The avalanche of *la tartera de la Pica* (Andorra)

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ABSTRACT. The great extension of the avalanche path of "la tartera de la Pica" was identified during a systematic avalanche cartography in Andorra (Pyrenees). There are witnesses who, around 1930, saw the avalanche going down around 1200 m (vertical drop) and reaching a zone that, at present, is included in the city of Andorra la Vella and have a dense settlement. The altitude (2295 m at the top of the path), the aspect (SE) and the information about the meteorological characteristics of this zone suggest that, while the long return period extreme avalanches can reach the inhabited area, in general there are not avalanches in this path or they are very small. As a consequence, the population do not have a sense of danger and there is not any prevention or protection measure or control against this avalanche. In this paper we present the study of this avalanche path. The aim of this work is to characterise the extreme avalanches in order to protect this area of high vulnerability. The results of the present study come from the comparison and combination of different techniques and methods: expert criteria, photointerpretation, application of a statistic model and a dynamic model and use of ancient photographs from historical archives.
Key words: Pyrenees, maximum run-out distances, expert criteria, photointerpretation, statistic and dynamic models, historical archives.

INTRODUCTION

The great extension of the avalanche path of "la tartera de la Pica" was identified during a systematic avalanche cartography in Andorra (Pyrenees) (figure 1). This avalanche path is located in the Southernmost part of the Eastern Pyrenees. This region is affected by snow storms originated on the Atlantic ocean and the Mediterranean sea but, because its Southern location and its maximum altitude (2295 m), in general the snowfalls are not very intense.

In this situation, big avalanches are not frequent, but long return period extreme avalanches can reach the inhabited area of Andorra la Vella (figure 2). The population do not have a sense of danger and there is not any prevention or protection measure or control against this avalanche.

In this paper we present the study of this avalanche path carried out by the comparation and combination of different techniques and methods. The aim of this work is to characterize the extreme avalanches in order to protect this area of high vulnerability.

DESCRIPTION OF THE AVALANCHE PATH

La tartera de la Pica avalanche path is located on a Southeast facing slope. Its maximum altitude is 2295 m and there is a vertical drop of 1200 m until the Valira river (994 m). The city of Andorra la Vella spreads at the foot of this steep slope and specially on the west edge of the river in this area (figure 2).

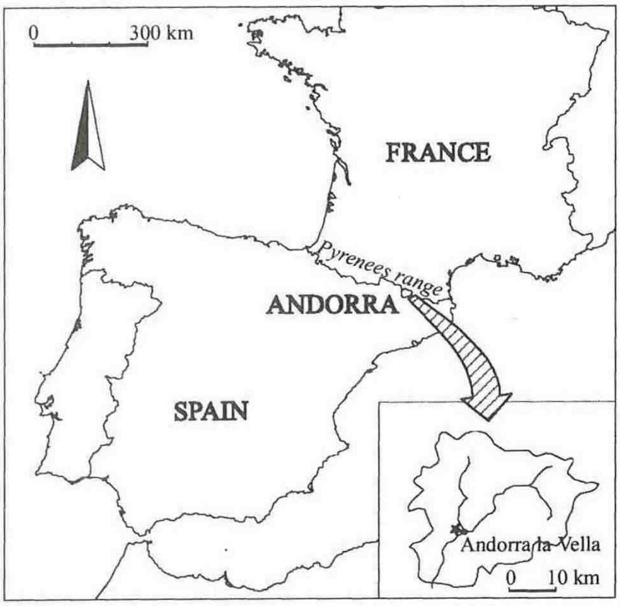

Figure 1: Regional setting of Andorra and the city of Andorra la Vella. The West part of the city was built on "la tartera de la Pica" avalanche path.

In the zone of the middle of the slope the well developed channels confer some roughness. The vegetation of this zone consists on some bushes and few damaged trees. This damage is produced mostly by avalanches and, in some cases, by rock falls.

The top of the slope has a very open basin morphology with very clearly incided chanels. This part of the slope, corresponding to the starting zone of avalanches has a low roughness and has a discontinous recovering of grass.

The lower part of the slope consists on a big and active debris cone, generated by numerous rock falls. The roughness of the surface of this form is very small. On the upper part of the cone there are some damaged trees: some of them present broken branches and scars on the trunk, probably produced by both, rock falls and avalanches, and some of them are broken and clearly oriented in the sense of the maximum inclination as a consequence of their transport by an avalanche flux. On the lower part of the cone there are few damaged trees.

About the inclinations of the slope we can distinguish three different zones: between 2295 m and 1300 m (3/4 of the vertical drop) the inclination range varies between 28° and 42°. Between 1300 m and 1050 m the inclinations are between 15° and 28°. And the last 50 m of vertical drop present an important flattening of the topography.

METHODS AND RESULTS

The present study was carried out by comparing and combining different techniques and methods, some of them suitable for studies of recent history: expert criteria, photointerpretation, use of ancient photograps from historical archives, application of a statistic model and application of a dynamic model.

