



Can the propagation speed of snow avalanches be determined by seismic methods?

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SUMMARY

The main question of the given work is whether the propagation speed of snow avalanches can be determined using seismic observations. The significance of having at least an order of magnitude estimate of this basic physical parameter is doubtless: in order to reduce the risks associated with this frequently occurring natural phenomena it is crucial to design the constructions (including protective structures) that can withstand the impact pressures exerted by avalanches. However, the estimation of these pressures requires the knowledge of the propagation speed of the avalanche. The same is also true in case of determination of the hypothetical run out distances of avalanches during the modelling procedure. In this study we illustrate different methods, with its advantages and pitfalls, of estimating avalanche propagation speed from seismic observations. For this purpose, we utilize a set of seismic data from the avalanche test site in Ryggfonn, Norway.

1. INTRODUCTION

One of the basic physical parameters characterizing the dynamics of snow avalanches is its propagation speed. The knowledge of the given parameter is essential to study the risks associated with this frequently occurring natural phenomenon. In particular, without the knowledge of the speed of the avalanche it is impossible to estimate the impact pressures on various objects encountered by the avalanche along its path, as well as to determine the hypothetical run out distances of avalanches during the modelling procedure.

The snow avalanche team of the Universitat de Barcelona (UB) has been studying the characteristics of snow avalanches since 1996, mainly utilizing the seismic methods of investigation (Suriñach et al., 2000). Until recently our studies have concentrated on studying the seismic signals of the avalanches that occurred in the valleys of Boí Taüll and Núria (Catalan Pyrenees) and Vallée de La Sionne (Swiss Alps). However, starting from 2002, within the framework of the EU funded project "Avalanche Studies and Model Validation in Europe" (SATSIE) we have extended our studies to the avalanches recorded at the test site in Ryggfonn, Norway. One of the main objectives of this project is to contribute to a better understanding of the dynamics of the avalanche propagation by observations and measurements of various physical parameters and their consequent incorporation into the numerical models.

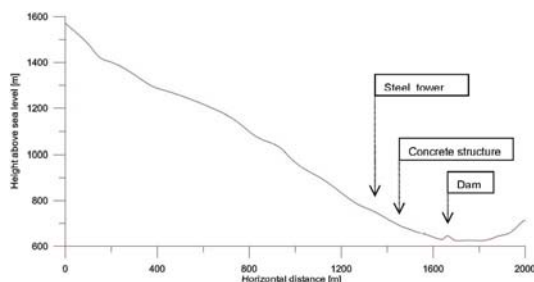


Figure 1 – Topographic profile of the full scale avalanche test site in Ryggfonn, Norway (after Lied et al., (2002))

In order to provide answers to the objectives set by the SATSIE it is essential to provide an estimate of various physical parameters that characterizes the avalanche and its propagation. With this in mind, the test site in Ryggfonn has been equipped with various scientific instruments (see the discussion below), including two three-component geophones installed by the UB team in Autumn 2003. The installation of this equipment was prompted by the success of our previous studies, conducted in the Alps and the Pyrenees (Biescas, 2003). In Ryggfonn we adopt the same

methodology taking into account different snow and topographic conditions of the given site.

In this study we utilize the seismic data collected in Ryggfonn in the previous years by the Norwegian Geotechnical Institute (NGI) using a set of one-component vertical geophones. This was done with the aim of preparation for the analysis of the new data expected to be recorded by the new equipment installed by us recently. In addition, we have explored the possibility of determining the propagation speed of avalanches by using the signals already recorded by the NGI geophones.

2. EXPERIMENTAL SITE

All of the data presented in the given paper were collected at a full scale avalanche test site located in Ryggfonn, North-West Norway and operated by the NGI (Lied et al., 2002).

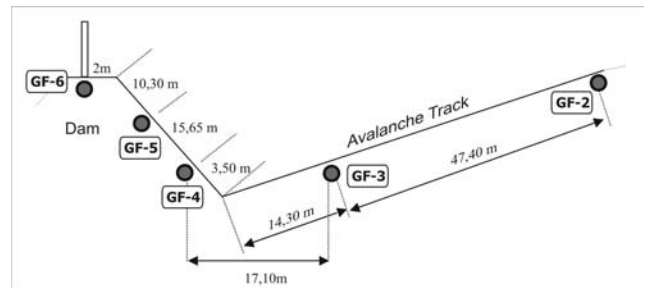


Figure 2 – Distribution of geophones in the lower part of the site.

The site consists of a concave shaped channel of 900 m vertical drop and a path length of 2100 m. Typical avalanches range in magnitude from 10,000 m³ to 500,000 m³, with maximum velocities up to 60 m/s. The NGI has initiated its experiments at Ryggfonn in 1980 and since then the configuration of the instruments deployed at the site has varied. Most prominent feature of the Ryggfonn site is the existence of 16 m high and 100 m long catching dam at the bottom of the avalanche path (Figures 1 and 2). The site is equipped with various instruments, including the pressure load plates, strain gauges and geophones. The data collected from the latter will be the subject of our discussion.

In total the site is equipped with 6 vertical component geophones (model SM-6 from Input/output Inc) with a natural frequency of 4.5 Hz. The 1st geophone is located inside the tubular steel tower 330 meters up-slope the avalanche path (Figure 1). This sensor is used to trigger the data logger that acquires the signals from five geophones that are buried in the ground in the lower part of the avalanche path. Two of these sensors (GF-2 and GF-3) are located before the dam and three (GF-4, GF-5 and GF-6) in the front of it (Figure 2). The signals from all the sensors were recorded with a PC-based data acquisition system (model LogBook 300 of IOTech Inc.) located



inside the instrument shelter ~500 m away from the dam. The sampling rate was 125 samples per second.

