INTERACTION AVALANCHE-OBSTACLE: A FIRST ATTEMPT OF COMPARISON BETWEEN A REAL CASE STUDY AND NUMERICAL SIMULATIONS

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ABSTRACT: The purpose of this work, within the Project "DynAval - Dynamique des avalanches: départ et interactions écoulement/obstacles" - European Territorial Cooperation objective Italy - France (Alps), is to analyse the effects of the snow avalanche impact against structures by the comparison of a real case study with simulations. By a back analysis of the damages occurred on 15 December 2008 in Aosta Valley (North West of Italy), and more precisely in the village Les Thoules in Valsavaranche, the impact pressure is estimated. In this event 12 houses are destroyed or damaged, as well as electric poles, trees and an high voltage pylon. A first simplified attempt of simulation of the impact area is consequently proposed. The avalanche behaviour, considered as an incompressible fluid, is described by a two-dimensional, in the avalanche slope, Navier-Stokes equations to which an advection equation is coupled to take into account the shape variation. A two dimensional and a three dimensional stationary models are implemented too. The models allow to describe the velocity and the pressure at every point. The role played by the natural dam localised in the site of protecting the down-wind structures is analysed. In addition, the pressure acting on the different parts of the houses is investigated, proposing different Cp coefficients, in order to evaluate which parts should have been more resistant. Finally, since the objects involved had different shapes and dimensions, an investigation into the Cd coefficient is made. Finally, the capabilities and the deficiencies of the models proposed are shown.

1 INTRODUCTION

The purpose of this work, within the Project "DynAval - Dynamique des avalanches: départ et interactions écoulement/obstacles" - European Territorial Cooperation objective Italy - France (Alps), is to analyse the effects of the snow avalanche impact against structures by the comparison of a real case study with simulations.

In particular the avalanche occurred on 15 December 2008 in the village Les Thoules in Valsavarenche, located in Aosta Valley (North West of Italy) is analysed. This avalanche, called La Frange, was registered only 3 times with a marginal interesting of the alluvial fan, never attending the extension of the 2008. Furthermore, the area was principally agricultural and shepherd used (RAVDA 2009).

Causing the instability of the snow cover and of the surcharge due to the new snow (in two days near Les Thoules more than 110 cm was been measured) from 2430-2320 m a mass having as maximal length 350 m was released. In its difference in height of about 880 m the avalanche destroyed or damaged seriously 7 houses and partially 5 ones. In addition electric and telephonic poles was crushed and an high voltage pylon is damaged. The regional and the communal roads were obstructed too. Trees was uprooted, and about 10 animals was killed. Luckily, nobody was in the houses, and consequently no dead occurred (RAVDA 2009). To mitigate the avalanche risk in 2009 2.6 Km of "snow umbrella" was located. In the winter 2010-2011 the impressed pressure of the snow cover on them will be measured.

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2 METHOD

To reproduce the interaction between the avalanche and the different structures located along its path three different procedures are used, based on a stationary approach and on a transient one.

In all the cases the avalanche is considered as an incompressible fluid characterised by a density ρ_{av} and a viscosity η_{av} (see Table 1). The Navier-Stokes equations are consequently used:

$$\begin{cases} \nabla \cdot v = 0 \\ \rho\left(\frac{\partial v}{\partial t} + v \cdot \nabla v\right) = \nabla \cdot T + F \end{cases} \tag{1}$$

where **v**=(u,v) (or **v**=(u,v,w) in the three dimensional case) is the velocity, $T = -pI + \eta(\nabla v + (\nabla v)')$ is the stress tensor, p is the pressure and F takes into account the gravitational force and the friction one.

Table 1 - Avalanche characteristics behaviour.

ρ_{av}	130 kg/m^3
v_0	25 m/s
η_{av}	$10 \cdot \rho_{av}$ kg/ms

2.1 Two dimensional stationary approach

In the first approach presented the whole final area is occupied by the snow in movement (see Figure 1). The velocity at the end of the channel (boundary number a) is set equal to v_0, as well as the initial condition (Table 1). The value of v_0=25 m/s is been estimated by Fusinaz (2010) using the Voellmy-Salm model. In the final part of the channel (boundaries b-h) the slip condition is imposed, to indicate that the avalanche is channelled, while afterwards the open slope allows the avalanche expands itself outside the domain.

The Navier-Stokes equations are consequently solved in the stationary case with a Finite Element Method Software, named Comsol Multiphysic.

2.2 Three dimensional stationary approach

The same laws are solved even in their 3D version always with the Comsol Multiphysics software.

