CALIBRATION METHODS FOR NUMERICAL ROCKFALL MODELS BASED ON EXPERIMENTAL DATA

Andrin Caviezel[1], Marc Christen[1], Yves Bühler[1], Perry Bartelt[1]

Experimental data sets of induced rockfalls are used to enhance calibration methods for the existing RAMMS::ROCKFALL software package. Repeated release of the same rocks instrumented with acceleration and gyroscopic sensors yields statistical information of their deposition points and provides direct measurements of the rotational speeds and acting impact forces. The presented data and the subsequent calibration of the software code via real experimental data outlines an objective path for selection of terrain parameters.

Keywords: rockfall, experimental data, simulation, RAMMS calibration

INTRODUCTION

Residents in mountainous areas are well aware of the necessity of mitigation of rock fall hazards in order to prevent damage of infrastructure such as roads, railway lines, or houses. Mitigation of this hazard relies on the combined use of the different data sources such as observations, measurements and information gathered through numerical simulations. It is key that all available information is as objective as possible, without interpretation bias and that a quantitative measure of the information is provided

Amongst many other methods such as topographical analysis, consulting natural hazard registers, event maps, etc., information gathered via numerical modelling has become of growing importance over the past years. Several different mechanical models and thus simulation software tools have been developed ([1-6] and references therein) and are available for risk assessments. These 3D approaches bear the strong advantage that they include detailed terrain information and improve the estimation accuracy for outliers. Whereas its output is basically free of interpretation, the reliability and user friendliness relies on well calibrated input parameters for any given conditions. Due to the scarcity of real-world data most often a numerical model is calibrated via case studies. This approach already yields good results, however, the direct comparison with experimental data is preferred. Here, we present data gathered with an in-situ sensor node [7] and a similar in-
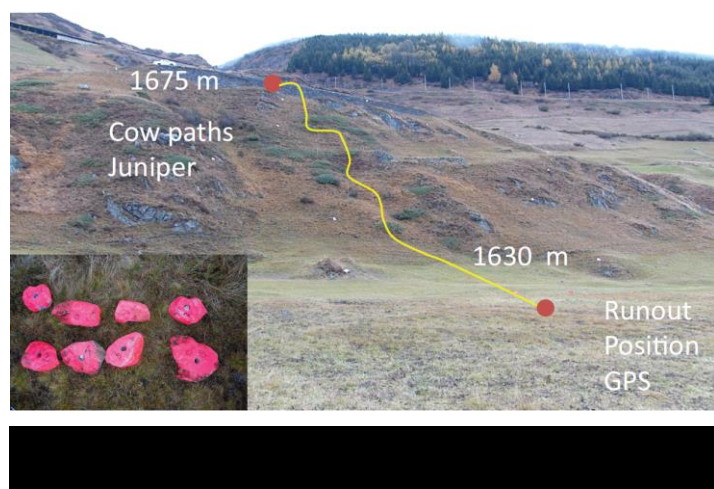
Rocexs: Rockfall Expert Networka   aa

house development. While only a few of such sensors have been developed so far [8,9] with either dated components or not sufficient sensor ranges the used sensors focus on improved ruggedness, form factor, update rates and convenient data retrieval. Details of the design and components can be found in Ref. [7]. We present typical data sets and provide a preliminary comparison to simulated data which drafts the up-coming calibration work.

EXPERIMENTAL SETUP

The experimental site in Tschamut is located at 696607/167726 (CH1903 LV03) near the small settlement Tschamut on the road to Oberalppass. The start position on the road is situated at roughly 1675 m.a.s.l, the runout situated at ca. 1630 m.a.s.l. with a rather uniformly alpine meadow. The slope consists of a inclined area of 40 degree, offering typical coexistence of alpine meadow, rocky sections, juniper vegetation and is shown in Figure 1. The Tschamut site offers good accessibility of the release and runout zones due to road access. The inset in Fig. 1 shows eight rocks collected in the Bondasca valley in Bergell. These granite rocks have been collected with the goal to overcome the frequent problem of fragmentation observed in previous experiments. Additionally to the eight Bergell rocks, the heaviest rock from a previous experiment and a normed shape EOTA rock are added to a second experimental campaign. A drilled hole of 68 mm diameter allowed to fix the used sensors closely to the center of mass. Figure 2 shows, that according to the Sneed and Folk classification (1958) the used rocks belong to the equant, compact bladed and elongated categories. Table 1 summarizes the specifications of the rocks taken from the digitized point cloud later used for RAMMS::ROCKFALL simulations.