3. DATA ANALYSIS

For the given study we have considered the geophone data from half a dozen avalanches (dry and power-dry snow) that occurred either naturally or were triggered artificially, between 1983 and 2000. Our data analysis technique consists of four main steps. In the first step we obtain the data from the data acquisition system and perform a quality check by examining the signal to noise ratio of the avalanche generated signal.

The example of the raw data from the 17/02/2000 avalanche is shown in Figure 3.

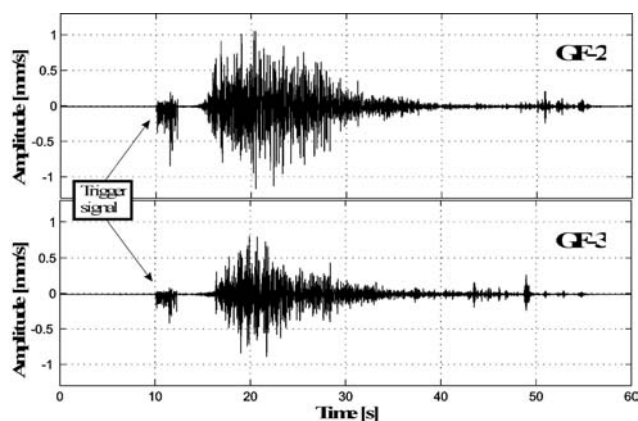


Figure 3 – Seismograms from GF-2 and GF-3 geophones recorded during the 17/02/2000 avalanche.

In the second step we perform a Fast Fourier Transform (FFT) of the avalanche signal with the aim of studying the spectral characteristics of the signal. In the third step we study the signals in more detail; we examine the data in the time and frequency domains by computing a running spectrum of each available seismogram. With this we obtain the evolution in time of the frequency content. An example is shown in Figure 4. Previous studies indicate that maximum amplitudes in high frequencies in the running spectrum correspond to the time when the body of the avalanche passes over the sensor (Biescas et al., 2003). This result is a consequence of the different attenuation of frequencies with distance. Thus, by means of combining the methods of running spectrum and a detailed time series analysis, we are able to differentiate the parts of the signal corresponding to different sources. The final fourth step of our data analysis includes the cross-correlation of pairs of signals corresponding to the same source recorded at the different sensors. With this approach we hope to obtain an estimate of the propagation speed of the snow avalanche. However, as discussed below, the reliable estimation of this basic physical parameter is not at all straightforward and might require further studies, including specially designed instrument setups.

4. DISCUSSION

Since the results and the discussions presented in the given paper are part of the ongoing investigation, they still carry a preliminary character and are subject to change. For this reason, at this stage we are not able to draw any definite final conclusions, but instead would like to engage in the discussion of the importance and the potential benefits of seismic methodology as applied to the snow avalanche studies. The main goal of the given work is to find out whether it is possible to estimate the propagation speed of an avalanche using seismic observations. Specifically, we seek the answer to the given question applied to one particular avalanche test site, located in Ryggfonn, Norway. Taking into account the specifics of the instrument setup at this site, including the fact that all data obtained in Ryggfonn have the same time base, we can think of three particular methods of determining the avalanche propagation speed,

although we do not exclude that one might think of other ways as well.

The first method utilizes a combination of the running spectra (Figure 4) and detailed time signal analysis in order to find the exact time of the passage of the avalanche overhead the buried sensors. With this knowledge we can obtain the time difference between the arrivals of the avalanche at two sensors. Combining this information with the distance between the sensors (derived from the precise topographic maps) should enable us to determine the propagation speed of the avalanche.

The second method involves the estimation of the time that it takes for the avalanche to travel from the GF-1 located on a steel tower (when the trigger signal is generated) to the particular geophone buried in the ground in the lower part of the path (ΔT_1 and ΔT_2 in Figure 4). Using these times and the distances between the two lower geophones and the steel tower we can determine the speed. Theoretically, this method should allow us to obtain a more precise estimate of the speed than the first one. This is due to the increased distance between the sensors and the steel tower, leading to the reduction of the errors in selecting the avalanche arrival time.

The third method is the most straightforward and consists in finding the time between the start of the trigger and the stop of the avalanche. The latter can be determined from the seismograms by finding the time when the seismic coda decreases to the noise level. If we combine this time with the distance between the steel tower and the place where avalanche stopped (obtained by the post avalanche field mapping) we can obtain an average estimate of the avalanche speed downhill the steel tower. With this method we are assuming that avalanche is not producing any seismic signal when it stops and we have enough sensibility in our sensors to discern between noise and signal.

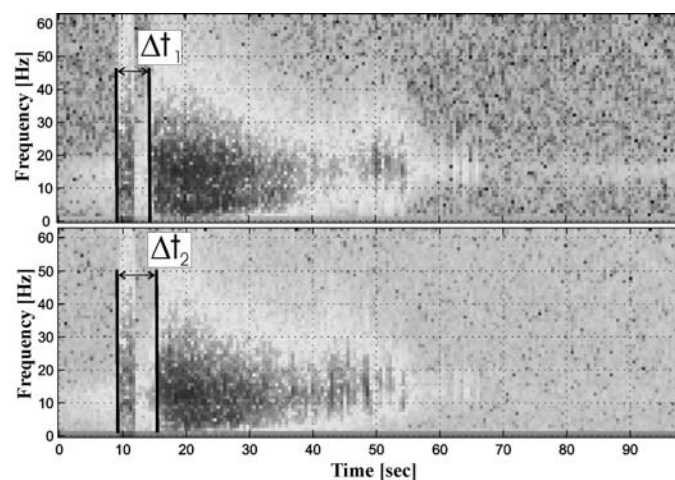


Figure 4 – Running spectra of seismograms shown in Figure 3.

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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