On the Use of Numerical Models for Flow-like Landslide Simulation

289

Marina Pirulli, Claudio Scavia, and Mauro Tararbra

Abstract

In the last years, numerical modelling has emerged as a useful tool for landslide runout analysis and risk assessment. Several of the developed models have included innovations that have significantly advanced both the ability to simulate real events and the understanding of rapid landslide processes. However, it is here evidenced that in both interpreting run-out results and evaluating numerical model performances a particular care is necessary. To this aim, the continuum-mechanics based code RASH3D is used to back-analyse the case of the Baio Dora debris flow. Carried-out analyses are intended to highlight the influence that some factors like (1) Digital Elevation Model (DEM) resolution; (2) rheological law; and (3) entrainment process can have on numerical results. In particular, it is observed that a low resolution DEM can make fail all the attempts of selecting and calibrating the more appropriate rheology. On the other side, the selection of a wrong rheology can give a unrealistic run-out path, that is the moving mass can go as far taking a completely incorrect flowing direction. Finally, it emerges that the entrainment of channel path material can significantly change the mobility of a flow, through rapid changes of both the flow volume and rheology.

Keywords

Numerical modelling • Flow-like landslide • Digital elevation model • Rheology • Entrainment

289.1 Introduction

Rapid landslide run-out analysis is an essential component of landslide risk assessment. In this framework, numerical models can represent a useful tool for investigating both propagation and deposition of a moving mass involving granular material, like debris flows, debris- and rock-avalanches.

In the attempt of modelling landslide dynamics, methods based on both discontinuum mechanics (e.g. Richefeu et al. 2012) and continuum mechanics (e.g., Savage and Hutter 1989) have nowadays emerged as promising approaches. Whatever the approach is used, the present paper is intended to highlight that, to avoid that wrong data and wrong interpretation can distort the reality, the use of a numerical model requires particular care.

This aim is pursued discussing the numerical results obtained through the application of the continuum mechanics code RASH3D (Pirulli 2005) to the analysis of the Baio Dora case of debris flow, that for its characteristics has allowed to touch on different important aspects: rheological law, digital elevation model and entrainment process.

M. Pirulli (✉) · C. Scavia
Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
e-mail: marina.pirulli@polito.it

M. Tararbra
Dipartimento Geologia e Dissesto - Monitoraggi e studi geologici, ARPA Piemonte, Via Pio VII 9, 10135 Torino, Italy

G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 2*,
DOI: 10.1007/978-3-319-09057-3_289,

289.2 Description of the RASH3D Code

The RASH3D code (Mangeney et al. 2003; Pirulli 2005) treats the moving mass as a homogeneous continuum. Under this assumption, the real moving mass is replaced by an "equivalent" fluid, whose rheological properties approximate the bulk behavior of the real mixture. Further, assuming that the vertical structure of the flow is much smaller than its characteristic length, the code integrates the balance equations in depth, obtaining the so-called depth-averaged equations (Savage and Hutter 1989).

Data necessary to run an analysis with RASH3D are the digital elevation area (DEM) of the investigated area, the geometry of the triggering volume and the selection of a rheological law with calibration of its parameters. As a function of the assumed rheological law, the number and type of parameters to be calibrated change. In the present work two different rheologies are tested:

(1) Frictional rheology, based on a constant friction angle φ, which implies a constant ratio of the shear stress to the normal stress. Shear resistance stresses are independent of velocity:

$$\boldsymbol{T}_t = -(\rho g_z h \tan\varphi)\,\mathrm{sgn}(\boldsymbol{v}) \qquad (289.1)$$

where $v(v_x, v_y)$ denotes the depth-averaged flow velocity, h is the flow depth, $T_t(T_{tx}, T_{ty})$ is the traction, ρ is the mass density and g is the gravity.

(2) Voellmy rheology, which consists of a turbulent term, $\boldsymbol{v}^2/g$, accounting for velocity-dependent energy losses, and a Coulomb or basal friction term for describing the stopping mechanism:

$$\boldsymbol{T}_t = -\left(\rho g_z h \tan\varphi + \frac{\rho g \boldsymbol{v}^2}{\xi}\right)\mathrm{sgn}(\boldsymbol{v}) \qquad (289.2)$$

where ξ is the turbulence coefficient.

