Comparison of Debris flow Depositional Scenarios using different DTMs.

Comparison of Debris flow Depositional Scenarios using different DTMs

Deangeli Chiara[1], Tiranti Davide[2], Marco Federica[3], Volpato Marco[1]

[1] DIATI, Politecnico di Torino, corso Duca degli Abruzzi 24, 10129, Torino, Italy

[2] Department of Forecasting Systems, Regional Agency for Environmental Protection of Piemonte, Torino, Italy

[3] Department of Geology and Geohazard, Regional Agency for Environmental Protection of Piemonte, Torino, Italy

The paper reports numerical simulations of two debris flows occurred in 2000, in the middle part of the Stura di Valgrande valley (Lanzo, North-Western Italy). A Cellular Automata Model, based on the dilatant fluid constitutive law, and two different Digital Terrain Models (DTM) were employed. The first simulations were performed with a DTM dated 1999 (grid 10x10 m) and reproducing the site topography before the events. The other simulations were carried out with a DTM dated 2011 (from Light Detection And Ranging surveys) with a grid 5x5 m. Although the results obtained with a post event DTM can be affected by morphological changes, however the agreement with in site evidences seems to be more consistent. The rheological parameters calibrated with back analyses for the two DTMs are different. These results seem to indicate the influence of the topography accuracy for the calibration of the rheological parameters.

Keywords: Debris flow, Cellular Automata Model¸ Numerical modeling, DTM, Rheological parameters.

1. Introduction

Debris flows are rapid or very rapid flows of sediment water mixtures, with high solid concentration. As these phenomena are among the most dangerous and destructive natural events, the definition of runout scenarios for risk assessment has received wide interest in the last decades. The estimation of runout can be performed with analytical or numerical models. Numerical models have the capability of simulating 3D scenarios, although they require several input data. Generally many numerical runs have to be carried out, by varying the input parameters, until a good agreement between in situ evidences and simulated events is obtained. Inaccuracy of the topography data affects the results of numerical simulations, resulting in preferential flow paths and deposition patterns that have not any confirmation with in site evidences. The inconsistency of such a type of errors can therefore be detected with the comparison between simulation results and in site evidences. As several other uncertainties affect the numerical simulations, sometimes it is difficult to establish the reliability of scenarios predicted with numerical simulations. The paper investigates the influence of Digital Terrain Model (DTM) features on debris flow deposition, by comparing the results of numerical simulations of two debris flows occurred in 2000, in the middle part of the Stura di Valgrande valley (Lanzo, North Western Italy). To this end a numerical code based on Cellular Automata Method (Segre & Deangeli,1995; Deangeli 2008; Deangeli et al. 2013) was used for the numerical runs.

2. Geological and geomorphological settings

The Urtorei and Cuccetta watersheds are located in the central part of the Piemonte Region, on the right side of the Stura di Valgrande valley, in front of the Chialamberto village (Torino, Italy). The slope, NE exposed, is completely vegetated and incised by steep water courses.

The Urtorei basin is characterized by an area of about 1.03 km^2, a fan area of about 0.06 km2 and a main channel length of 1985 m (Fig. 2.1). The main outcropping lithological units are: prasinites, serpentinites (Piemontese Zone “Green Stones”), talus deposits, gneiss and orthogneiss (Gran Paradiso Unit). According to the Piemonte basin lithological classification, proposed by Tiranti et al. (2008), the Urtorei watershed is a Bad Clay Maker: dominant torrential processes are classified as non-cohesive sediment gravity flows, with a granular behavior (silty sand-like matrix). On October 2000 Urtorei debris flow started near the crest along a secondary channel at an elevation of 1740 m asl; the debris flow deposited downstream of the fan apex pebbles and blocks with a mean thickness of 1.5 m. In situ surveying evidenced erosion along the channel of the order of 0.3 - 0.4 m.

