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NUMERICAL MODELLING OF THE DECEMBER 1999 CERVINARA FLOW-LIKE MASS MOVEMENTS (SOUTHERN ITALY)

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ABSTRACT

This paper deals with the flow-like mass movements which occurred on 15-16 December 1999 in Cervinara (Southern Italy). During this event, a huge amount of water, debris and boulders was transported from the hillslopes towards the piedmont areas causing victims, damage to buildings as well as the flooding of a large part of the urban area of the municipality. In this paper, a study is carried out with reference to the modelling of the propagation stage of the occurred phenomena which has yet to be satisfactorily addressed in current scientific literature.

To this aim, the geological, geomorphological and geotechnical settings are firstly drawn up based on the available advanced data-set. Then, the event scenarios are reconstructed referring to rainfall data, information on damage and eyewitness accounts. It is highlighted that three mountain basins were affected by three debris floods and, three hours later, a huge debris flow occurred. For all the phenomena, the propagation areas are characterised and the rheology of the propagating masses assessed; subsequently, the numerical modelling of the propagation stage is carried out. For the numerical analyses, a commercial FLO-2D code is used and different scenarios are considered with reference to different digital elevation models, inflow hydrographs and rheological parameters. The results obtained for the propagation areas match either the in-situ evidence or the eyewitness accounts of the December 1999 events. Moreover, the role of the major factors is outlined for the propagation stage of the analysed phenomena. Finally, the possibility to extend the obtained results to other similar contexts is discussed.

KEY WORDS: modelling, landslides, flow-like, flood, propagation

INTRODUCTION

Rainfall events can trigger different types of flow-like mass movements (HUTCHINSON, 2004) inside the same territory depending on either the slope morphology or solid/water percentages of the propagating mass. These phenomena can be classified as debris flows (HUNGR *et alii*, 2001) when "a very rapid to extremely rapid flow of saturated non-plastic debris in a steep channel" occurs. If a smaller amount of solids is transported, these phenomena are usually referred to as hyperconcentrated flows (COUSSOUT & MEUNIER, 1996). Finally, when water prevails over solids, the phenomenon is usually called either debris floods or water floods (COSTA, 1988).

The run-out distances and consequences associated to debris flows, hyperconcentrated flows and debris floods are extremely different. Thus, it is important to distinguish these phenomena for risk analysis and zoning. The latter, in turn, necessarily requires an appropriate evaluation of the propagation stage.

Current scientific literature gives either empirical or numerical models for the analysis of the propagation stage as recently reviewed by HUNGR *et alii* (2005). The empirical models generally provide an

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Fig. 1 - Cervinara study area: a) location, b) 3D view

estimation of the run-out distance which mostly depend on the amount of the unstable volume (Corominas, 1996) as well as the features of the source areas and slope morphology (Cascini *et alii*, 2008a, 2010). Numerical modelling (Pastor *et alii*, 2009; Pirulli & Sorbino, 2008; Hungr & Mc Dougall, 2009) also provides the velocity and height of the propagating mass, which are important inputs for risk analysis. However, literature does not satisfactorily address case studies concerning an almost simultaneous occurrence of different types of flow-like phenomena that, quite often, are not distinguished. Thus, creating a significant misunderstanding of the related effects.

This is the case of the 15-16 December 1999 Cervinara events (Southern Italy) which caused 6 victims as well as a huge amount of damage to buildings and facilities.

The area threatened by the 1999 events is located 75 km from the Vesuvius volcano, in the eastern part of the Campania region, which is one of the most at risk landslide areas of Europe (Cascini *et alii*, 2008b) (Fig. 1). In this region, unsaturated pyroclastic soils derive from the explosive eruptions of Vesuvius volcano and are mostly sands/gravels (pumice soils) and silty sands/sandy silts (ashy soils) (Bilotta *et alii*, 2005).

Pyroclastic soils are extensively widespread over carbonate bedrocks (Cascini *et alii*, 2008a) and are frequently affected by rainfall-induced shallow landslides of the flow-type (Cascini *et alii*, 2008a).