289.3 The Baio Dora Debris Flow (Borgofranco d'Ivrea, Italy)

The analysed debris flow, involving a debris volume of about 42,000 m^3, detached on June 12, 1942 from the slopes of the Cavallaria Mount at an elevation of 1050 m a.s.l. (Piedmont Region, North-Western Italy) and running along the Rio Prietto torrent reached the valley bottom at 250 m a.s.l., where it stopped alongside of the Baio Dora hamlet, in the Borgofranco d'Ivrea municipality (Fig. 289.1).

The remarkable availability of overlying shifting material coming from the active landslide that involves the area (as evidenced by the 2013 GPS data of the Arpa Piemonte Landslides Monitoring System RERCOMF) along with a very high slope angle and heavy orographic rainfall can be identified as the main causes of the event.

289.4 Numerical Simulation Results

Beyond the importance that back-analysed data can have for the calibration of forward-analysis, the Baio Dora event was selected for back-analysis in consideration of the characteristics of the site in terms of both quality of digital data of the area and dynamics and run-out path of the 1942 debris flow.

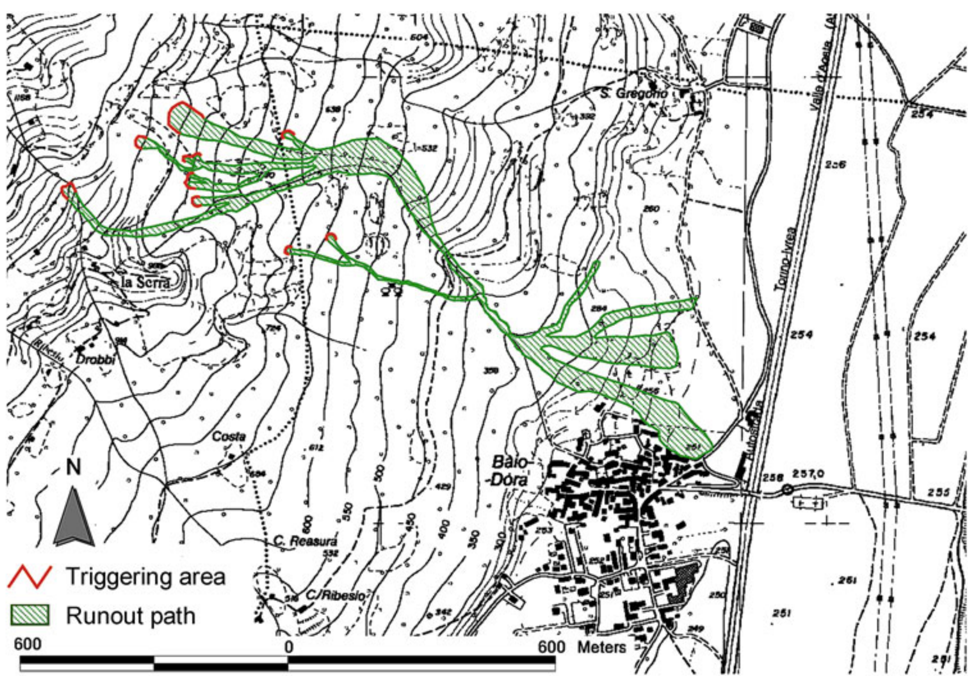

Fig. 289.1 Superimposition of run-out path of the 1942 debris flow on the regional technical chart

Its analysis made in fact possible to highlight at the same time the influence of three key aspects on a numerical simulation results: (1) Digital Elevation Model (DEM) resolution; (2) Morphology and substrate influence on rheology selection; and (3) Role of entrainment process.

Each of the above aspects is discussed in the following sub-sections starting from the numerical results obtained with the RASH3D code.

289.4.1 Digital Elevation Model (DEM) Resolution

A set of numerical analyses were initially carried out with RASH3D using the Provincia di Torino (Piedmont region, Italy) DEM, a Voellmy rheology and no entrainment along the run-out path.

A comparison between obtained numerical results and boundaries of the run-out area as surveyed on site evidenced the impossibility of calibrating rheological values to well back-analyze the past event. Combinations of friction coefficient and turbulent coefficient that allow the mass to reach the valley bottom cause an over-spreading of the mass. An example is carried in Fig. 289.2a.

As a consequence of the obtained results an in-depth analysis was carried out of the characteristics of the used DEM. The presence of some errors in the valley bottom topography emerged from a superimposition of the DEM on the Regional Technical Chart (CTR). These errors cause some topographical irregularities due to the propagation of some wrong altimetric values of the DEM.

