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Influence of DEM resolution on numerical modelling of debris flows in RAMMS - Selanac case study

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Abstract Debris flows induced by intensive rainfall represent very hazardous phenomena in many parts of the World. Methods for prediction of runout distance of flow like mass movements are different and depending on the input data, rheology, and available or appropriate numerical solution. However, sometimes it is not easy to obtain pre event and post event high-resolution data in the rural or mountainous area. Thus, the topology of terrain is the most important input parameter for the every real case study modelling,. This paper presents results of continuum mechanics-based models tested in RAMMS:DEBRIS FLOW® with different resolution of input data on the Selanac debris flow in Western Serbia.

Keywords debris flow, modelling, RAMMS, DEM

Introduction

Debris flows are one of the most dangerous and unpredictable landslide types. In modelling of flow type landslides, there are few approaches nowadays that should be considered: mathematical, constitutive (rheological) and finally numerical approach. Generally, numerical approaches are divided into two goups: empirical-statistical (Rickenmann, 1999, Legros, 2002), while others are based on physical-deterministic (dynamical) approaches (Savage and Hutter, 1989; Hungr, 1995; Iverson, 1997; Takahashi, 2007; Wu, 2015). Many empirical-statistical methods for run out prediction require only a few input parameters and they are relatively easy to use. In contrast, dynamical models are independent from local conditions, since such models implement physical principles, like the conservation of mass, momentum and energy of bulk mixtures (Rickenmann, 2005).

In this paper, results of RAMMS debris-flow dynamical method are tested, based on Voellmy (1955) approach, which was specially designed for snow avalanches (Bartelt, 2015; Christen et al., 2007; 2010a; 2010b). Nevertheless, it is also suitable for modelling of other processes such as rock avalanches and debris flows (Schraml, 2015; Sosio, 2007; Frank, 2017). As input, three quantities must be specified to perform a numerical calculation: (1) a digital elevation model (DEM), (2) source zone area and (3) model friction parameters. Pre-event DEM resolution characterizes the natural terrain surface geometry and it is therefore the most important input parameter. Resolution of DEM defines at the same time precision of curvature, and finally precision of initial parameters and deposition zones.

The Selanac debris flow was triggered after extreme precipitation of about 230 mm over a period of 72 h in May 2014.The Selanac is a complex debris flow, with large depth in source zone (30m), and length of about 1.5km. First results were made using 30x30m DEM as input, and another with much more precise 5x5m DEM. New UAV scanning of post event topology was obtained in 2017 and additionally had helped in defining precise dimension of release, erosion and deposition zones for better models. Better resolution affected a lot in results about deposition depth, but also on choosing right frictional parameter in rheological model.

Method

One of well used rheological model is Voellmy method (Voellmy, 1955) firstly used in snow avalanche models, which means that is basically one-phase. It is assumed that the initiation mass starts to move as a plug defining shear stress in different points of transportation path.

RAMMS DBF software is FVM (Finite Volume Method) based software for modelling of debris flows. RAMMS was developed in 2005 by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Birmensdorf) and the Swiss Federal Institute for Snow and Avalanche Research (SLF, Davos).

The mass balance equation incorporates the field variables flow height H (x, y,t) and flow velocity U (x, y,t) and is given by:

$$Q(x,y,t)^{\cdot} = \partial tH + \partial x\,(H\,Ux) + \partial y\,(H\,Uy) \qquad (1)$$

where Q(x, y,t) $^{\cdot}$ describes the mass production source term, and Ux and Uy represent the depth-averaged velocities in horizontal directions x and y (Christen et al., 2010 Frank et al 2017). The depth-averaged momentum balance equations account for the conservation of momentum in two directions x and y:

$$Sgx - Sfx = \partial t\,(H\,Ux) + \partial x\,\left(cxH\,Ux^2 + g_z k_{\frac{a}{p}} \frac{H^2}{2}\right) + \partial y\,(H\,UxUy) \qquad (2)$$

$$Sgy - Sfy = \partial t\,(H\,Uy) + \partial x\,(H\,UxUy) + \partial y\,\left(c_y H\,Uy^2 + g_z k_{\frac{a}{p}} \frac{H^2}{2}\right) \quad (3)$$

where the earth pressure coefficient ka=p is normally set to 1 when running the standard Voellmy–Salm friction approach, cx and cy represent topographical coefficients determined from the digital elevation model, Sg is the effective gravitational acceleration, and Sf is the frictional deceleration indirections x and y (Christen et al., 2010b).