RESULTS AND DISCUSSION

The first experimental campaign (*RF04*) has been conducted after heavy rain falls on rather soft terrain. It consisted of six releases of Rock 1-8, yielding 48 deposition points of which 25 trajectories have been successfully recorded with in-situ intruments. Figure 3a shows the overview of the experimental site with all of the deposition points as well as the release point. The second experimental campaign (*RF05*) depicted in Fig. 3b has been conducted on frozen ground with six releases of Rock 1-8 and TS2 and seven releases of the EOTA block totalling to 57 deposition points due to the destruction of Rock 7 in the third release. In-situ data are available for 26 trajectories. The larger runout distances for frozen ground are evident.

Fig. 2: Sneed and Folk classification (1958)
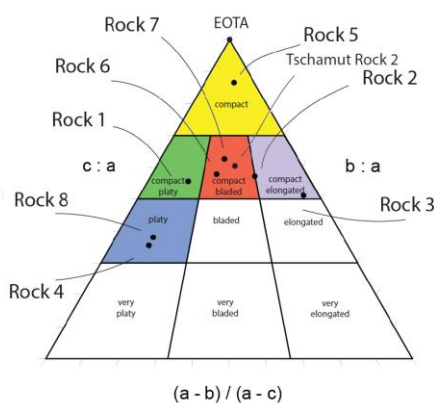
Rock	Dimensions (m)	Weight (kg)	Volume (m^3)
1	0.36/0.32/0.20	30.5	0.011
2	0.41/0.30/0.24	34.8	0.013
3	0.49/0.25/0.27	42.4	0.016
4	0.43/0.48/0.18	34.8	0.012
5	0.37/0.34/0.32	42.6	0.016
6	0.45/0.37/0.26	41.1	0.016
7	0.33/0.40/0.25	29.9	0.011
8	0.52/0.58/0.22	52.2	0.019
TS2	0.50/0.39/0.30	78.4	0.030
EOTA	0.3/0.30/0.30	44.0	0.016

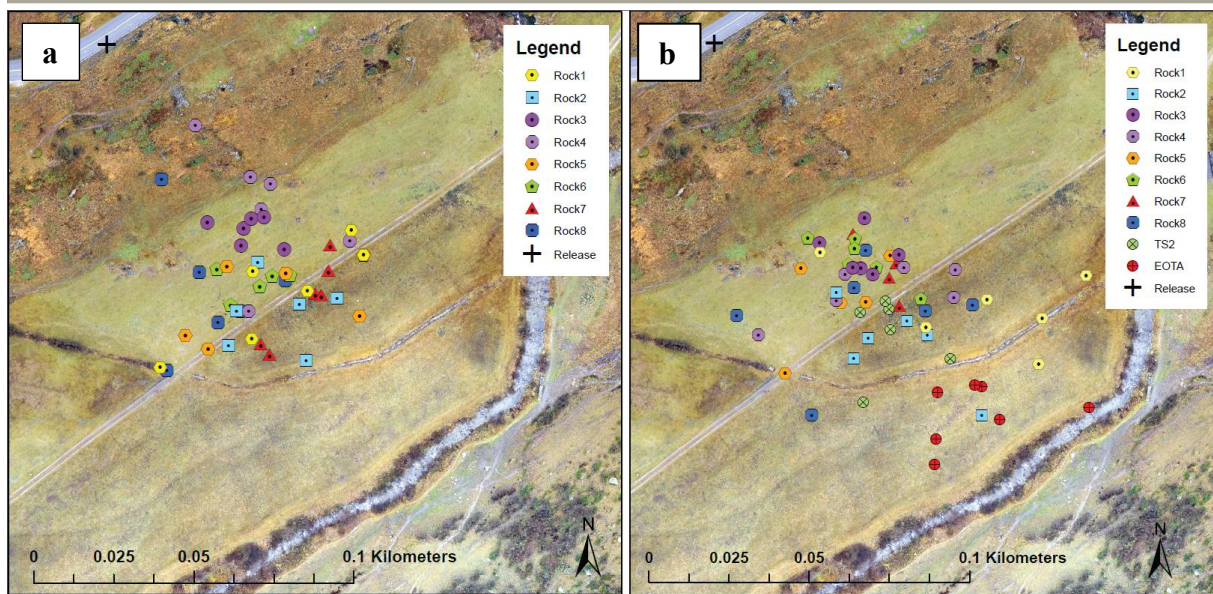**Tab. 1**: Dimensions, weights and volumes of the used rocks

