Use and validation of a three-dimensional simulation model to quantify the rockfall residual hazard on the funicular railway in Vall de Nuria.

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This dissertation is a study of rockfalls using a three-dimensional simulation model called Rotomap. The aim of this study is to evaluate-quantify the rockfall hazard on the funicular railway in Vall de Nuria, in an area of high priority action in the work done to prevent rockfalls.

The dissertation is divided into three parts:

In the **first section** we gave an introduction to the studied area, a description of the previous situation and we expounded the aims of this dissertation.

In the **second section** I explained the current ideas relating to rockfall and the parameters that determine their behaviour. I showed some of the two-dimensional models that attempt to explain the phenomenon and then I embarked on an explanation of a three dimensional (3D) rockfall simulation program, called Rotomap (Geo & soft). Here we looked at the parameters observed within this model: boulder mass, the normal and tangential coefficients of restitution, the friction coefficient of the rolling boulders, the limit angle and the 3D topography described by a Digital Elevation Model.

In the **third section** I utilised all previously obtained knowledge in a real situation. I applied the Rotomap rockfall simulation program in a high rockfall risk area in the funicular railway in Vall de Nuria. This railway line has suffered many rockfalls throughout its history; these have been of great magnitude on more recent occasions. For this reason we tried to understand the residual hazard, considering this latter as a hazard despite the protective systems, in this case, as barrier fences. In the second section I explained the methodology used to obtain the previously mentioned parameters and the difficulties encountered in calculating some of these, given that the reality of any practical situation is always more complex than the theoretical models initially presented. I explained how we do the model calibration in order that the simulated boulders imitate the recent rockfalls. Once the model is calibrated we can used it to predict the nature of future rockfalls.

In the bibliographic searches that have been undertaken no real examples of the rockfall simulation using the Rotomap 3D model have been found. Therefore I have made a special effort to understand the influence of each parameter of the model in the results I obtained, thereby studying the variants in the results when making small changes to the said parameters.

I assessed the magnitude of the hazard presented by means of the Energy of the rocks in each point of the trajectory, the most probable trajectories of the boulders, and the high of the bounce caused by the impact against the terrain. Based on these results we carried out a design and find an alternative location where we can incorporate the currently existing protective systems, in order that these measures allowed us to diminish the residual level of hazard and ensure an acceptable level of risk for the railway line, for the funicular and for the people.

I carried out the simulation using two different topographic bases: the first is from Digital topographic Map scale 1:5.000 and the second is a detailed topography obtained through the new laser scanner technique. I carried out a comparison between the two because I didn't attain satisfactory results from the former, whereas the results obtained using the latter were in fact satisfactory.

The methodology used to obtain the parameters of the simulation model and the readings obtained from these parameters were used as a basis for rockfall peligrosity studies in other problem areas in Vall de Nuria. These studies are outlined in the applied research project REN 200-0518/RIES "Geological Hazard and Risk assessment in mountain areas exposed to snow avalanches and rockfalls", the researcher responsible for this work is J.M.Vilaplana, my dissertation tutor. The results obtained from this model were used as a guide for the execution of the work done to prevent rockfall hazard in the studied area, in the event that the residual hazard is greater than acceptable hazard.