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Abstract

The Selanac debris flow is a very huge event triggered after extreme rainfall caused by Cyclone Tamara activity in the Republic of Serbia in May 2014. The Selanac case study was already modelling in different programs using Voellmy rheology assumptions like RAMMS software. In this paper research are focusing particularly on the process of debris flowing from initiation zone to main deposition area using Geoflow SPH two-phase model considering frictional rheology law. Main rheological parameters are back-calculated using also Voellmy turbulent coefficient where best-fitted parameter was 1000 m/s^2*. The amount of entrainment material was included and calculated using Hungr approach. Apart from detail engineering geological mapping of debris flow, Electrical Resistivity Tomography (ERT) are used for validation of models, since depths and dimension of occurrence do not allow using regular geotechnical investigations. Validation of results was made by comparing against the field investigation and high resolution Digital Terrain Model (DTM), also. Final models show accurate results comparing to the depths in deposition zone, but actual run-out distance of debris flow was longer than the measured run-out distance obtained by the SPH simulation model. Also, simulation results show heights and volume change as well as depths of eroded material, which are in accordance with previous research results. It can be concluded that the SPH simulation model is capable to obtain reasonable results and properly back-calculate the deposition depth and run-out distance.*

1 INTRODUCTION

Debris flows occur usually after saturated, mainly poorly sorted material, started to flow down the slope as a result of motion of solid and fluid phase. Different mechanisms, rheological and numerical models are used in this area of research. Generally, there are mainly two groups of models used for modeling on flow type landslides: empirical-statistical (Rickenmann, 1999, Legros, 2002), or physical (deterministic)-dynamical or numerical (Savage and Hutter, 1989; Hungr, 1995; Iverson, 1997; Takahashi, 2007; Wu, 2015). Physical models are progressing nowadays and giving a wide range of possibilities. Some of the available approaches treat the heterogeneous and multiphase moving mass as a single-phase continuum. The others are considering two phases, solid and liquid, i.e. a granular skeleton with voids filled with either water or mud. If the shear resistance of the fluid phase can be neglected, the stress tensor in the mixture can be decomposed into a ‘pore pressure’ and an effective stress, and the mechanical behavior of the mixture can be described by a system of differential equations governing the dynamics of each of the phases as well as the coupling among them (Pastor et al, 2008). SPH (Smoothed Particle Hydrodynamics) is a mesh-less approach, widely used in different fields of research, and it is found very suitable in different parts of fluid mechanics. Its main difference from other most used methods like finite element and finite difference methods, is in absence of numerical grid, and while mass is presented with particles of solid and fluid phase. Each particle has information about height, velocity as well as pore water pressure if coupled model is included. Geoflow SPH proposed by Pastor 2009, already has been used on different cases in the world (Pastor et al. 2015, 2009, Cascini et al. 2014, Cuomo et al. 2014).Within the SPH model, it is possible to incorporate numerous rheological features of both, the viscoplastic and the frictional type.

In this paper a real case study of Selanac debris flow in Serbia is presented, focusing particularly on the, the process of debris flowing from initiation zone to main deposition area, modeled via SPH. Validation of results was made by comparing against the field investigation and high resolution Digital Terrain Model (DTM). Concerning entrainment of material, which was deep in some parts of debris flow process, simulation results of eroded material was also taken into account.

2 CASE STUDY

The Selanac debris flow was activated after the Cyclone Tamara hit Balkan region, including the Republic of Serbia, in May 2014. It caused severe floods, flash floods and landslides throughout the affected areas. Continuous and intensive precipitation triggered many first-failure flow type landslides especially across the Western Serbia. Most of these occurrences were defined as granular flows, which were not a typical landslide mechanism for this area. One such example is Selanac debris flow, which stands among the largest occurrence of this type of landslides recorded in Serbia, recently (Fig. 1).

Figure 1 A) UAV image of main scarp B) UAV image of transportation zone

The Selanac debris flow is a complex flow type landslide phenomenon, firstly triggered as slide of huge initial block which is 30 m thick in the deepest part. Subsequently, it propagated as a debris flow process, with a long runout distance, including about 1 km long transportation by Selanačka river torrential influence. That has caused numerous instabilities downstream as well as significant erosion of material.