The frictional deceleration Sf of the flow is determined using the Voellmy friction relation (Salm et al., 1990; Salm, 1993) and specifies the dry-Coulomb term (friction coefficient / scaling with the normal stress and the viscous or turbulent friction (coefficient/ depending on the flow velocity U (Christen et al.,2010a, 2012; Bartelt et al., 2013):

$$S_f = \mu\rho g H \cos\varphi + \frac{\rho g u^2}{\xi} \quad (4)$$

where ρ is the mass density, g is the gravitational acceleration, φ is the slope angle, and Hgcos φ is the normal stress on the overflowed surface. The tangent of the effective internal friction angle of the flow material can be defined for the resistance of the solid phase (the term containing / which extensively controls deceleration behaviour of a more slowly moving flow. The resistance of the viscous or turbulent fluid phase (the term including / prevails for a more quickly moving flow (Bartelt et al., 2013).

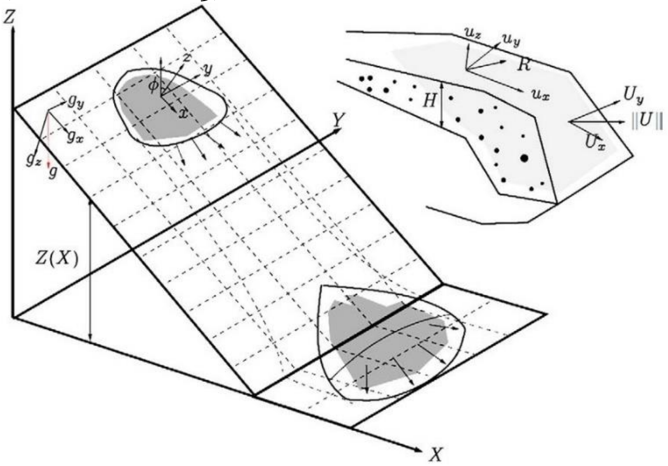

Figure 1 The topography Z(X, Y) is given in the Cartesian framework, X and Y being the horizontal coordinates. The surface induces a local coordinate system x, y, z (Christen et al., 2010a) .

It is discretized such that its projection onto the X, Y plane results in a structured mesh (from Christen et al., 2010a)(Fig. 1).

Case study

Selanac debris flow was triggered after extreme rainfall event in May 2014. Continuous precipitation for 45 days affected triggering of many new landslides across the Western Serbia. Most of new occurrences were defined as granular flows, which were not so typical landslide type for this area. The nearest meteorological station Loznica registered maximum of 230 mm of rain for 72 hours. Huge amount of material started to move as a block during the night of May, 15th 2014, which is visible on the main scarp 30m high. Material further transported as a flow throw two predisposed gullies with occasional flows. Geographical position of tested area is shown on Fig.1.

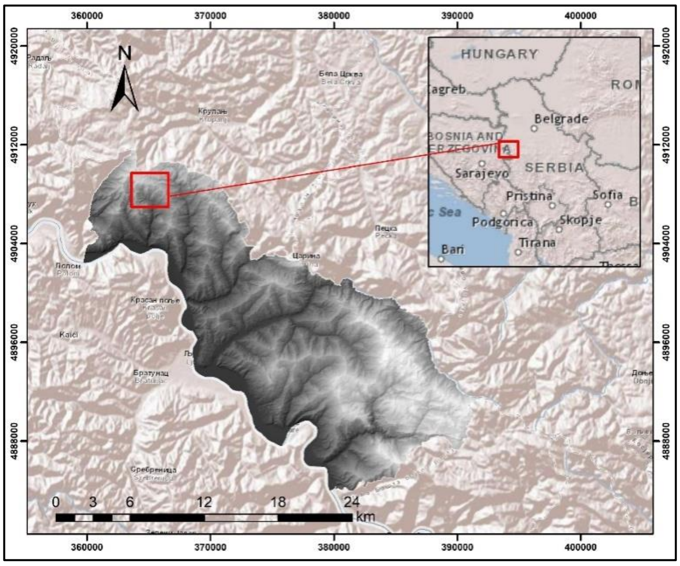

Figure 2 Geographical position of the Selanac case study

Geological settings are very complex; initiation zone belongs to Jurassic ophiolites, while transportation and deposition area belongs to tectonic contact of Triassic limestones and magmatic rocks with Palaeozoic metamorphic rocks. Debris flow material is highly heterogeneous in lithological composition, as well as grain size distribution (up to m^3 boulders) (Fig. 3).

