Measuring of rotation and acceleration during rockfall

Werner Gerber, Dipl. Bauing. FH[1]; Christoph Wartmann, Dr.[2]; James Glover, Dr.[3]

INTRODUCTION

The rotational velocity of rockfalls is an important component of the total kinetic energy of rockfalls, in addition to the dynamics involved during an impact. These are important parameters for rockfall modeling and the dimensioning of rockfall protection barriers. The rotational speed of rocks can be related to the translational velocity and the average diameter of the rock, and during ground impacts the frictional contact is responsible for changes in rotational velocity. This is in part dependant on the damping properties of the soil and the form and angularity of rocks. Detailed measurements of the rotational velocity and accelerations due to impacts are however largely unknown. In this contribution we describe the development of a measurement module which can be inserted into a rock to capture its rotations and impact accelerations about its three principal geometric axes during rockfall motion. The module is controlled wirelessly and stores data internally which can
be downloaded via the wireless connection following an experiment. We present the findings from laboratory calibration experiments and initial rockfall field testing with the module using small sized rocks (concrete cube).

ROCK MOTION LOGGER

The rock motion logger is a module of micro sensors complete with wireless interface and custom software to allow remote control and data extraction in field situations. Installed in the module is a three axis gyroscope ITG-3200 measuring up to 35 rad/s (2000°/s), and three ADXL 193 acceleration sensors measuring up to 250 g. Data are stored on a 128 MB SD card the Module is controlled using an Arduino FIO Microcontroller (ATMEL 328) which is communicated to through using a ZigBee Wireless communication system at 2.4 GHz. One of the challenges during its development was to find an efficient data storage method that could deliver the high frequency data logging required to capture the rapid motions of rockfalls. The best solution was to use SPI to read and write to the SD card with raw data (which means without file system like FAT). With this it is possible to capture activity at a rate of 600 Hz. The use of micro sensor technology in its construction has ensured that the module is sufficiently small (7.5cm x 3.5cm x 2.5cm) that it can easily be inserted into the centre of a rock by drilling into its centre.

VERIFICATION OF MEASUREMENT DATA

In order to verify the sensor data, the measurement module was attached to a bike wheel and rotated. The experiment was filmed using a high speed camera from which the rotational velocity could be verified and compared to the measurements of the gyroscope. The accelerations were verified using the same data set by calculating the centrifugal force acting on the accelerometers during their rotation in the wheel. This was calculated using the known distance of the accelerometers to the centre of the wheel and the rotational velocity measured with both the gyroscope and video data. Knowing the maximum rotational speed was important for the accelerometers because with this it was possible to calculate the maximum g-force the accelerometers would be exposed to. The verification experiments have shown that the measurement module is functional and that the measurements of rotation speed and acceleration are correct. Following this verification, experiments in the field and with other conditions could be made.

FIELD TESTING

First field tests were conducted using a concrete cube with dimensions of 20-20-20 cm with a mass of 18 kg. The measurement module was fixed into a 50 mm diameter plastic tube and mounted in the centre of the concrete cube. At first the cube was

thrown into short slopes of 10-30 m in length with an inclination of about 30°. In total the duration of the experiments was 3-7 s. The data clearly indicate individual impacts as significant acceleration peaks which are also reflected in stark changes in the rotational velocity. The maximum time interval between two ground contacts was 0.5-0.7 s, and the maximum absolute acceleration values were 500-700m/s^2 with an average of 100-300 m/s^2. The change in rotation speed is clearly visible during ground contacts, between the ground contacts constant values are measured. The maximum values of the absolute rotation speed were 20-40 rad/s (Fig.1).
In addition to this small test series a second field experiment was conducted using the small concrete cube in which the runout distances were extended to between 80 and 250 m with a height change of 35-100 m. The terrain was mostly grassy slope of about 35°. Under these conditions, significantly higher speeds of the cube were observed and in all the movements lasted 10-40 s. This generated a large data set of many individual impacts in which the maximum accelerations were mostly between 500-1000 m s-2 for impacts on the grassy slope.

On the test slope there was a portion of a mountain road, of the impacts that occurred on the denser more compact road surface, accelerations of between 1500 and 2500 m/s2 were measured. In all the rotational velocities ranged between 40 and 60 rad/s and as in the initial verification experiments, the maximum rotational capacity of the gyroscope sensor could be exceeded.

DISCUSSION

Within this project it could be demonstrated that three dimensional rotational velocities and accelerations of a rock body impacting the ground can be measured during rockfall runout. The results of the field tests clearly show that the limit capacity of the individual rotation sensors (35 rad/s) are achieved relatively quickly. Moreover, with the hard impacts on paved roads, the capacity limits of 2500 m/s2 can be achieved. In the future experiments with larger rock bodies it is therefore necessary that higher capacity sensors are installed. With this project for the first time very interesting and good results about acceleration and rotation speed have been achieved.

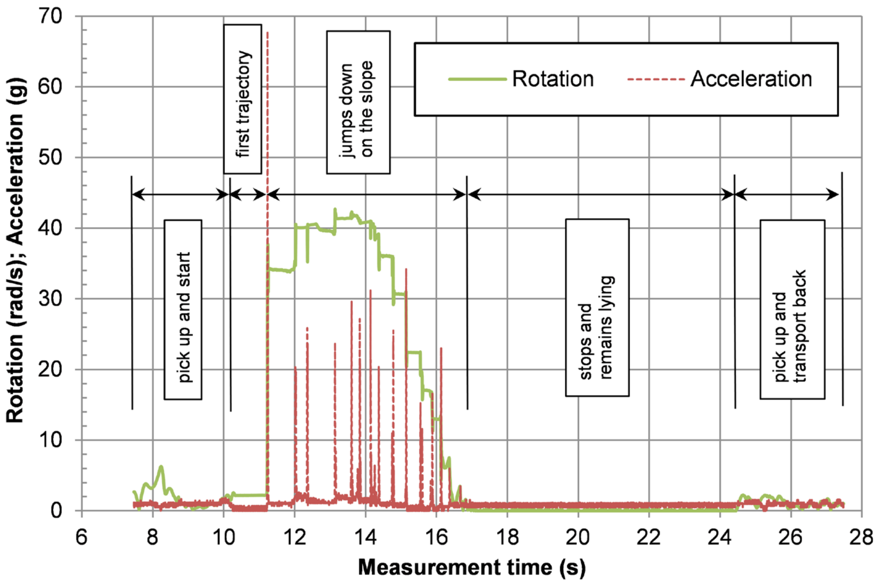

Figure 1. Measurement of rotation and acceleration during the entire experiment

KEYWORDS

Rockfall; rotation; acceleration; measuring

1 Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, SWITZERLAND, werner.gerber@wsl.ch
2 Embedded Lab, Totalpbachstr. 8, Davos, SWITZERLAND
3 WSL-Institute for Snow and Avalanche Research SLF, Davos, SWITZERLAND