF THE BUILDINGS IN THE PROCESS

If the knowledge about materials behavior, including reinforced concrete under complex loading is progressing steadily, modeling the behavior of a complete building remains a major challenge due to:

- Knowledge of the exact geometry: if by chance, construction schemes are available, they were possibly subjected to changes or revisions
- Knowledge of the actual characteristics and implemented materials: it is generally not feasible to conduct surveys whereas the recommendations at the time of construction could offer resistance variations...themselves modified by aging.
- Combination of different scales between the details of a connection (post-slab, for example) and the whole behavior.
- Knowledge of the "boundary conditions" and connections with foundations
- Contribution of secondary elements against avalanche penetration.

In parallel, the general knowledge of the spatial and temporal avalanche solicitation against an obstacle remains limited so that an adequate level of description is necessary for a consistent procedure.

3.1 Geometric/mechanical approach: "sufficient obstacle"

The intensity of avalanches is a subject that has undergone numerous evaluations particularly to connect pressure and potential damage. Different scales exist (McCLung and Schaerer 2006) and confirm that the resistance of a building comes mainly from the supporting structure. Additionally, for example, by back-analyzing destruction during major disasters (Keylock and Barbolini 2001), it is possible to obtain fragility curves connecting pressure and level of damages for some major types of buildings (Fig.6). Fig.7 provides a synthesis of different references for reinforced concrete buildings.

However, for the needs of this study, one difficulty is then to link the level of damage and the ability to remain a "sufficient obstacle". At the same time, one completely destroyed building will ultimately continue to act as an obstacle (rubble piles forming a barricade of about one meter per destroyed floor – Gebremichael 2013). Furthermore, most of existing studies have rather examined "small" buildings. This allows improved pressure thresholds, thanks to higher dead loads and by juxtaposing the equivalence of several "small" buildings in thickness (overall indirect shear strengthening).

Then once the snow-avalanche pressure is lower than the resistance of the building as a reliable obstacle, it is still necessary that it constitutes a high enough dam not to be submerged by the flow. Given the specific context of obstacles-flow interaction here, the necessary height of an avalanche dam is simply determined from the formula (Salm and others 1990) $H_{salm} = h_u + h_f + h_s$ where h_u is the required height due to the kinetic energy or the velocity of the avalanche, h_f is the thickness of the flowing dense core of the avalanche, and h_s is the thickness of snow and previous avalanche deposits on the ground on the upstream side of the dam before the avalanche falls. The term h_u is computed according to the equation $h_u = u^2/2g\lambda$ where

u is the velocity of the chosen design avalanche at the location of the dam, g is the acceleration of gravity, and λ is an empirical parameter intended to reflect the momentum loss when the avalanche hits the dam, as well as the effect of friction on the flow of the avalanche during run-up along the upstream side of the dam. Thanks to vertical uphill faces, λ value is assumed equal to 3.

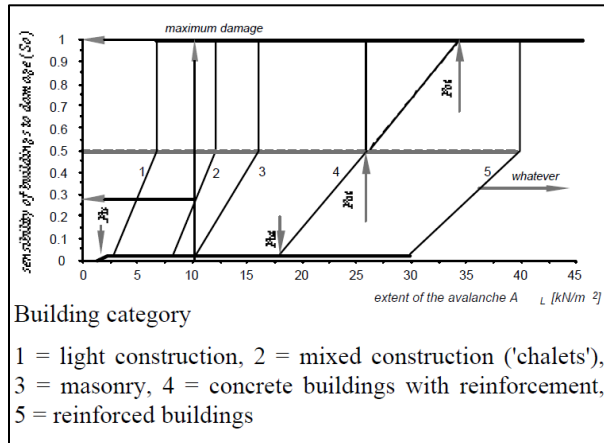


Fig. 6: " Damage sensitivity of different building types " (Whilelm 1997)