2.3 Two dimensional transient analysis

In the third approach a domain taking into account the avalanche zone and the around air is considered (Bovet 2009a,b). The two-phases (snow and air) are modeled introducing a fluid having for the density and the viscosity the following laws:

$$\rho = \rho_a + H(s_2)(\rho_{av} - \rho_a)$$
$$\eta = \eta_a + H(s_2)(\eta_{av} - \eta_a) \qquad (2)$$

depending on the density/viscosity of the air (a) and of the avalanche (av) through the Heaviside function $H(s_2)$. The level set function s_2 is characterized to be equal to zero on the free surface, to be positive in the zone of the more dense and more viscous fluid (avalanche) and to be negative where the less dense and less viscous one (air) is situated (Bovet 2007).

The interface is transported by the advection equation:

$$\frac{\partial s_2}{\partial t} + v \cdot \nabla s_2 = 0 \qquad (3)$$

In the transient case, in the only avalanche area the velocity is imposed equal to v_0. The boundary conditions are the same of the previous analysis, less the boundary a.

The Navier-Stokes equations and the advection one are thereby solved in the transient analysis with the Comsol Multiphysic software.

3 RESULTS

3.1 Streamlines analysis and flow direction

The firsts simulations in the stationary situation are done using the viscosity in Table 1, considered suitable for the dry snow saltation layer. The streamlines show as the flow is divided by the dam created by the morphology. The flow directions agree with these observed on the site (Figure 2). In our simulation, contrarily to the real case, the flow after the dam can rejoin itself, since it can not consider the differences in aspect.

In addition the house 4, really damaged, results not protected by the dam, as the streamlines confirm. On the contrary, the yellow structures near it (Figure 2) have a reduced pressure since in the previous impact with the house n.4 the avalanche looses energy.

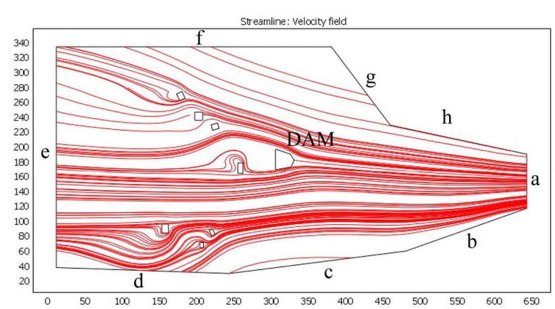

Figure 1: Streamlines in the final avalanche domain

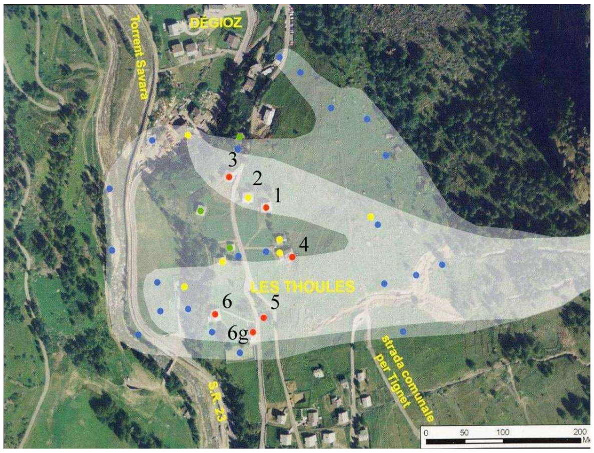

Figure 2: Observed area of influence from the RAVDA (2009).

As concerns the left branch, a simulation is carried.

Initially the velocity direction is proposed only horizontally. In this way, for the house 5 and the garage 6 the pressure values obtained (of order of 40 kPa) agree with those found by Fusinaz (2010) by a back analysis of the damages occurred. On the contrary the house 6 has an underestimated pressure (Figure 3).

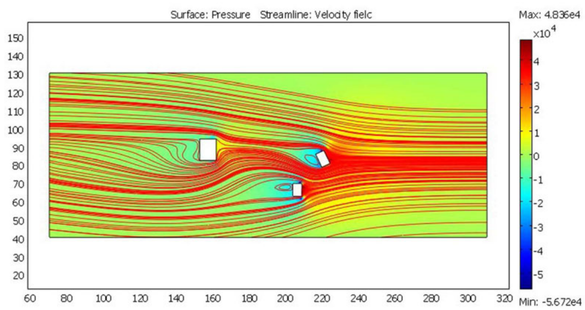

Figure 3: The values of pressure obtained agree with the real ones for the structures 5 and 6g.

Changing the position of the structure 5 the pressure on the house 6 is always to much low (14KPa), in fact it results protected by the previous house.