The Cuccetta basin is characterized by an area of about 0,7 km^2, a fan area of about 0.07 km2 and a main channel length of 1465 (Fig. 2.1). The main outcropping lithological units are prasinites (Piemontese Zone “Green Stones”), gneisses and orthogneisses (Gran Paradiso Unit). As in the previous case, also the Cuccetta watershed can be classified as a Bad Clay Maker. On October 2000 Cuccetta debris flow started in the central zone of the basin, at an elevation of 1330 m asl. The debris material flowed on the poorly incised left side of the main channel. The deposit was composed of gravels, pebbles and rare blocks at the fan toe, with a mean thickness of 0.5 m. The erosion depth along the channel was estimated in the order of 0.1 - 0.2 m (Fig. 2.2).

3. Numerical simulations

The propagation and deposition of debris flows in the two watersheds were simulated with a 3D numerical code based on Cellular Automata Method (Segre & Deangeli, 1995; Deangeli, 2008).

The numerical code can analyze debris flows in the inertial regime (Segre & Deangeli, 1995), according to the solution of Takahashi (1978, 1991), based on the dilatant fluid constitutive law (Bagnold, 1954). A detailed description of the mathematical algorithms implemented in the code is reported in the papers of Segre & Deangeli (1995) and Deangeli (2008). This code was successfully applied to analyse the evolutive behavior of several actual granular flows, occurred in different settings and contexts (Deangeli & Grasso, 1996; Deangeli & Giani, 1998; Deangeli, 2008; Deangeli et al., 2013).

Back analyses of the events occurred in 2000 in Stura di Vallgrande valley were carried out using a DTM dated 1999 (with a grid 10x10m) and a DTM dated 2011 (LiDAR) (with a grid 5x5m). The first simulations were carried out with the volumes estimated in the zones of initiation. As erosion phenomena occurred along the debris flow paths, a second set of simulations were performed with increased initial volumes. The adopted approach is undoubtedly simplified, but the study was not focused on the mechanics of erosion processes. Considering that the results of the numerical code are in terms of depositional patterns on the alluvial fan area, modelling of erosion phenomena was not considered relevant for the analysis. Several numerical runs were performed by varying the solid concentration and the friction angle in order to match the depositional patterns observed in site.

Figures 3.1 a) and b) report the numerical results obtained with a solid concentration equal to 0.4, friction angle equal to 25° for the DTM dated 1999. Figure 3.1 a) reports the depositional pattern by considering the initial volume and Figure 3.1 b) an increased volume: 9450 m^3 (on the left) and 20250 m^3 (on the right) for the Cuccetta and Urtorei watersheds respectively. The results indicate that the volumes of debris material subject to erosion must be taken into account in the analysis of the two events. Topography inaccuracies seem to affect preferential flow paths. In fact in the Cuccetta basin (on the left) the simulated flow path and the area of deposition are not correspondent to those observed in site.

Figure 3.2 a) reports the numerical results obtained with the DTM dated 2011, (grid 5x5m) by considering the conditions reported in Figure 3.1 b). Deposition occurs beyond the perimeters of the actual events and affects the Stura di Valgrande river. Consequently in this case is not possible to reproduce the deposition scenarios of the two events with the same rheological parameters. Several other runs were performed by varying the volume, the solid concentration and the friction angle. In general the patterns of deposition differ substantially from the results obtained with the DTM dated 1999. Only with an increase in solid concentration (0.5) and friction angle (35°) the modeled area of deposition is slightly similar to the previous analysis in the Urtorei watershed (Figure 3.2 b)). The better resolution of the 2011 DTM results more effective in the Cuccetta watershed, where the deviation of the path, at elevation 975 m, is no longer occurring. In general it is expected that the results obtained with a post-event DTM should be different from those obtained with a pre-event DTM. However, considering the relatively small volumes involved in the two debris flow events and the limited remedial works carried out on the alluvial fan, a substantial variation of the morphological setting of the watersheds seems to be not relevant. For this reason the results of the simulations seem also to be affected by DTM resolution. In fact a comparison between the two DTMs revealed substantial differences not only on the alluvial fan area but also in the upper part of the watersheds.