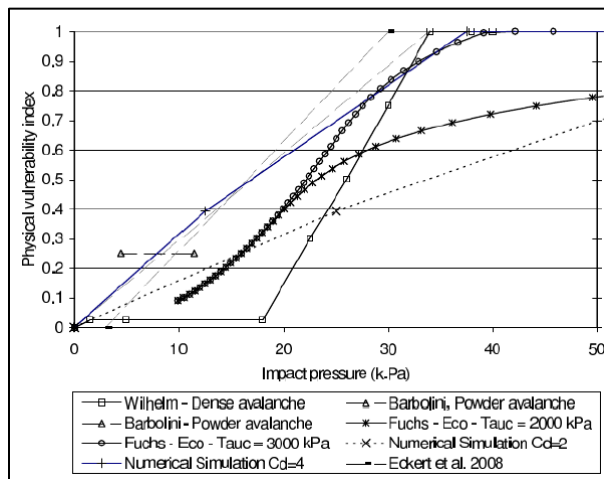


Fig. 7: Overview of different vulnerability curves from the literature for reinforced concrete structures.

3.2 Modified roughness approach: "forested gully"

If the above approach is to consider the presence of an obstacle not to be overpassed, these buildings can also be seen as obstacles to be crossed

and generating opposition. Analogously to the consideration of the forest in avalanche modeling, the second approach is to consider the building as a field singularity indirectly leading to increased friction values. Examination of usual parameters of RAMMS software (SLF 2013) shows that the forest mostly corresponds with a decrease in the coefficient ξ (representative of turbulence) and a very slight increase in the friction μ . At the same time, μ is also heavily dependent on the type of terrain (" unchanneled ", " channeled ", " gully " or " flat "). However, the passage through a building can be seen as far more penalizing than the passage in a deep thalweg. Given the differences between the category " flat " and " gully " in RAMMS reference table, an increase of μ by 0.2 is assumed to be a conservative minimum to represent the passage through a building..

3.3 Introduction in RAMMS

The influence of buildings is finally evaluated by comparing RAMMS modeling results applying the same reference avalanche scenario with or without buildings. The next diagram summarizes the various possible cases regarding criteria of mechanical (blue) and geometric (red) "sufficiency".

Relative to the two methods presented above, the following possibilities of the software are respectively used to introduce each building:

- Following the primary verification of its strength and height to form a " sufficient obstacle", the building in question is considered a perfect unsinkable obstacle and introduced in Ramms as an "obstacle / no flux feature"
- Buildings places are introduced as forested zones whose corresponding parameters are modified during the automatic Muxi Procedure by applying an increase of μ of 0.2 ("forested gully") or 0.4 (double forested gully") in each line of the table corresponding to forest.

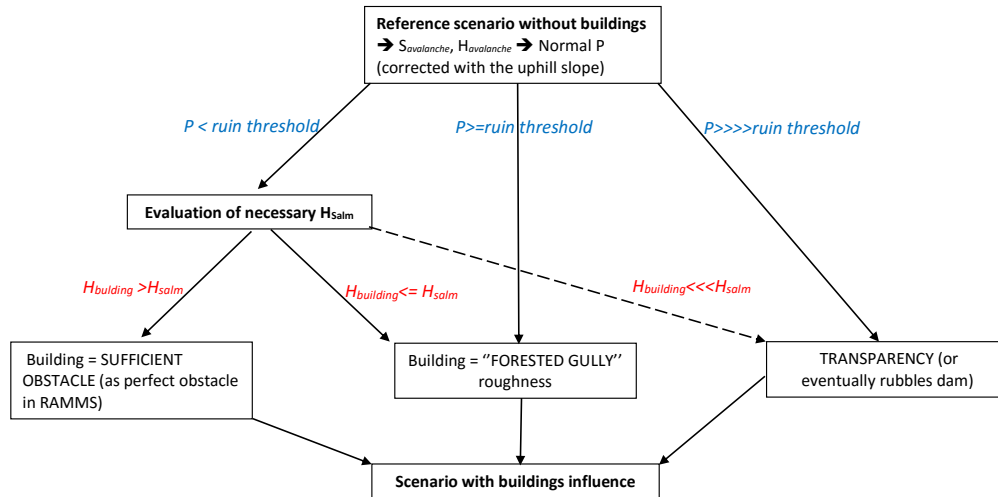


Fig. 8: Diagram of the buildings evaluation for their introduction in the process.