Geological setting of the site is very complex; initiation zone belongs to Jurassic ophiolites, while transportation and deposition area belongs to tectonic contact of Triassic limestones and magmatic rocks from one side with Paleozoic metamorphic rocks from the other. Debris flow material is highly heterogeneous in lithological composition, as well as grain size distribution (from fines to up to m^3 boulders in volume). The total length of the flow is 1.5 km and width is about 350 m in the widest part in the source area (Fig. 2). The nearest Main Meteorological Station Loznica (around 50 km far way) had registered maximum of 230 mm of precipitation in 72 hours for period 14-16 May 2014.

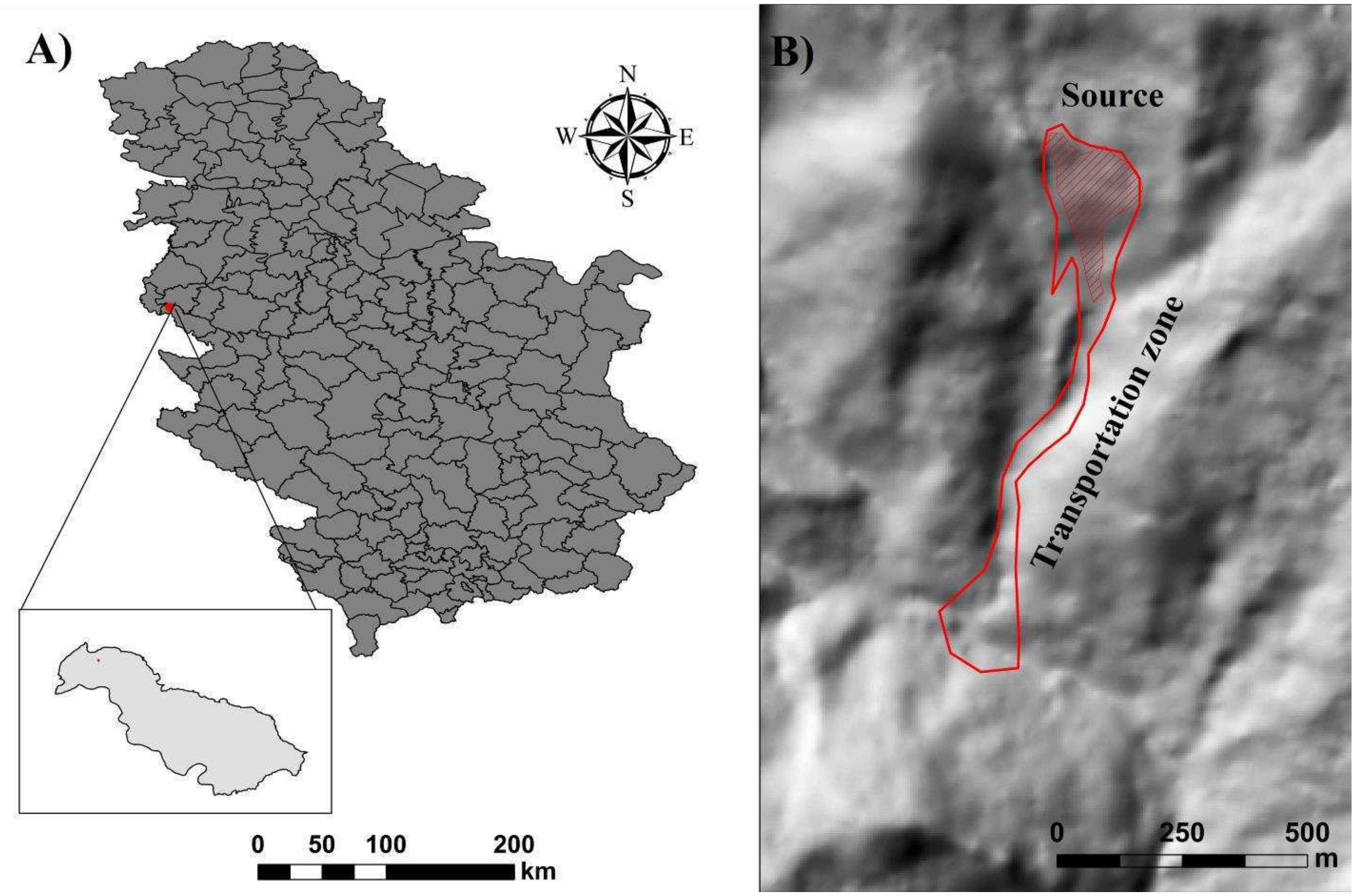

Figure 2 A) Location of case study B) geometry and main parts

3 METHOD

SPH (Smoothed Particle Hydrodynamics) was firstly proposed by Lucy (1977) and Gingold and Monaghan (1977) and applied in astrophysical modeling. In time, it became widely used in different fields (Liu and Liu 2010; Chen et al. 1996; Huang et al. 2015).