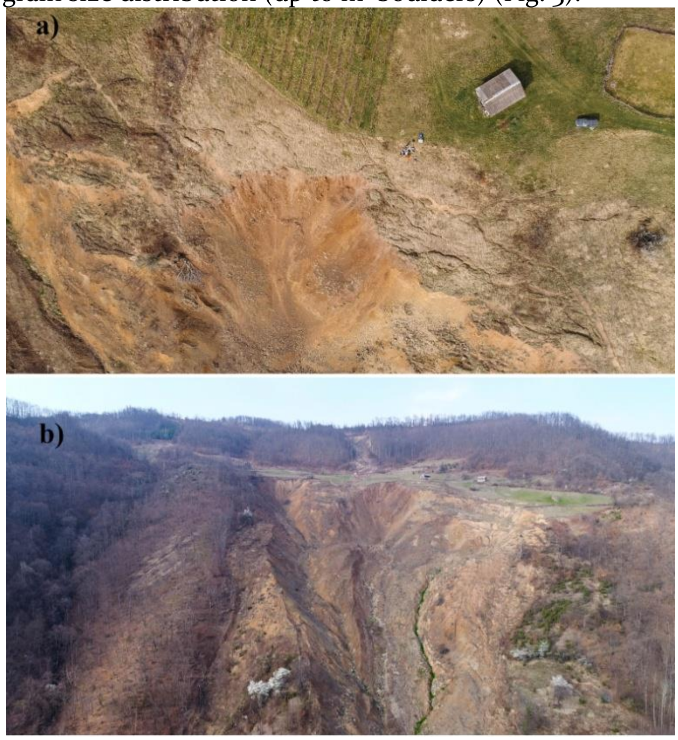

Figure 3 UAV images of a) soure area b) transportation zone (April 2017)

Erosion

The erosion algorithm in the RAMMS model, is defined using the maximum potential erosion depth e_m and a specific erosion rate. The erosion algorithm predicts the maximum potential depth of erosion e_m as a function of the computed basal shear stress in each grid cell:

$$em = 0 \, for \, \tau < \tau c \quad (5)$$

$$em = \frac{dz}{d\tau}(\tau - \tau c) \, for \, \tau \geq \tau c \quad (6)$$

The potential erosion depth (per kPa) dz/dt controls the rate of vertical erosion (in the z-direction) as a linear function of channel-bed shear stress.

Even the estimated erosion is very high in some parts (in average 12m), here will be shown results according to transported initiated mass, since first results was made without erosion calculation. Precision of topology finally affected precision in calculated eroded material, which is quite deep in this case.

Input Data

RAMMS uses DEM (Digital Elevation Model) as a basic data for defining simple geometry of model. Some researchers suggested 5x5m resolution as an optimal, explaining that even using smaller resolution gave quite similar results. New updated version of RAMMS gives opportunity to use friendly models of the terrain with better resolution, as a standard model. More precision in defining source area, erosion depth and deposition (Fig. 4) were provided after scanning of surface topology with resolution 5x5m in April 2017. Those input data were used for testing numerical model and results were compared with previously obtained 30x30m resolution topology input data and results (Krušić et al, 2018). The influence of topology resolution data on erosion/deposition model was also tested.