4. APPLICATION TO FLAINE

The reference scenario for Flaine is based on an historical avalanche (CLPA n°45) of 1937 taking into account a 300 year return period. Corresponding 3 days of snowfall are determined statistically from the local ski patrollers' measures database (since 1978). But differently to the historical event, all slopes above the two rows of buildings are willingly released simultaneously: the volume category is considered as tiny to correspond to the historical runout as figured on the CLPA (and including the topography modification induced by different platforms created during the resort development) and as most avalanches lines flows parallel thanks to rather homogeneous slopes (Fig.9).

4.1 "Sufficient obstacles" results

Prior to model the flows taking into account the urbanization of Flaine, it is necessary to check if the various buildings can be a "sufficient-obstacle" under the reference scenario. For this, Table 1 summarizes main values and geometric and mechanical assessments for each building of the upper row. The lateral pressure threshold to ruin is increased from 30kPa to 60kPa considering firstly that the Flaine buildings are (at least twice) wider than a conventional chalet with a number of floors / dead loads descents that double (at least) the shear capacity. The results are finally optionally modulated according to each particular context by expert interpretation.

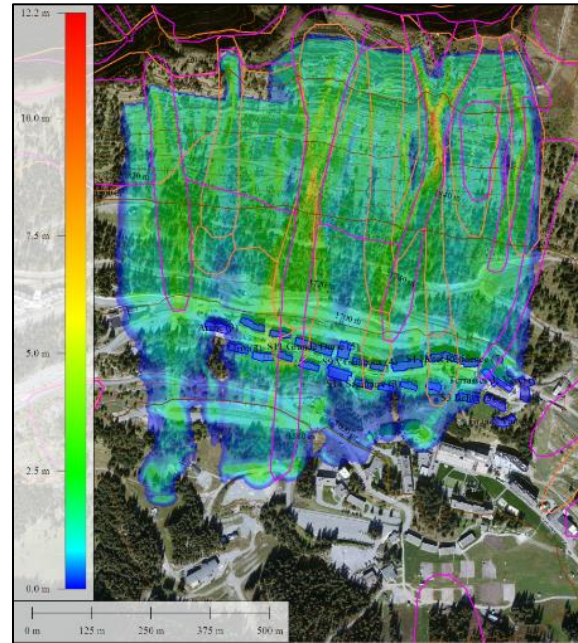


Fig. 9: Reference scenario without taking into account the urbanization of Flaine-Forêt - Hmax T300.

Then according to these assessments, the buildings which can be considered as "sufficient obstacles", are integrated into a new RAMMS calculation as no-flux features. As a new iteration, this allows to evaluate avalanche characteristics for buildings of the downhill row to assess them again as "sufficient obstacles" or not. Finally, all the buildings along the two rows that can play a role of "sufficient obstacle" (all except S19 auditorium, S18 Pégase, Pléiades, S16 Aquarissu) are

integrated in a final RAMMS modeling. Apart from the maximal flow line (avalanche 45) where all buildings were not selected as "sufficient obstacles", all other avalanches lines are properly stopped by the two successive rows of buildings (Fig.10).