On the contrary, changing the direction of the flow (by adding a vertical component in the flow), in coherence with the streamlines indicating in Figure 1, the pressure of about 40 kPa is registered on all the obstacles (Figure 4).

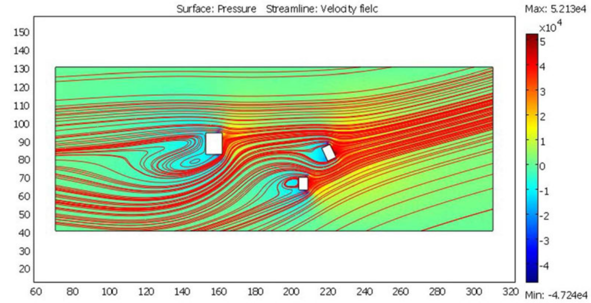

Figure 4: The simulated pressure is correct if the flow direction is oriented as in Figure 1.

Hence, the flow direction, and in particular the angle of incidence, plays a fundamental role in the magnitude pressure values. As in the Swiss procedure (Salm, 1990), the impact pressure is related to the incidence angle through the following relation:

$$p = p_{ref} \sin(90-\theta)^2 \quad (4)$$

This law is verified for a rectangular shape having dimension 5m X 5m. As p_{ref} the upwind pressure calculated for a structure with θ=0° is considered (Table 2).

Table 2: Pressure measured and calculated

Degree	Pressure simulated	Pressure calculated (Eq.4)
45	2,57· 10^4 Pa	2,60· 10^4 Pa
30	3,93· 10^4 Pa	3,91· 10^4 Pa
15	4,86· 10^4 Pa	4,86· 10^4 Pa
0	5,21· 10^4 Pa	5,21· 10^4 Pa

Finally, Figure 5 shows as the obstacles of negligible dimension, as trees of 30 cm of diameter, do not deviate the flow.

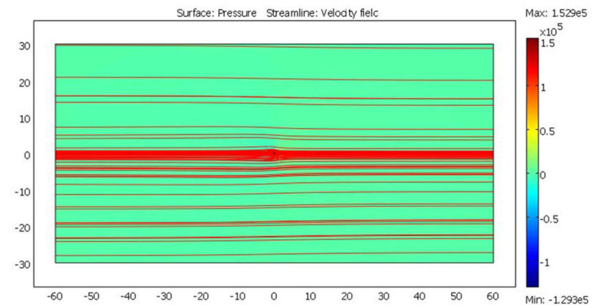

Figure 5: A tree with 30 cm of diameter does not change the flow direction

3.2 Analysis of the Cd coefficient

Usually the pressure is considered proportional to the velocity square through the coefficient Cd:

$$p = \frac{1}{2} C_d \rho_{av} v^2 \qquad (5)$$

The drag coefficient is defined as the following:

$$C_d = \frac{Load}{Bh\rho_{av} v^2 / 2} \qquad (6)$$

where *Load* is the total load in the flow direction, *B* is the width of the obstacle, *h, u* and ρ_{av} are the thickness, the depth-averaged velocity and the density of the avalanche.

Cd depends on the obstacle shape as well as on the avalanche characteristics. In literature different values are proposed. For instance (Jóhannesson 2009) a square within a dry avalanche has Cd=2, while in a wet one it has Cd=4-6, a circle has Cd=1.5 (dry) or Cd=3-5 (wet).

Since in our case of study houses, poles, pylon and trees are been involved, it is interesting to evaluate the Cd coefficient for different shapes, supposing always as initial velocity $|\mathbf{v}|=v_0$.

For instance, for the house number 3 having dimension of 8m x 10m x 8m the Cd obtained using the total force simulated is 1.9 in the case of a 2D stationary simulation, agreeing with the values in literature, and it is 1.59 in the 3D stationary one. Usually, in fact, the Cd obtained in a 3D analysis is lower than in a 2D one.

Furthermore an analysis of the dependence of the obstacle dimension on the Cd is carried, using a circular shape. It is clear, from Figure 6, as Cd decreases with a potential law (in this case having order -0.6). This tendency is experimentally seen by Sovilla (2008) and Thibert (2008) and numerically by Bovet (2010). In fact they suppose:

$$C_d \propto c_1 + \frac{c_2}{\text{Re}} \propto c_1 + \frac{c_3}{L} \qquad (7)$$

since in our case $\text{Re} = \frac{Lv}{\eta / \rho}$ changes due to the different sizes L.