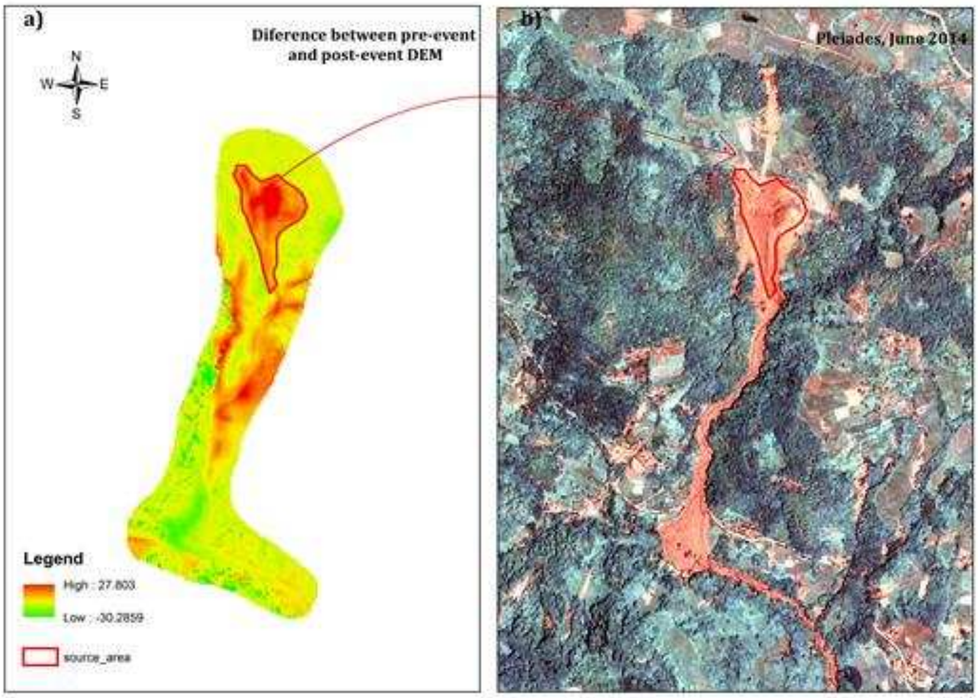

Figure 4a) Calculation of deference in topography before and after the activation of the debris flow, b) Pleiades image after the event and position of defined release area

Source area was defined as a block within average depth of 15 m. In previous results we considered much more averaged depth which resulted in large amount of initial material. Other possibility was to define input hydrograph, much more suitable for observed processes and measured flow heights.

Results

In both cases, we used post event DEM as a comparison for deposition depth and total deposition volume.

Using 30x30m DEM, as a best result gave back calculated μ=0.05 and ξ=500 m/s^2 best fitted resistance parameters. Enlarge of frictional parameter gave much more amount of material in deposition zone which is not estimated. Using this parameters, estimated material was reached, but with a less deposition height (Fig. 5).

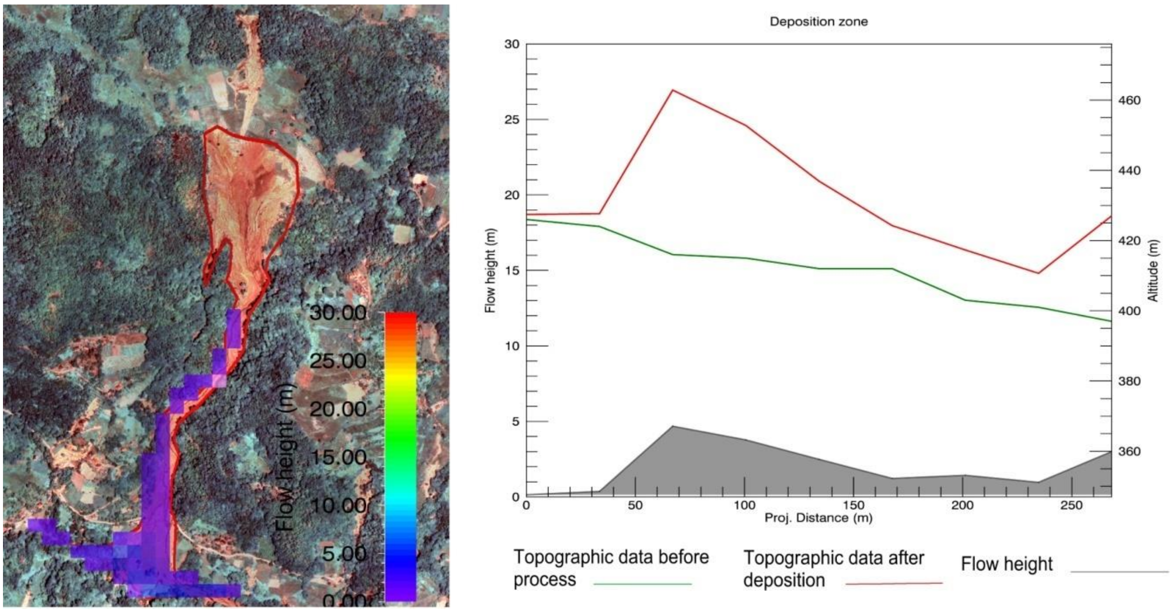

Figure 5 Final model with 30x30m DEM as input a) ξ =500 m/s^2,μ=0.05 b) deposited material depth≈5m