In particular, a road bridge was interpreted as summit of a topographic hill (Fig. 289.2b) and caused the impossibility of having a right distal point for the longitudinal propagation of the flowing mass front.

As a result, a new DEM was implemented where corrections to topography were made.

289.4.2 Selection of the Rheological Law

Using the new DEM (see Sect. 289.4.1), a set of analyses was initially carried out assuming the simple frictional rheology (Eq. 289.1).

The carried out parametric analyses evidenced the impossibility of defining a friction angle value able to reproduce the real event dynamics.

A second set of analyses was then carried out using a Voellmy rheology (Eq. 289.2). But not even this rheology was able to guarantee a correct runout of the mass: an excessive spreading and a premature stopping of the mass front persisted, even if in a smaller extent, as for the previous Provincia di Torino version of the DEM.

289.4.3 Influence of the Entrainment Process

The analysis of the historical documents of the period, multi-temporal aerial photo interpretation and morphologic survey allowed the geologists to evidence the role that the entrainment process played in the dynamics of the investigated event. Three different sectors were bounded and a

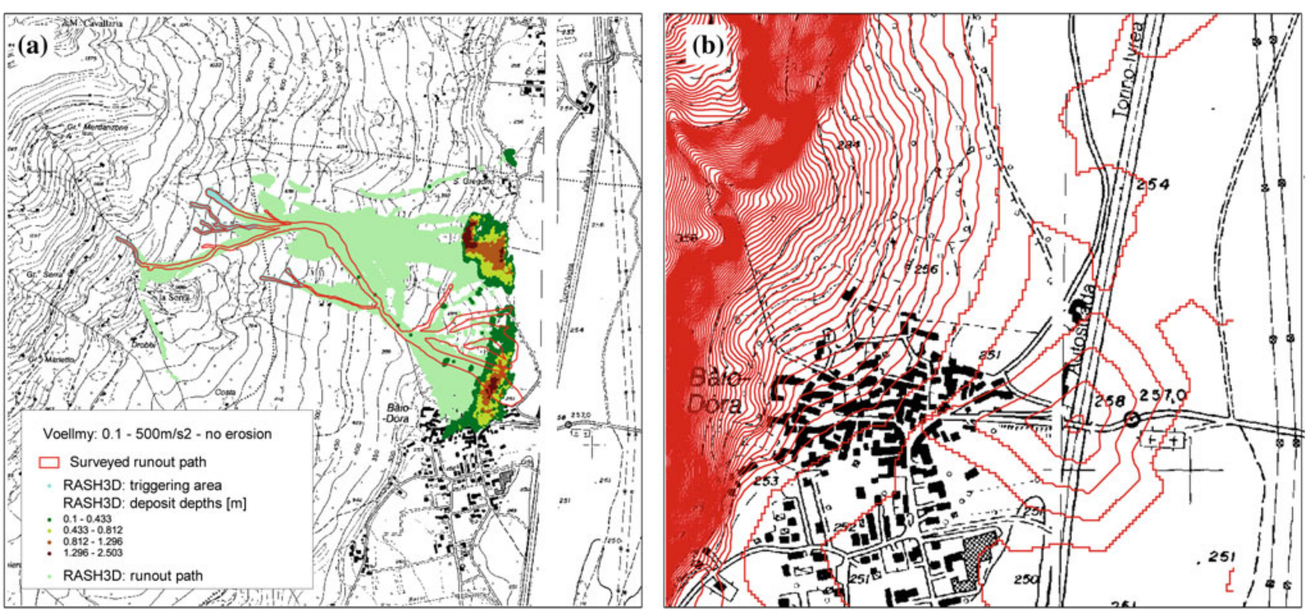

Fig. 289.2 **a** Results of a numerical simulation with RASH3D using the Provincia di Torino DEM; **b** Superimposition of the Provincia di Torino DEM on regional technical chart (CTR). A road bridge results as summit of a topographic hill