Fig 3: Release point and deposition points for two different experimental campaigns *RF04* and *RF05*: the left panel was conducted at rather soft soil conditions, the right panel at frozen ground.

A parameter sweep for RAMMS::ROCKFALL simulations is conducted. Due to the close to ideal runout area, the center of mass and the principal axis orientations of the two dimensional Gaussian ellipsoids are chosen to be the parameters of interest. Figure 4a shows the best fit for Rock 1, while Fig. 4b depicts the simulation result with these parameters for the entire rock ensemble Rock 1-8 and is in good agreement with the experimental result. The limitations of the principal axis criterion for circular distributions becomes obvious. Additionally, Fig. 5 shows the comparison of experimental sensor data of Rock 1 during the *RF04* campaign with simulation output using the best parameter fit of the previously conducted parameter search. The qualitative and quantitative agreement is striking.
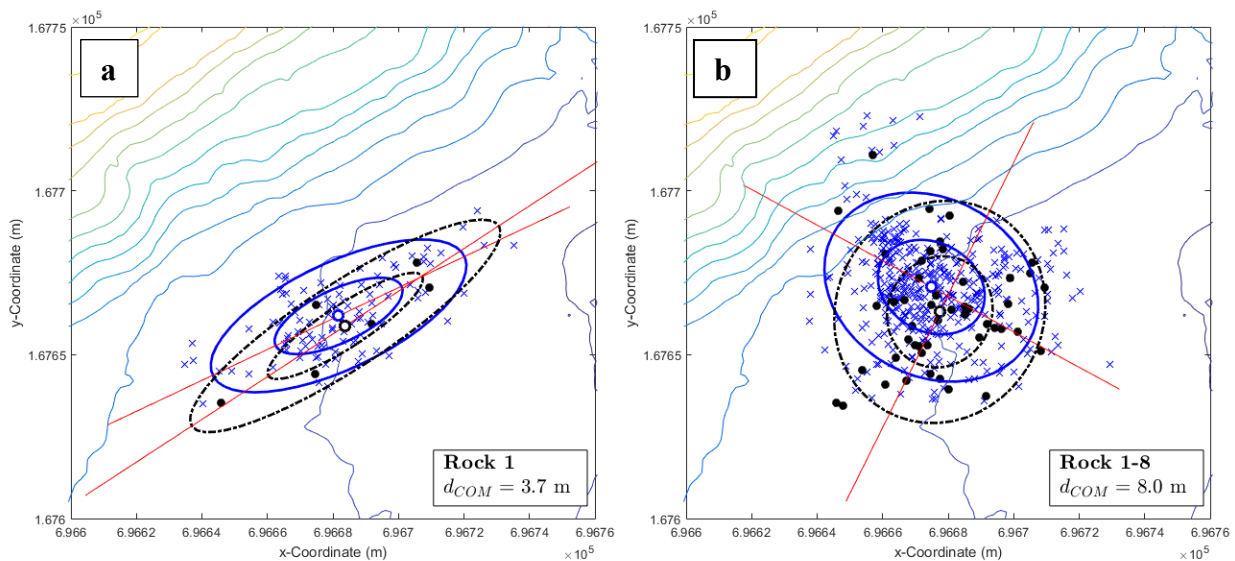