In other case, almost the same volume was reached in deposition zone but with much greater deposition height. The best fitted parameters that were chosen are μ=0.11 and ξ=500 m/s^2 (Fig 6). In both cases, there are a lot of outflow materials, since material was transported further throw valley of Selanacka river. This is something that would be interesting to include in future in modelling as an affect. By now we compared only amount of estimated volume.

Results show fewer amounts of deposited volume then volume that flow out of calculation domain. Including calculation of eroded material will change volumetric of deposited zone. Even if comparison of two epochs DEM gave as a result not so much difference in volume, estimated depth with ERT investigation is more (max 20m) and we can consider that transported material outflow of calculation domain its small part of initiated mass.

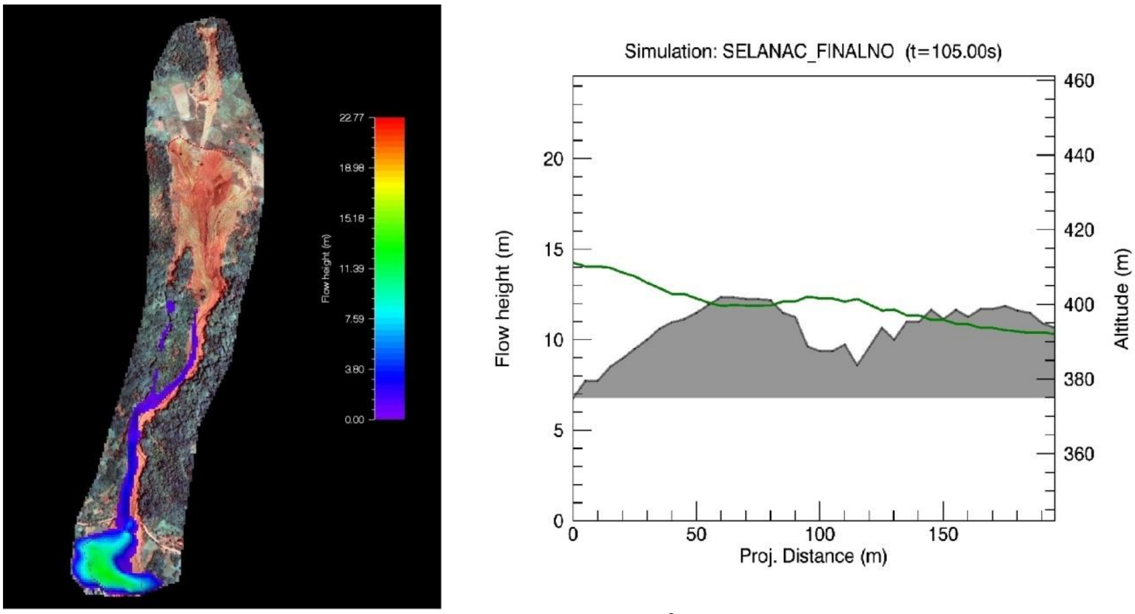

Figure 6 Final model with 5x5m DEM as input a) ξ =500 m/s^2,μ=0.11 b) deposited material depth≈14m

Conclusion

According to estimated depth in deposited zone, ERT investigation supposed 20 m in deepest part, and comparison of two epoch DEM ≈15m. Numerical model with better resolution of DEM give better precision. However, if we compare behaving of the flow and spatially deposited material, previous modelling gave quite reasonable results. Also the results of flowing material in both cases are quite similar ≈125.000 m^3, while estimated volume was about 121. 000 m^3. However, this prediction we can't consider as good assumption since mainly total critical mass and eroded material were stopped in deposited area, and drained water was transported further with torrential flow which also made instabilities in the Selanačka river valley. Generally it is necessary for further research to testing model with influence of the torrential flood on the deposition zone in the same time as Selanac debris flow. Also it is supposed that using some type of 2-phase numerical models potentially could provide more accurate results.

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