The 1999 Cervinara event has already been analysed in previous studies. Particularly, Budetta & de Riso (2004) outline that the reach angle of the major 1999 landslide is comparable with those of previous similar events which occurred in the Campania region. For the same landslide, Revellino *et alii* (2004) provide a 1D numerical modelling of the propagation stage which outlines the important role of erosion phenomena along the propagation path. However, a comprehensive analysis of all the occurred December 1999 flowlike mass movements has yet to be provided in current scientific literature.

Due to the availability of an advanced data-set, the paper firstly outlines the geo-environmental context affected by the 1999 events which are reconstructed and characterised. Then, the numerical modelling of all the recognised flow-like mass movements is provided with reference to their propagation stage. The obtained results are compared with both the eyewitness accounts and results of the previous studies. Finally, the role of the key factors is outlined in relation to the propagation stage of the occurred flow-like phenomena.

THE 15-16 DECEMBER 1999 CERVINARA FLOWLIKE MASS MOVEMENTS

GEO-ENVIRONMENTAL SETTING

Cervinara is a village (about 10,000 inhabitants) located at the toe of Mount Partenio (Fig. 2) where the mountain basins are characterised by high-order drainage networks and extensions varying from 0.62 to 3.22 km^2. Inside the mountain basins (located 320 - 1300 m a.s.l.), the main geomorphological units are represented by either zero order basins or open slopes (Cascini *et alii*, 2008a), where shallow deposits of pyroclastic soils have depths lower than 2 - 3 m. These deposits generally lie on steep slopes (30° - 40°) constituted by a fractured carbonate bedrock (Olivares & Picarelli, 2003).

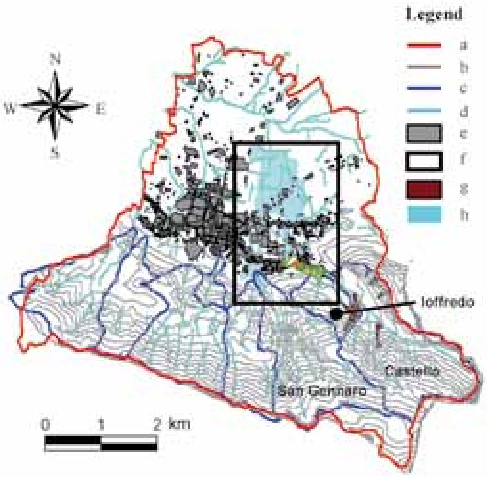

Fig. 2 - Geo-environmental setting of the Cervinara study area and 1999 flow-like phenomena: a) boundary of Cervinara municipality, b) 50 m elevation contour lines, c) main watersheds, d) main drawing network, e) buildings, f) mostly affected area by the propagation stage of the December 1999 events, g) debris flow, h) debris flood

Figure 2 shows the main watersheds of the Cervinara municipality (data provided by the River Basin Authority "Liri- Garigliano-Volturno rivers"). In the same figure, an area of about 6.40 km^2 (box named "f") is also shown, which was mostly affected by the 1999 events. This area will be referred to in the following sections of the paper as the study area for the numerical modelling.

TEMPORAL AND SPATIAL OCCURRENCE

Between 14-16 December 1999, starting from 14th December 12 a.m, a cumulated rainfall of 264 mm in 38 hours (Fiorillo *et alii*, 2001) was recorded at the S. Martino Valle Caudina rain-gauge (Fig. 3). Hydrological analyses show that the return period of the cumulated rainfall over the previous 24 hours was equal to 10-20 years on 15th December at 6:00 p.m. and it rapidly increased up to values of 50-100 years on 16th December at 00:00 a.m. (Cascini *et alii*, 2005).

During the rainstorm, multiple flow-like mass movements threatened the Cervinara municipality in about three hours. From the available data-set (source: River Basin Authority "Liri-Garigliano- Volturno rivers"), eyewitness accounts of the inhabitants of Cervinara (personal communication) and in reference to table 1 and figure 4, it can be obsrved that: i) on 15th December at 22:15, a street was flooded at location named "Valle" (point 1); ii) on 16th December at 00:15 another flooding was recorded (point 2) due to a local break of the levees of the Castello torrent; iii) afterwards (at 00:35) both water, debris and trees propagated downhill (point 3); iv) at the same time (about 00:40), in Piazza Ioffredo (point 4), the cross section of a bridge over the Ioffredo torrent was completely filled with debris and trees coming from the upslope Ioffredo basin; v) finally, from the same mountain basin, a huge amount of debris flooded Via Ioffredo (point 5) at 01:20.