Table. 1: Systematic assessment of each building of the upper row as "sufficient obstacle"

Building	H avalanche (m)	V avalanche (m/s)	Equivalent lateral P (kPa)	P < 60kPa	H apparent building (m)	H Salm necessary (m)	Geom verif
Panramic	1	0	0	OK	18.9	-	-
Terrasses de Véret	1	5	7	OK	18.9	2.9	OK
S1 Hotel Residence	3	17	65	NO	18.9	9.2	OK
S10 Andromede	2	16	58	OK	18.9	7.8	OK
S9A Gémeaux	3	15	60	OK	10.8	8.3	OK
S9B Gémeaux	4	15	60	OK	10.8	8.8	OK
S19 auditorium	1	7	15	OK	2.7	3.3	NO
S11 Grande Ourse	4	20	90	NO	13.5	12.3	OK
S18 Pé-gase	4	24	130	NO	10.8	14.8	NO
S20 Doris	3	18	94	NO	10.8	10.0	OK

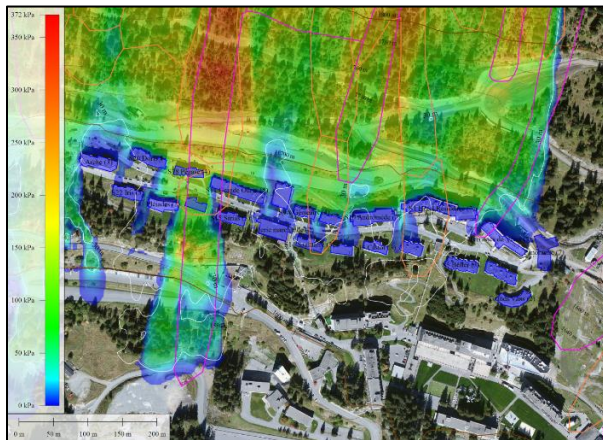


Fig. 10: Reference Scenario with introduction of all "sufficient obstacle" buildings - P_{max} T300.

4.2 "modified roughness" results

The previous results already show an interesting trend especially for the eastern half of the zone. However, the approach remains very pessimistic as it confers no effect to a whole group of buildings as the first approach is only binary ("sufficient obstacle" ... or not). Finally, the main avalanche line flows as it was free. However, full transparency is unrealistic particularly given the size of these buildings and their capability to become at least "piles of rubble" even beyond their ruin.

So the "modified roughness" approach is applied. A first calculation is performed giving "forested gully" roughness characteristics to surfaces occupied by all buildings (Fig.11).

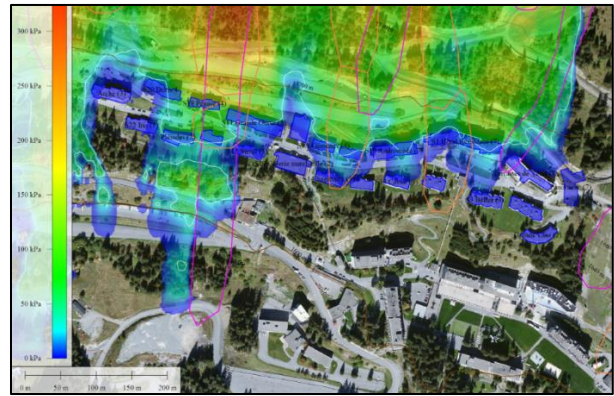


Fig. 11: Reference scenario including all buildings as "forested gully" modified roughness – P_{max} T300.

At this level of roughness, most flows are stopped by buildings and the downstream extension of the avalanche 45 is already reduced. However, the reduction in speed remains below values of Romang (2008) : about 5 m / s here whereas 7.5 m/s could be expected for a braking dam.

This may justify an increased value of the roughness, intuitively, crossing a building is equivalent to a confinement on 4 sides (floor, roof and 2 lateral walls) with additional obstacles along the way, (much) more penalizing that only following a gully. From this point of view, this can result in a doubled increase of around 0.4 for the coefficient μ ("double forested gully"). In this case (Fig. 12), even the avalanche 45 is almost completely stopped under the reference scenario.