4. Conclusions

The paper reported numerical back analyses of two debris flows occurred in 2000 in two watersheds in Stura di Valgrande of Lanzo (North-Western Alps). To this end a pre-event DTM (dated 1999, grid 10x10 m) and a post-event DTM (dated 2011, grid 5x5m) with different resolutions were used. The rheological parameters and volume of the events were changed in order to match in site depositional patterns. However the complete agreement between field evidences and numerical results for both DTMs could not be obtained. The differences between modeled and observed phenomena can be attributed to the inaccuracies of the pre-event DTM. On the other hand the results achieved with the post-event DTM can be affected by variations of the morphological setting of the watersheds. However in this last case the agreement seems to be slightly better than in the previous analysis. Furthermore the rheological parameters used in the numerical simulations for the best fit were different for the two types of analysis. These findings seem to indicate that the rheological parameters calibrated with back analyses can be influenced by DTM resolution.

References

Bagnold RA (1954): *Experiments on a gravity-free dispersion of large solid spheres in a Newtonian fluid under shear*. Proc R Soc Lond A 225, pp 49–63

Deangeli C (2008): *Laboratory granular flows generated by slope failures.* Rock Mech Rock Eng 41(1), pp 199–217

Deangeli C, Giani GP (1998): *Physical and numerical models to rehabilitate a waste disposal site.* In: Proceedings of 8th international congress IAEG, Balkema, Vancouver/Rotterdam, pp 1813–1818

Deangeli C, Grasso P (1996) *The evolutive mechanism of debris flows: analysis and protection works.* In: Proceedings of 7th international symposium on landslides, Balkema, Trondheim/Rotterdam, pp 1183–1188

Deangeli C, Paltrinieri E, Tiranti D (2013): *Debris Flow Analysis: From Lithological Classification of the Basin to Deposition.* In: Landslide Science and Practice, Vol. 3, Springer-Verlag Berlin Heidelberg

Segre E, Deangeli C (1995) *Cellular Automaton For Realistic Modelling of Landslides,* Non Linear Proc. Geoph., Verlag, , 2:1, pp.1-15

Takahashi T (1978): *Mechanical characteristics of debris flow.* J. Hydraul. Div. ASCE, 104, pp 1153–1169.

Takahashi T (1991): *Debris Flow*, IAHR Monograph, Balkema, Rotterdam.

Tiranti D, Bonetto S, Mandrone G (2008) *Quantitative basin characterization to refine debris-flow triggering criteria and processes: an example from the Italian Western Alps. L*andslides 5 (1): pp 45–57

Figures and Captions:

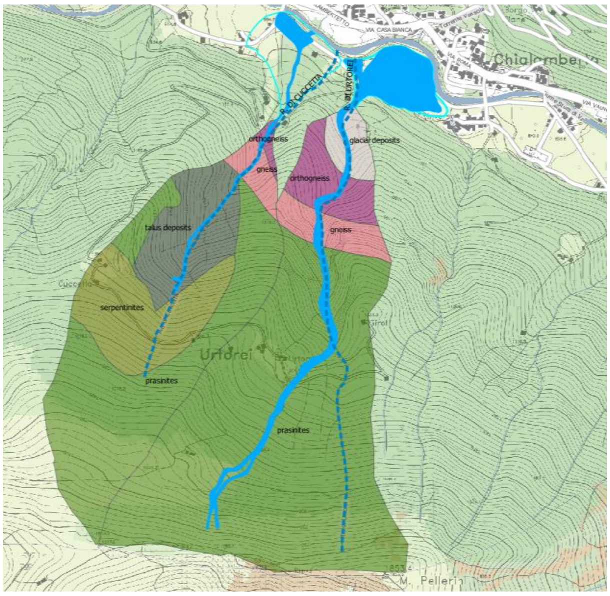

Fig. 2.1 Lithological setting of Urtorei and Cuccetta watersheds. (light blue: alluvial fans; light green: prasinites; green: serpentinites; pink: gneisses; purple: orthogneisses; light grey: glacial deposits; dashed blue: main water courses; blue: October 2000 debris flows)