The function values $F(r')$, at the particles are firstly approximated by an integral function, $F(r)$, where r' and r are the position vectors of the particles. This function smooths each particle with respect to its surrounding particles over a domain of influence (Ω), through the use of a smoothing function, called a kernel, and is given by

$$F(r) = \int_{\Omega} F(r') W(r-r', l)\, dr', \qquad (1)$$

- where W is the kernel function and l is the smoothing length of the domain of influence. This mesh-less method makes SPH well adapted to modelling problems involving large deformations and free surface problems, as the complex re-meshing process is avoided.

The SPH model proposed by Pastor et al. (2009), defines propagations of mass as mixture of soil and water particles with calculation of velocity. In addition, calculation of pore water pressures propagation is possible to be obtained using Finite Difference Method coupled with two-phase model. Herein, just results of two-phase model propagation will be presented. The main equations are discussed by Pastor et al. (2009) considering:

A. balance of mass of the mixture—propagating along the slope and increasing due to bed entrainment—combined to the balance of linear momentum of pore water,
B. the balance of linear momentum of the mixture,
C. a kinetic relation between the deformation-rate tensor and velocity field, and

D. rheological equation relating the soil-stress tensor to the deformation-rate tensor.

Generally, it consists of the discretization of the depth averaged Biot-Zienkiewicz equations (Zienkiewicz and Schiomi, 1984) and it can be used with a variety of rheological laws and pore water pressure treatments. Two different meshes will be used, one to describe the terrain topography while the other consist of SPH nodes. Detailed discretization of equations can be found in Pastor et al. (2009). Hereinafter, rheological and empirical relations will be presented in order to unfold the mentioned mathematical equations

3.1 Frictional rheology

If the friction angle between fluidized soil and basal surface is smaller than the friction angle of the fluidized soil, the basal shear stress is given by:

$$\tau_b = -\rho_d\,{}'g \tan\varphi_b \frac{\overline{v_i}}{|\overline{v}|}, \qquad (2)$$

- where are: τ_b basal shear stress, $\overline{v_i}/|\overline{v}|$ depth averaged velocity, and ρ'_d is submerged density given by

$$\rho' d = (1 - n)\rho_s \cdot \rho_w \qquad (3)$$

There are different approaches for calculating erosion. Here, the one that is obtained by Hungr (1995) will be presented. It is considering the calculation of erosion rate, i.e. time derivative of the ground surface elevation, which is supposed equal the product of velocity (v), propagation height (h) and “landslide grow rate” (Er). The latter is independent to the flow velocity and is related by Hungr (1995) to the initial and final landslide volume as well as to the traveled distance (D) as follows:

$$Er = \frac{\ln\frac{V_{final}}{V_0}}{D} \qquad (4)$$

Once assigned, an Er, the amount of bed entrainment depends on both the height and velocity of the propagating mass at each point of the landslide path. The e_r and Er are related by the equation

$$e_r = Er\, h\, v \qquad (5)$$

The erosion rate can be modelled as proportional to the product of velocity (v) and propagation height (h).

4 RESULTS

DTM of 5x5m resolution is used as main topo file, with 133 452 points. Definition of the source area was made by comparing DTMs of different sequences (Krušić et al. 2019). Herein, a simulation with subtraction of release area, which has an influence on the movement of material, is appended.

Selected rheology law is frictional with Voellmy turbulent coefficient; so $tan\varphi$=0.35 (φ is frictional angle), and turbulent coefficient ξ= 1000 m/s^2. Erosion coefficient proposed by Hungr (1995) is set to 0.0001. Effects of pore water pressure were not included in this calculation. Plot screen of the final models are shown in Fig.3

The total motion of material from the main deposition zone further to Selanačka river valley is also depicted. Final results were compared with deposited material heights measured with ERT (Electric Resistivity Tomography) profiles. According to geophysical ERT investigation, the highest depths of the deposits are about 20 m.

Calculated final volume is about 495 000 m^3 while initial volume was computed to be 447 400 m^3. The results of erosion depth at different time steps are given in Fig.4.