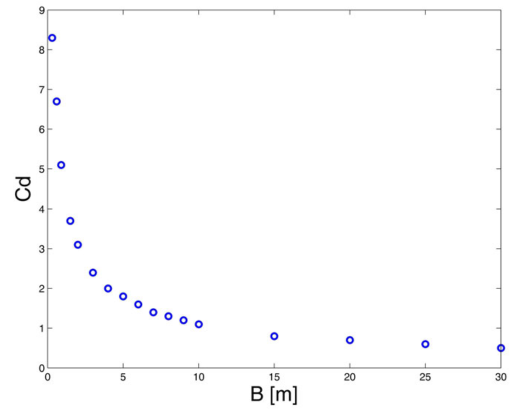

Figure 6: Dependence of the Cd on the obstacle size.

These result do not depends on the domain dimension: for instance for a circular obstacle having diameter of 1.5m (it is tested for a diameter of 30m too) the total load simulated with a domain of 60m x 120m, or of 600m x 1200m is almost the same (2.24e5 Pa m against 2.23e5Pa m). The mesh dimension does not influence these results too.

3.3 Analysis of the Cp coefficient

Along the edges of the structures the pressure assumes different values depending on the Cp coefficient. This analysis has as aim the evaluation of which parts should have been more resistant. In particular, upwind Cp is positive, while laterally and downwind it is negative, indicating a depression. This is in coherence with the wind effects. For instance, the Eurocode (1995) proposes for a square having of edge B and an area larger than 10 m^2 a factor +0.8 for the upwind side, -0.3 for the downwind one, and a factor varying from -0.8 in the first B/5 reached by the flow, to -0.5 in the remaining lateral side. Let is note that these values are quite different in other regulations and take into account of some security factors.

Figure 7 shows, in the stationary 2d simulation, the ratio between the pressure and the maximal positive pressure for the house number 3, supposing an incidence angle of 0 degrees.

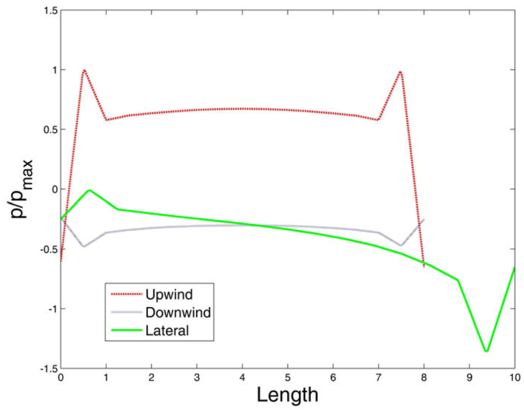

Figure 7: The pressure values along the different edge of the house having dimension 8m x 10m scaled with the maximal positive pressure.

The situation of a 30 cm tree is analysed in Figure 8 too, plotting directly on the boundaries the values of the pressure, scaled with the maximal positive pressure.

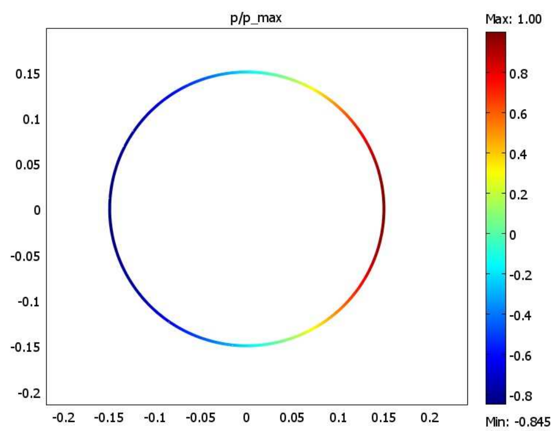

Figure 8: The pressure values, along the boundary of a tree of diameter 30 cm, scaled with the maximal positive pressure.

In the three dimensional approach too, it is possible to visualize the different values of the pressure, as in Figure 9. For instance the pressure upwind is of order 4e4Pa. In particular the values characterizing the roof can be evaluated too. Let is note that in this case the flow depth is introduced.

3.4 *Evolution in time*

In addition, thank to a transient analysis, it is possible to evaluate the evolution in time of the characteristics of the avalanche. For instance, in

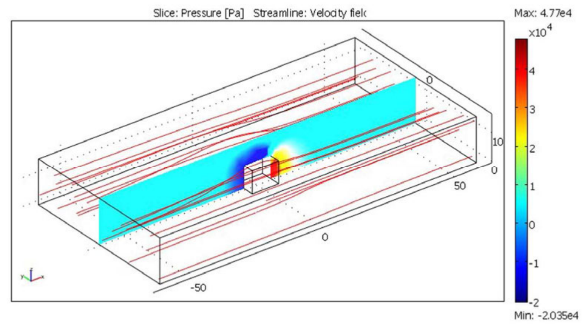

Figure 9: The pressure of impact on the house number 3 with the three dimensional model.