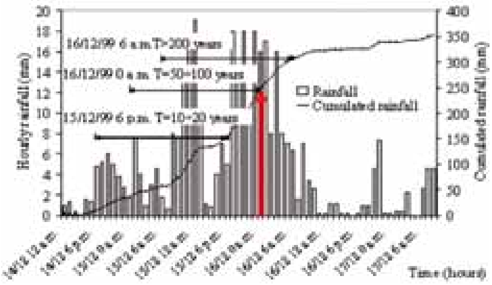

Fig. 3 - Rainfall data recorded at S. Martino Valle Caudina rain-gauge (288 m a.s.l., 2 km far from Cervinara) (modified from Cascini et alii, 2005)

ID	SITE	DATE	OBSERVATION
1	Valle	15th Dec, 22:15 h	flooding
2	Via Ponteforastico	16th Dec, 00:15 h	flooding
3	Via S. Paolino	16th Dec, 00:35 h	water and debris
4	Piazza Ioffredo	16th Dec, 00:40 h	flooding
5	Via Ioffredo	16th Dec, 01:20 h	water and debris

Tab. 1 - Temporal occurrence of the events

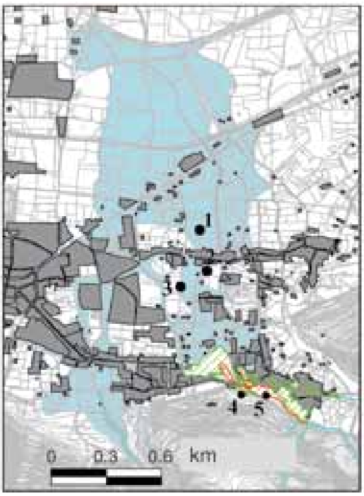

Fig. 4 - Spatial occurrence of the events inside the area "f" of figure 2

Fig. 5 - Typical examples of damage caused by debris floods occurred at San Gennaro, Ioffredo and Castello watersheds

Fig. 6 - Typical examples of damage caused by the Ioffredo debris flow

From the reconstruction of the events, it can be outlined that: i) firstly three debris floods occurred at the San Gennaro, Ioffredo and Castello watersheds (Fig. 4), ii) 3 hours later, a debris flow was triggered at the Ioffredo mountain basin (Fig. 4). The three debris floods travelled distances up to 2.50 km inside the piedmont zone involving an area of about 4.70 km^2. The Ioffredo debris flow propagated 1.50 km downsslope from the crest of the source area, affecting an area of about 0.20 km^2 in the piedmont zone.

Regarding the observed damage, debris floods mostly caused the inundation of streets and bridges with debris and trees (Fig. 5a, 5b) as well as minor damage to buildings (Fig. 5c, 5d). The Ioffredo debris flow, characterised by a much greater amount of debris, caused the collapse of either non-structural (Fig. 6a, 6b) or structural parts of buildings (Fig. 6c, 6d).

Considering the differences among the 1999 flow-like phenomena and the time delay in their occurrence, it can be consistently assumed that their propagation patterns were independent. Therefore, they are hereafter separately back-analysed. To this aim, numerical models are used to assess the propagation areas of all the types of the flow-like mass movements.

NUMERICAL MODELLING OF THE PROPAGATION STAGE

THE FLO-2D MODEL

Numerical modelling of the propagation stage of flow-like mass movements can be carried out through several numerical codes available in current literature (Pastor *et alii*, 2009; Pirulli & Sorbino, 2008; among others). In this paper, the commercial numerical code FLO-2D (O'Brien *et alii*, 1993) was used, since its efficacy has been extensively proven (Bello *et alii*, 2003; Pirulli & Sorbino, 2008).