As there is a testimony of a big avalanche ocurred arround 1930, before the spreading of Andorra la Vella, we compared the different methods assuming the "natural conditions" (without buildings) of that time. This gave us a good approach to the magnitude of the extreme avalanche on this path.

Cartography

The first step consisted on a "classic" French or Spanish cartography of the extreme avalanche envelope by using different sources of information (Borrel, 1994; Furdada, 1996). The original point in the elaboration of this cartography is the combination of two very different approaches, the first one based on expert criteria (mostly topographic and morphologic) and the second one based on techniques used by historians specialised in studies of recent history. The following paragraphs synthesize the two approaches and the most significant data obtained.

Expert approach. This approach consists of the photointerpretation of vertical aerial photographs (in this case colour photos at scale 1:16000 from August 1995) and careful summer field recognition. The result of this cartography is shown in figure 2.

The following considerations can be deduced from the expert analysis of the morphology, the topography and the vegetation of the avalanche path:

-Because of the location and the altitude of the path the snowfalls are scarce. Also, the Southeast aspect of the slope helps the melting of the snow, so there must converge very extraordinary conditions to accumulate enough snow to produce a big avalanche.

-On the other hand, the relative low inclined slopes at the starting zone (never superior to 42°) suggest that big avalanches are rare. These avalanches probably reach long run-out distances because the great amount of snow accumulated before their triggering.

As big avalanches are so rare, there is a loss of historical memory and the population do not have any sense of danger in this area.

Recent history study techniques approach. This approach proved to be very useful in two fields. Firstly to find witnesses and oral information about the avalanches and the snow conditions. And secondly to find graphic information in archives.

About the avalanche testimonys the most important data obtained are:

-February 1996 avalanche: This year was a very snowy year in the Eastern Pyrenees. There were a lot of very big avalanches and a lot of them reached very low zones (one of them was the extreme avalanche of Arinsal, in Andorra, that destroyed a four floor building on its run-out zone). The avalanche of "la tartera de la Pica" stopped at 1300 m of altitude, at the upper part of the debris cone. The feeling of the inhabitants of Andorra la Vella was that this was not a dangerous avalanche.

-1930 decade avalanche: There is not a precise date for this big avalanche, but there exist a testimony. The avalanche reached the altitude of 1010 m (the altitude references nowadays at 1010 m are a new hotel and a school).

The ancient photograps from the 1930 and 1950 decades show a well developped oak forest whose limit correspond to the 1930 decade avalanche.

With all these informations the 1930 decade avalanche was mapped (figure 2).

Another interesting data is about snow accumulations: on the upper part of the slopes located to the West of "la tartera de la Pica" path sometimes there are cornices of 4 meters and snow depths superior to 1.5 m (for example during the 1996 winter).

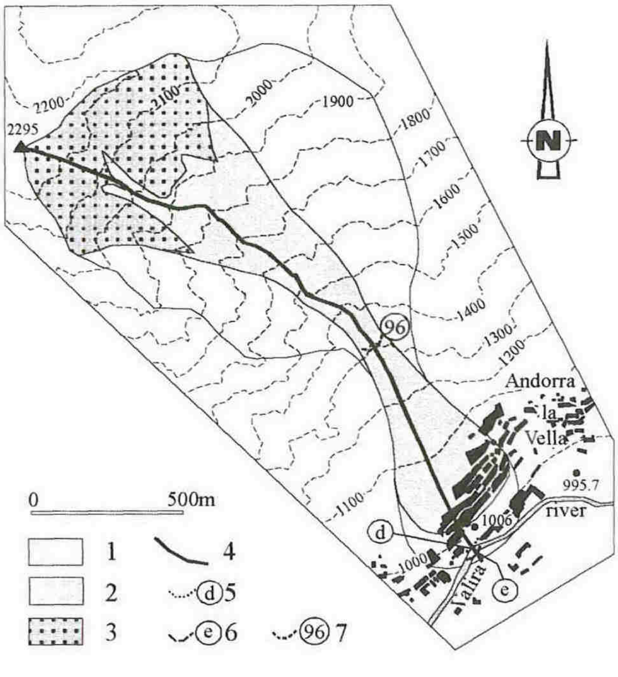

Figure 2: Map of the avalanche path of "la tartera de la Pica". 1: extreme avalanche determined by photointerpretation; 2: avalanche determined by field work, witnesses and photograps from historical archives; 3: estimated starting zone; 4: main avalanche flux line; 5: maximum run-out position (near the Valira river) determined by the Voellmy-Salm-Gubler dynamic model; 6: maximum run-out position (near the Valira river) determined by the statistic model; 7: run-out limit of the 1996 avalanche.

The full integration of an historian to the team gave very good results. With this full integration the historian understood the avalanche problem and the information required to recognize a big avalanche with a long return period. So he was able to find very useful data to improve the final cartography

Use of a statistic model

The statistic model used in this work (Furdada and Vilaplana, in press) was obtained from 216 avalanches of the Western Catalan Pyrenees, very close to Andorra and in the same mountain region (McClung et al. 1989). The method used to obtain the model was that of Lied and Bakkehoid (1980).