Figure 10 the pressure in the central point upwind the house 3 is shown. Three phases can be distinguished. In the first one, the unreal initial peak means probably that the snow impacting compresses itself. In the second one, a stationary situation gives a pressure similar to the simpler two-dimensional stationary analysis. The third phase shows as in the avalanche tail the pressure decreases to zero.

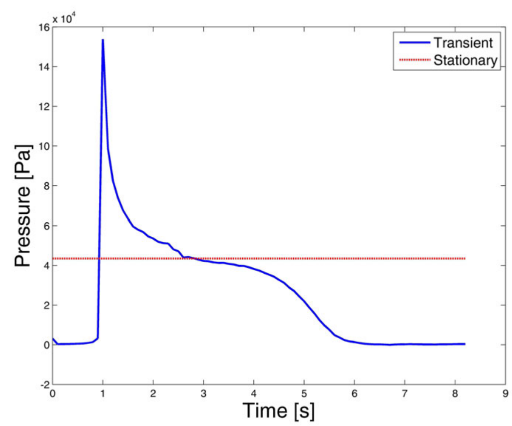

Figure 10: The evaluation of the pressure in the central point upwind the house 3 using the level set method.

3.5 *Different methods comparison*

The 2D stationary simulations are faster, being of order of minutes, than the transient ones, being of order of hours, and give the possibility of having a very fine mesh. Besides they allow to study the coefficients as the Cd and the Cp. However they are not able to analyse the first instants of the impact, on the contrary of the transient analysis. More analysis and studies of the first time step should be made. The 3D simulations, finally, studying the flow along the depth allow to evaluate, for instance, what happen on a roof too. However, the mesh should be refined to have satisfactory results.

4 CONCLUSION

In this paper some analysis, based on a real case study, are carried using different models. The values of the impact pressure simulated are in coherence with those calculated by a back-analysis of the damages. In particular the Cd and the Cp coefficients estimated are in coherence with those found in literature. Besides by the analysis of the streamlines, some considerations on the role played by the dam as well as on the importance of the incidence angle during the impact are proposed.

5 REFERENCES

Bovet, E., Chiaia, B. and Preziosi, L., 2009a A new model for snow avalanche dynamics based on Non-Newtonian fluids, Meccanica, doi:10.1007/s11012-009-9278-z

Bovet, E., Chiaia, B. and Preziosi, L., 2010.Two dimensional numerical analysis of snow avalanche interaction with structures, Geophysical Research Abstracts, Vol. 12, EGU2010-1857-1, 2010 EGU General Assembly 2010, Vienna

Bovet, E., Chiaia, B. and Preziosi, L., 2009b. Numerical analysis of snow avalanche mechanics and of its interaction with structures, XIX Congresso AIMETA, Ancona, 14 – 17 settembre 2009

Bovet, E., Preziosi, L., Chiaia, B., and Barpi, F..2007. The Level Set Method Applied to Avalanches, Proceedings of the European COMSOL Conference 2007 in Grenoble, France

ENV 1991-2-4:1995. 1995.Eurocode 1. Basis of design and actions on structures. Part 2-4: Actions on structures -Wind actions.

Fusinaz, H. 2010. Vulnerabilità delle costruzioni a rischio valanghe: applicazione ad un evento in Valle d'Aosta. Thesis.

Johannesson, T. Jóhannesson, P. Gauer, P. Issler, K. Lied. 2009. The design of avalanche protection dams, European Communities.

RAVDA. 2009. Rendiconto Nivometorologico, Inverno 2008-2009. Regione Autonoma Valle d'Aosta, Direzione Assetto Idrogeologico dei bacini montani, Ufficio Neve e Valanghe. Musumeci Editore

Salm, B., Burkard, A. and Gubler, H. 1990 Berechnung von fliesslawinen: eine anleitung f ur praktiker mit beispielen. Institut fédéral pour l'étude de la neige et des avalanches.

Sovilla, B., Schaer, M. and Rammer, L. 2008. Measurements and analysis of full-scale avalanche impact pressure at the vallée de la Sionne test site. Cold Regions Science and Technology.

Thibert, E., Baroudi, D., Limam, A. and Berthet-Rambaud, P.2008. Avalanche impact pressure on an instrumented structure. Cold Regions Science and Technology.