The FLO-2D model assumes the propagating mass as a continuum "equivalent" fluid whose rheological behaviour must approximate the behaviour of the real mixture of solid and fluid phases. The dynamic behaviour of the equivalent fluid is described by the mass balance equation (eq. 1) and momentum balance equation (eq. 2-3), which written in Eulerian form, depth-averaged and implemented in a finite difference scheme are the following:

$$\frac{\partial h}{\partial t}+\frac{\partial\left(h\overline{v_x}\right)}{\partial x}+\frac{\partial\left(h\overline{v_y}\right)}{\partial x}=i \qquad (1)$$

$$S_{fx}=S_{ox}-\frac{\partial h}{\partial x}-\frac{v_x}{g}\frac{\partial\overline{v_x}}{\partial x}-\frac{v_y}{g}\frac{\partial\overline{v_x}}{\partial y}-\frac{1}{g}\frac{\partial\overline{v_x}}{\partial t} \qquad (2)$$

$$S_{fy}=S_{oy}-\frac{\partial h}{\partial y}-\frac{v_y}{g}\frac{\partial\overline{v_x}}{\partial y}-\frac{v_x}{g}\frac{\partial\overline{v_x}}{\partial x}-\frac{1}{g}\frac{\partial\overline{v_x}}{\partial t} \qquad (3)$$

where S_f denotes the depth-averaged flow velocity, h is the flow depth, v the velocity, i is the rainfall intensity on the flow surface and g is the gravity constant. The friction slope components S_{fx} and S_{fy} are written as functions of the bed slope S_{0x} and S_{0y}, the pressure gradient and the convective and local acceleration terms.

Regarding the rheological characteristics of the flowing mass, the quadratic rheological approach proposed by Julien & Lan (1991) is adopted. In particular, the friction slope components S_{fx} and S_{fy} are provided by the following expression:

$$S_{fi(i=x,y)}=\frac{\tau}{\rho gh}=\frac{\tau_y}{\rho gh}+\frac{K\eta\overline{v_i}}{8\rho gh^2}+\frac{n_{td}^2\overline{v_i}^2}{h^{4/3}} \qquad (4)$$

where τ is the shear stress at the contact between the flowing mass and the bed load, τ_y is the Bingham yield stress, η is the Bingham viscosity, K is the flow resistance parameter and n_{td} is the equivalent Manning coefficient for the turbulent and dispersive shear stress components. Particularly, the first and second terms on the right hand side of Eq. (4) are, respectively, the yield term and the viscous term as defined in the Bingham equation. The last term represents the turbulence contribution (O'Brien *et alii*, 1993).

INPUT AND METHODS

In order to simulate the propagation stage of the 1999 events, different digital elevation models (DEM), available from 1:25,000 and 1:5,000 maps, were used. Aimed at solving the governing system of equations (1-4), for a given DEM, the FLO-2D code overlays the topographic surface with a square finite difference grid system and the flow is routed in eight possible flow directions (the four compass directions and the four diagonal directions). In the analyses carried out, either 25 m or 5m topographic grids were used depending on both the type of phenomena and analysis purposes. As input data, the location of the source areas were assigned as well as the amount of the unstable mass which was introduced as an inflow hydrograph. The latter, in turn, requires the evaluation of the mobilised volume and/or the flow discharge.

Particularly, for the debris floods occurred inside the San Gennaro, Ioffredo and Castello watersheds (Fig. 2), the propagating mass was assumed as a Newtonian equivalent fluid eventually considering low debris concentrations (by volume) not larger than 0.2. Accordingly, the hydrograph was assumed triangular with the maximum corresponding to half the duration of the hydrograph, in agreement with current literature. From the data-set (source: River Basin Authority "Liri-Garigliano-Volturno rivers") the peak discharges were available, evaluated explicitly considering the morphometric features of the watersheds. The watershed concentration times (Chow et alii, 1988) were assumed as the total duration of the inflow hydrographs (Tab. 1). Particularly, two hydrographs were available, respectively computed referring to: i) a rainfall characterised by a return period T = 100 years, according to VAPI procedure (Rossi & Villani, 1994) (hydrographs "a", later on), ii) the rainfall intensity measured during the 15-16 December 1999 rainstorm (hydrographs "b", later on). Hydrographs "a" and "b" are reported respectively in figure 7a and 7b, being the peak discharge and duration of the former hydrograph much larger than those of the latter one.