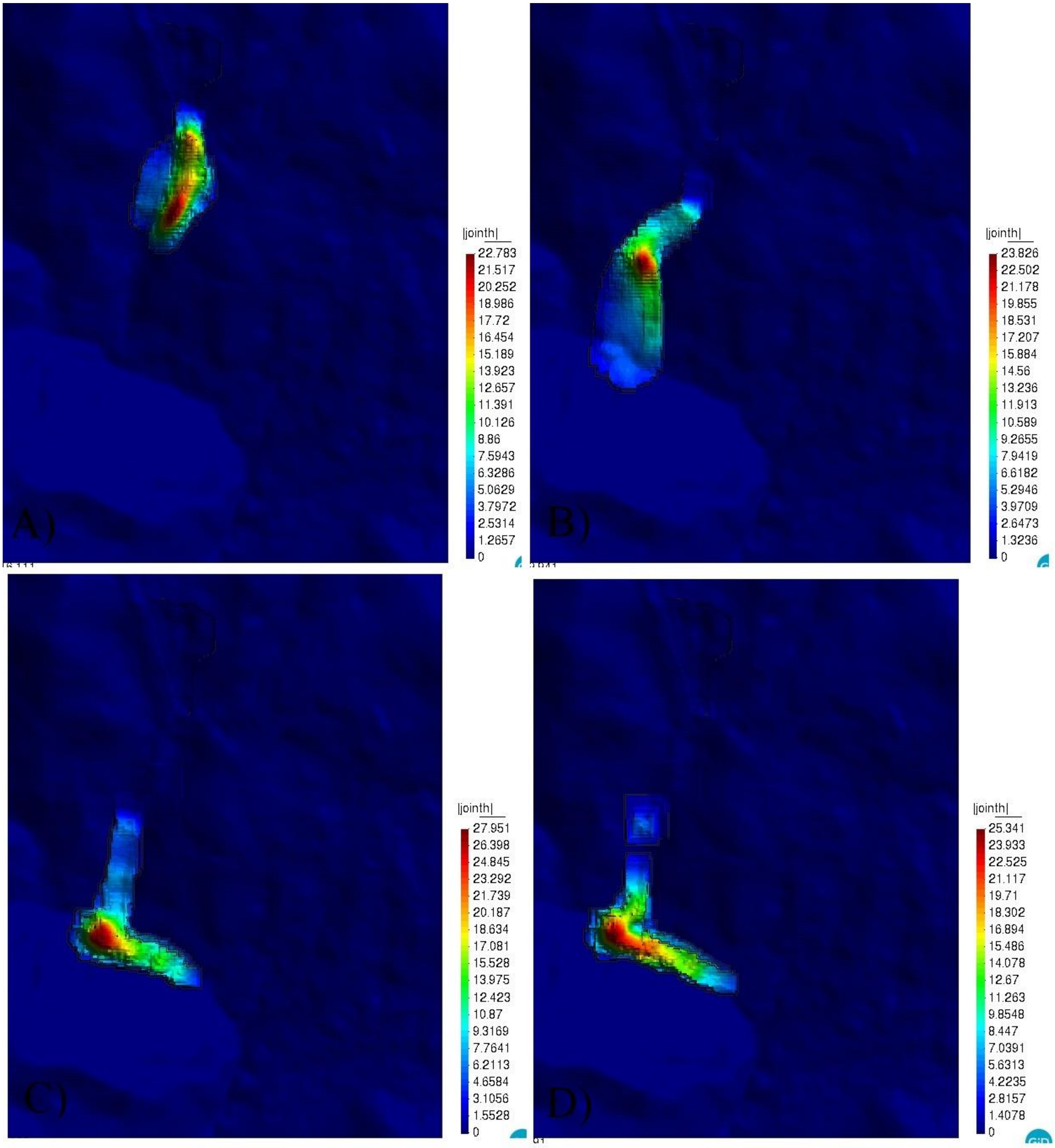

Figure 3 Final model of flow heights A) 16s B) 30s C) 50s D) 100s

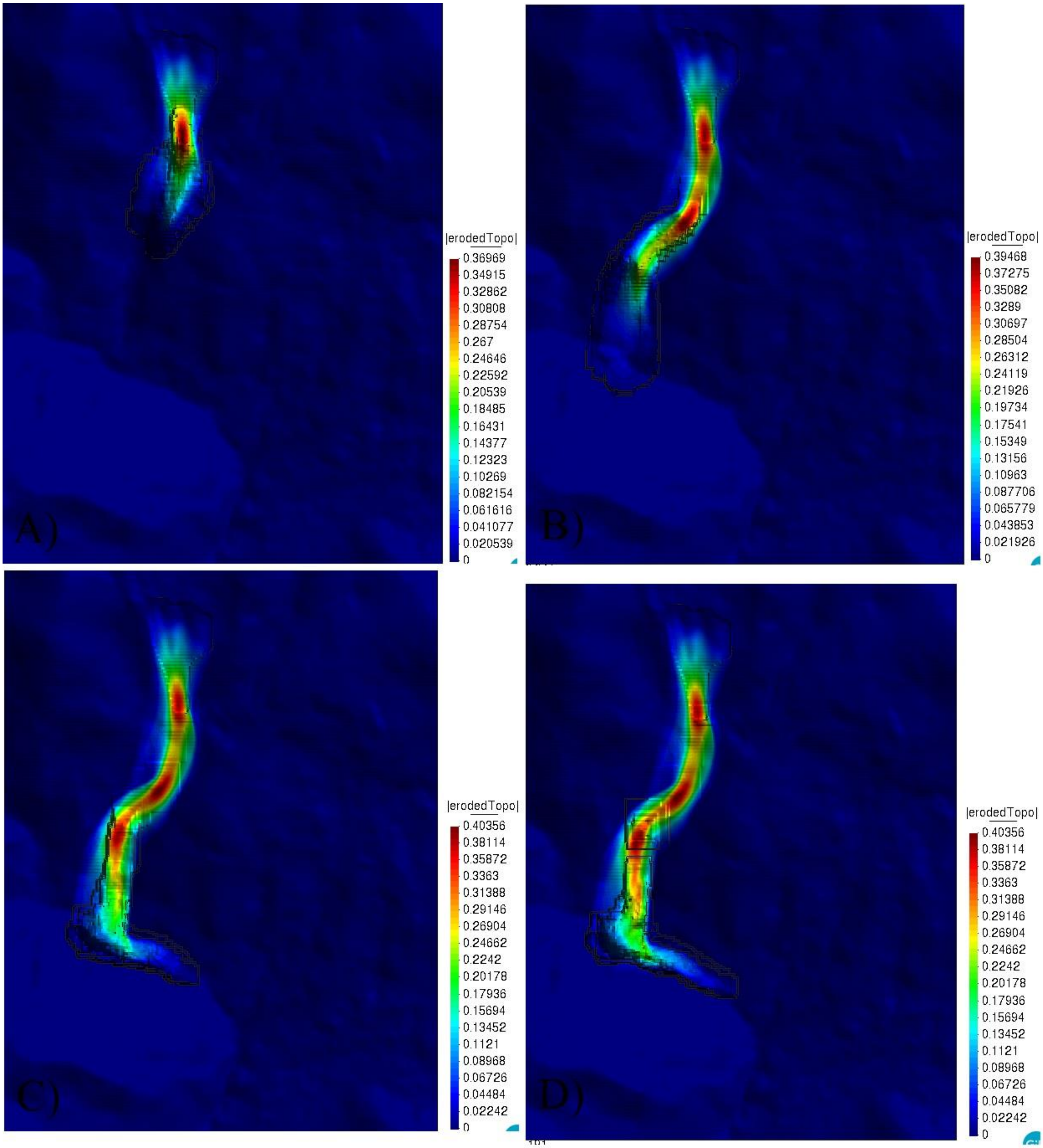

Figure 4 Erosion depths in meters in time steps A) 16 s B) 30 s C) 50 s D)100 s

5 CONCLUSIONS

Final models show accurate results comparing to the depths in deposition zone (Krušić et al. 2019). The actual run-out distance of this debris flow is longer than the measured run-out distance obtained by the simulation model. Selanačka river transported material about 1 km longer, making instabilities down the river valley, which is likely due to the fact that it already had significant momentum upstream to begin with (torrential floods of its tributaries upstream). Moreover, eroded depths in some parts were very deep. These models predict that volume of eroded material was about 47 000 m^3 which is quite similar with the previous models made using Voellmy (1955) rheology. Final depths in deposition zone are deeper than estimated depths using ERT and comparing DTMs from different sequences showing approximately 15 m difference in deposition zone (Krušić et al, 2019). In effect it can be concluded that the simulation model is capable to obtain reasonable results and properly back-calculate the deposition depth and runout distance. However, Selanačka river had a significant influence on process which was not considered in the simulation models. It can be supposed that taking into account influence of the river will give complete insight in behavior of the process.

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