The model used to calculate the maximum run-out distance (figures 2 and 3) was:

$$\alpha = -1.20+0.97\beta \qquad (R^2 = 0.87,\ \sigma = 1.74°)$$

The parameters of the model are the following: α [degrees] is the inclination of the straight line between the outer end of avalanche debris and the starting point or gradient of the avalanche path and represents the maximum run-out distance; β [degrees] is the inclination of the straight line between the point on the terrain profile where the slope angle equals 10°, and the starting point or gradient of the track.

For "la tartera de la Pica" avalanche path, the values are β = 32° (from the original map at scale 1:10000) and the calculated α = 29.84°. This means that, in natural conditions and without any topographic obstacle (like buildings), the extreme avalanche just crosses the Valira river.

A possible error in the determination of the run-out distance can be considered. If we apply the criterion of Lied and Bakkehoi (1980) we can approach this error in function of σ. When applying this error and considering the shortest possible run-out distance, the avalanche limit coincides with that obtained with the oral information and the ancient photographs.

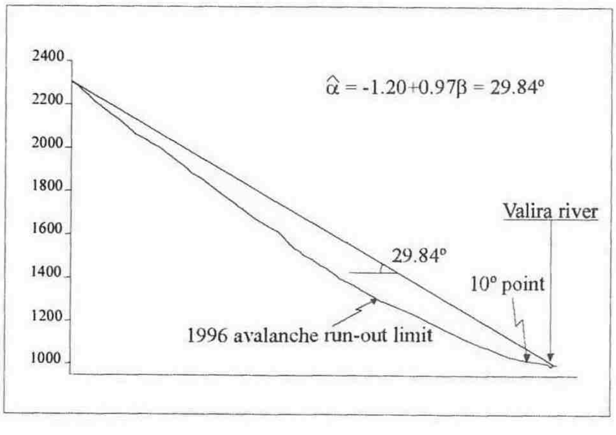

Figure 3: Topographic profile of the main flux line on the avalanche path of "la tartera de la Pica" (see figure 2). The 10°β point, the calculated maximum run-out distance and the avalanche limit of 1996 are located on the profile.

Use of the Voellmy-Salm-Gubler dynamic model

The Voellmy-Salm-Gubler dynamic model (Salm et al. 1990) was also used to calculate the maximum run-out distance of the avalanche. The parameters used were the following:

-fracture depth (perpendicular to the slope) = 1.5 m
-μ (kinetic friction coefficient) = 0.2
-ξ (turbulent friction coef.) starting zone = 800
-ξ (turbulent friction coef.) run-out zone = 1000

The width, length and inclination of the starting zone and the cross section and angle of the track and run-out zones were estimated from the map (figure 2) at an original scale 1:10000. Of course, the values of the parameters were chosen after a careful field inspection. The fracture depth is an estimation because of the lack of accurate snow accumulation data, but we think it is a very reliable value.

The extreme avalanche calculated by this method reaches the Valira river (figure 2).

Figure 2 shows the different limits for the well known, the deduced and the calculated avalanches of "la tartera de la Pica" path. In the case of this path, the limit of the extreme avalanche determined by photointerpretation and the extreme position calculated by means of the statistic model and the dynamic model coincide near the edges of the Valira river, with a difference of around 20 m. These 20 m correspond to the river channel.

On the other hand, the big avalanche occurred in the decade of 1930 coincides with the shortest maximum run-out distance calculated by the statistic model.

The difference between the two positions is about 100 m, so we think that an avalanche larger than the decade of 1930 one can occur.

CONCLUSIONS

As a first conclusion we want to point out the interest of working with an historian, specially in this zone were there is no sense of danger after the no extreme avalanche of 1996. This allowed us to combine the topographic and morphologic indices, the best oral information and the ancient photographs from historical archives to delimit the last big avalanche.

From the comparison of the different methods used it can be seen that:

-In this case, the photointerpretation, the statistic model and the dynamic model gave a similar result: the maximum run-out distance reach the Valira river. There is a difference of about 20 m (that corresponds approximately to the river channel) between the three limits of the avalanche.

-The avalanche occurred around 1930 was a little bit smaller than the extreme avalanche determined by photointerpretation, the statistic model and the dynamic model, so a bigger avalanche than 1930's one might happen.

The maximum run-out limit of the extreme avalanche gives us an idea of the size of the avalanche. Andorra la Vella buildings spread over the avalanche run-out zone (70000 m^2). Nevertheless, an extreme avalanche would affect the first line of buildings, but would not reach the river.

We think that prevention measures in the starting zone would be adequate to decrease the avalanche danger. Any protection measure built in the run-out zone would bear in mind also the active rock fall dynamic.

As a last comment, we want to point out again that the historical memory is lost very easily, so it is very important to generate avalanche cadastres as complete as possible and, if it is possible, do it with the aid and the complete integration of historians on the working teams.

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