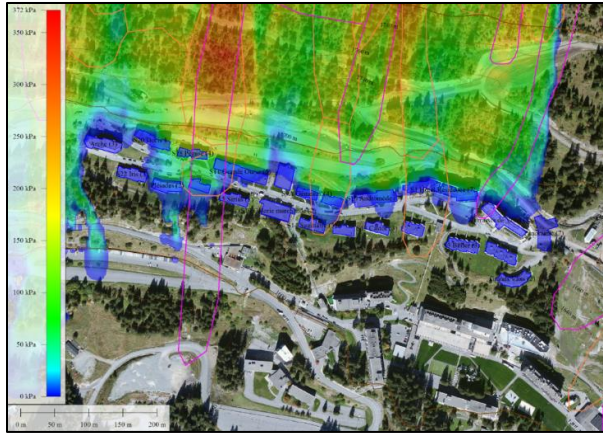


Fig. 12: Reference scenario including all buildings as "double forested gully" modified roughness – P_{\max} T300.

5. CONCLUSION

Developing a methodology to include (large) buildings' influence changes the point of view of avalanche hazard zoning in urbanized areas. Even if it was applied to a very original case at Flaine-Foret, obtained results confirm a possible major influence. In that particular case and if a certain caution remains necessary, the results tend to show that most slopes below the two staggered rows of buildings are protected from avalanches or subjected to only medium hazard level ("blue zone"). Of course, this also opens related questions about the future of these buildings (for instance, are the owners obliged to maintain their buildings as they constitute a protection for third persons? What if they become destroyed by an avalanche or fire?) or the way to take into account "indirect" protections in avalanche hazard zoning. However, the main paradox is to consider that these "non avalanche designed" buildings, so not self-protected, could become protections for others buildings downstream: this provides a different treatment regarding safety depending where inhabitants stay: the initial question asked by the French administration was surely acceptable only because all the slopes above are in reality already strongly stabilized by kilometers of active protections...

More generally and depending on the type of buildings, this work also shows that avalanches real extension in urbanized areas could be reduced thanks to this existing buildings effect: it could also help to prioritize evacuation plans instead of applying a uniform risk level as if avalanches were flowing on open and free slopes.

ACKNOWLEDGEMENTS

We would like to acknowledge the Haute-Savoie Territory central administration (Ariane Stephan) for submitting the initial question, the two communes of Araches-La-Frasse and Magland for their financial support and Raymond T. Mumford for English improvement

REFERENCES

- Bonnefoy M., Cabos S., Escande S., Gaucher R., Pasquier X., Tacnet J.-M., 2010: *Localization map of avalanche phenomena (CLPA) and collection of eye witness accounts: field investigation method, biases, alternatives and limits, data quality*, Proceedings of the International Snow Science Workshop, Squaw Valley, CA.
- Gebremichael B. 2013: *Statistical indicators of demolition debris volume*, Tampere University of Applied Sciences
- Keylock C.J. and M. Barbolini, 2001: *Snow avalanche impact pressure – vulnerability relations for use in risk assessment*, Can. Geotech. Journal, 38, 2001
- McClung, D. M. and P. A. Schaerer, 2006: *The Avalanche Handbook*. 3rd ed The Mountaineers, 347 pp.
- Romang H. (Ed.) 2008 : *effet des mesures de protection*. Plateforme nationale « Dangers naturels », PLANAT, Bern 289 p
- Salm, B., A. Burkard and H. U. Gubler. 1990: *Berechnung von Fliesslawinen. Eine Anleitung für Praktiker mit Beispielen*, Mitteilung 47, Eidg. Institut für Schnee- und Lawinenforschung, Davos.
- SLF, 2013. RAMMS, rapid mass movements simulation. A numerical model for snow avalanches in research and practice, User Manual v1.5 and new RAMMS version 1.6
- Willelm C. 1997: *Wirtschaftlichkeit im Lawinenschutz*, Mtt.Eidgenössisches Institut für Schnee und Lawinenforschung, 54, Davos