Fig. 4: Parameter evaluation for Rock 1 (a), and Rock 1-8 (b) for the deposition points conducted on soft ground. Accuracy of the evaluated parameters is judged via the offset in the center of mass of the deposited rocks as well as the deposition angle of the distribution.
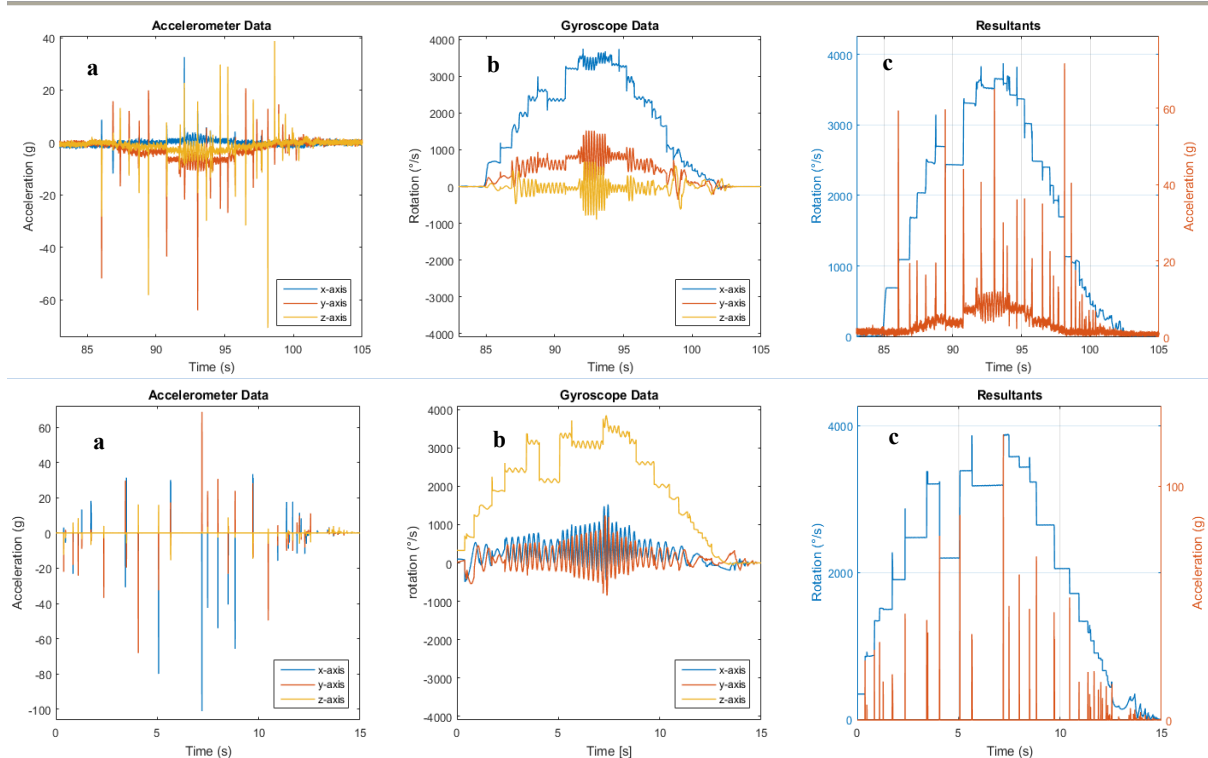
Fig. 5: Typical measurement traces (upper panel): (a) tri-axial accelerations, angular velocities (b), and (c) absolute magnitudes representing the third run of the compact bladed *Rock 1* in RF04. The lower panel shows a single simulated trajectory of Rock 1.

CONCLUSION AND OUTLOOK

Experimental data of induced rockfall experiments are used as calibration input for the simulation module RAMMS::ROCKFALL. Terrain parameters are chosen corresponding to the best congruence of the respective Gaussian ellipsoids. Strong qualitative and quantitative agreement of acting accelerations and rotations between simulation outputs and experimental data are found. Extended analysis routines will involve congruence fitting of all used rocks and comprehensive cross-checking for best fits. Therefore, a stringent routine has to be determined to tackle this multidimensional problem.

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