Fig. 2.2 Cuccetta (on the left) and Urtorei (on the right) alluvial fans, after October 2000 debris flows (Flight “Alluvione 2000” Regione Piemonte, 2001)

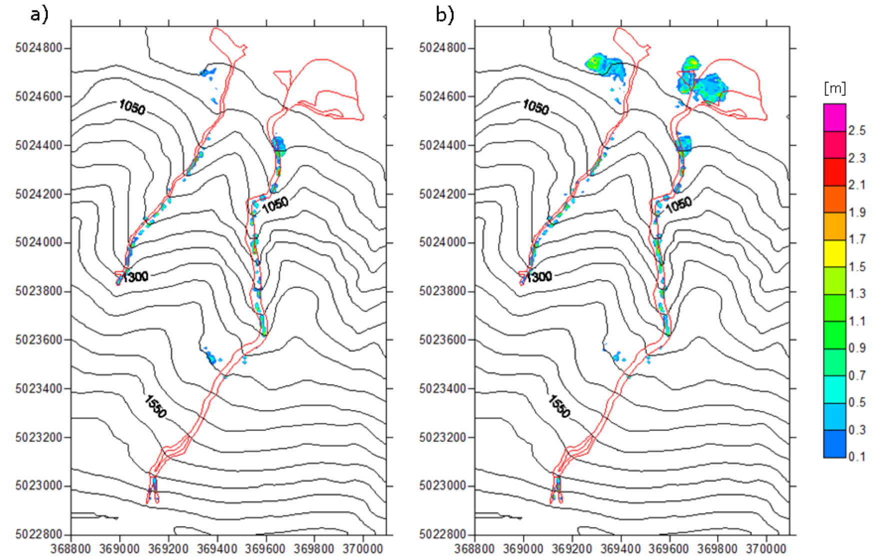

Figure 3.1. Numerical simulations of the two debris flows occurred in 2000, with a DTM dated 1999 (grid 10x10m). a) volume of the triggering zone; b) increased volume. Red contour: boundary of the real events.

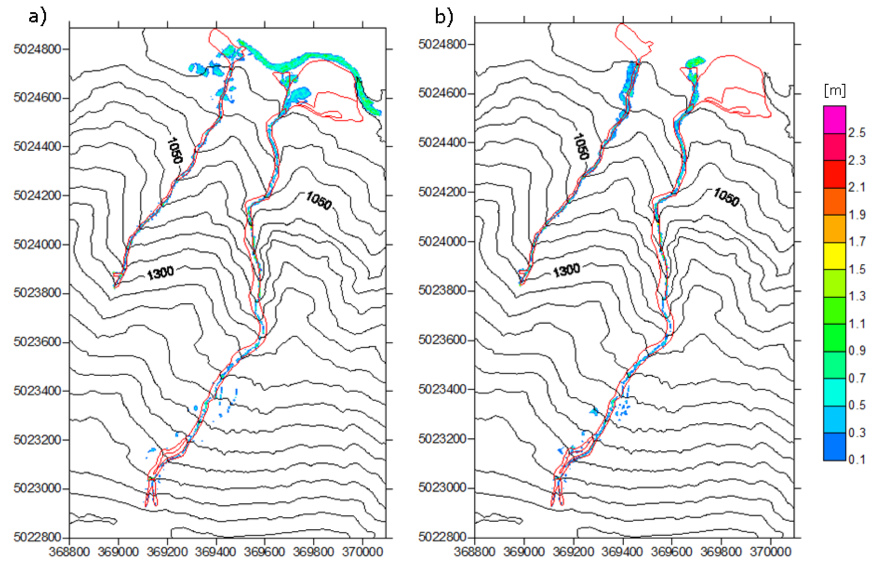

Figure 3.2. Numerical simulations of the two debris flows occurred in 2000, with a DTM dated 2011 (grid 5x5m). a) with the same parameters used in figure 3.1 b). b) with increased solid concentration and friction angle. Red contour: boundary of the real events.