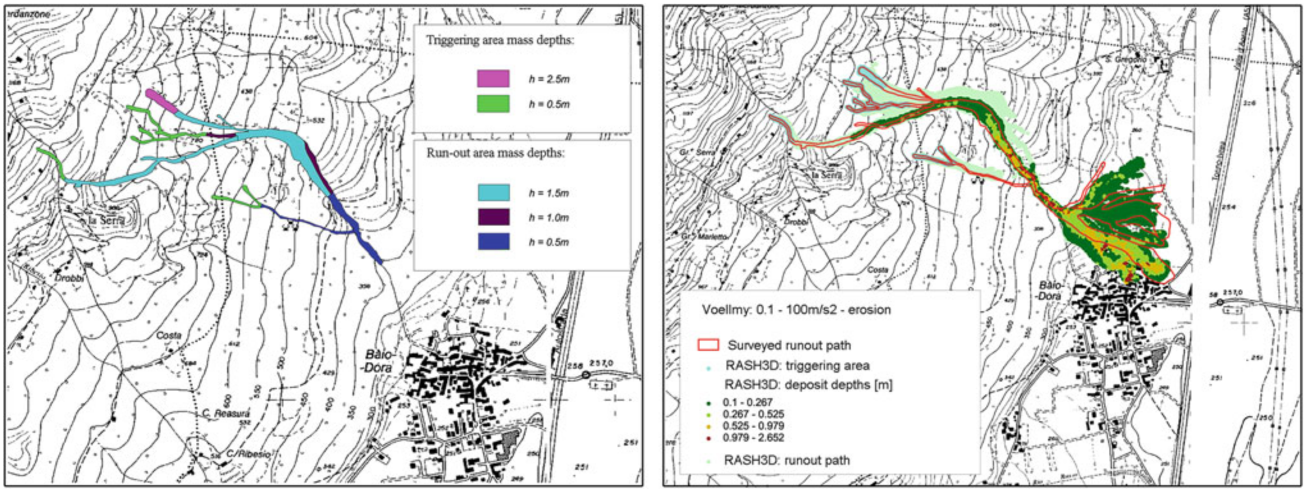

Fig. 289.3 **a** Distribution of the mass depth in triggering and entrainment areas; **b** Results obtained with RASH3D using a Voellmy rheology and the new implemented DEM

different potential depth for erosion was assigned to each of them (Fig. 289.3a)

A new set of analyses was then run and the Voellmy rheology with the new DEM and the entrainment process were adopted. As a result, new simulations reproduced in a satisfactory way the past event (Fig. 289.3b).

The presence of a small quantity of material in areas that were not reached by the real moving mass has been considered acceptable as a function of the change that the topography can have suffered in time and of the not exact delimitation that the runout area can have due to the impossibility of verifying interpretations on site, due to the long time period passed from the event date.

289.5 Discussion and Conclusions

In the present paper the RASH3D code has been used to back-analyze the debris flow event of Baio Dora and evidence that in both interpreting numerical simulation results and evaluating numerical model performances a particular care is necessary.

From numerical results it emerged that errors in topographical data can make ineffective any attempt of correctly reproducing the dynamics and the runout of an investigated event. According to Pirulli and Marco (2010), a DEM has good or bad quality as a function of the type of phenomenon to be investigated.

The failure of soil and rock slopes under natural conditions involves a variety of mechanical processes that can produce several kinematically and structurally distinct types of landslide phenomena that not all the rheologies can catch. An attentive selection is necessary.

Even if a good DEM is adopted and the right rheology is selected, results can be unsatisfactory if an aspect that played an important role in the movement is neglected. It was here the case of the entrainment of channel material along the runout path.

In conclusion, the findings of carried out analyses have showed that results of numerical analyses can be a useful tool for land management but that their results can be distort by bad quality of digital data or wrong interpretation of the event dynamics.

Acknowledgments This research work was carried out under the financial support of the ARPA Piemonte.

References

Mangeney A, Vilotte JP, Bristeau MO, Perthame B, Bouchut F, Simeoni C, Yerneni S (2003) Numerical modelling of avalanche based on saint Venant equations using a kinetic scheme. J Geophy Res 108(B11):2527–2542

Pirulli M (2005) Numerical modelling of landslide runout, a continuum mechanics approach. PhD Thesis, Department of Structural and Geotechnical Engineering, Politecnico di Torino, Italy

Pirulli M, Marco F (2010) Description and numerical modelling of the October 2000 Nora debris flow, Northwestern Italian Alps. Can Geotech J 47(2):135–146

Richefeu V, Mollon G, Daudon D, Villard P (2012) Dissipative contacts and realistic block shapes for modelling rock avalanche. Eng Geol 149–150:78–92

Savage SB, Hutter K (1989) The motion of a finite mass of granular material down a rough incline. J Fluid Mech 199:177–215