Watershed	San Gennaro	Ioffredo	Castello
length (km)	3.19	1.09	3.09
area (km^2)	2.92	0.62	3.2
z_{max} (m a.s.l.)	1,290	875	1,300
z_{min} (m a.s.l.)	320	330	370
z_{mean} (m a.s.l.)	850	575	800
t_c (minutes)	38	23	43

Tab. 2 - Morphometric and hydrological characteristics of the watersheds (z: elevation, tc: watershed concentration time)

For the debris flow occurred at the Ioffredo watershed, the volume mobilised inside the source area was initially evaluated. In particular, assuming a mean depth of the slip surface from the ground surface equal to 1.5 m (Damiano, 2003), the mobilized volume was estimated equal to 31,000 m^3. This value is in agreement with that estimated by Damiano (2003), while it is quite smaller than those outlined by Revellino et alii (2004) and Budetta & De Riso (2004) respectively equal to 120,000 m^3 and 240,000 m^3.

Regarding the rheology of the propagating mass, the quadratic rheological approach proposed by Julien & Lan (1991) was used adopting values of the rheological parameters taken from current literature (Pirulli & Sorbino, 2007, 2008). Particularly, it is assumed that the unit weight of the propagating mass is equal to 12 kN/m^3; the sediment concentration (by volume) ranges from 20% to 40%; the Bingham yield stress, τ_y is in the range from 0.5 kPa to 0.7 kPa; the Bingham viscosity η is equal to 10 - 20 Pa·s. Moreover, as suggested in literature (Pirulli & Sorbino, 2007, 2008), a triangularshaped hydrograph was referred to with the peak discharge Q_p corresponding to 1/3 of the duration of the hydrograph. The peak dis-

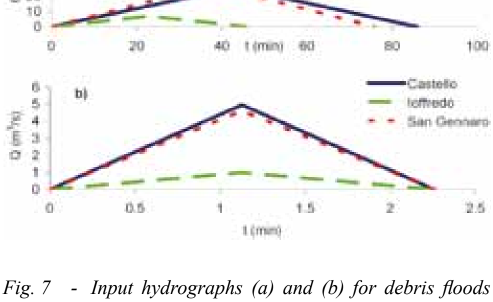

Fig. 7 - Input hydrographs (a) and (b) for debris floods (data source: River Basin Authority "Liri-Garigliano-Volturno rivers")

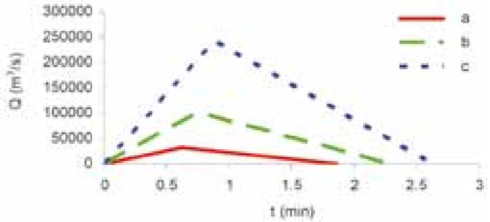

Figure 8. Input hydrographs for the Ioffredo debris flow assuming different mobilised volumes: 30,000 m^3 (a), 120,000 m^3 (b), 240,000 m^3 (c)

charge was estimated through the empirical relationship proposed by RICKENMANN (1999) which follows:

$$Q_p = 0.1 \cdot V^{5/6} \qquad (5)$$

where Q_p (m^3/s) is the peak discharge and V (m^3) is the volume of the debris flow. The computed values are reported in Figure 8.

NUMERICAL RESULTS FOR DEBRIS FLOODS

For the numerical modelling of the debris floods occurred in the three watersheds of table 2, a 25 m x 25 m Digital Elevation Model was used and different event scenarios were analysed by changing: i) the inflow hydrograph, ii) the debris concentration and iii) considering or not the presence of buildings (Fig. 9).

Figure 10 shows the flow depths simulated considering the hydrographs of figure 7. In particular, assuming the hydrograph "a" of fig. 7a, the propagation area is overestimated both for the watersheds 1 and 2-3 (Fig. 10a). Conversely, assuming the hydrograph "b" of fig. 7b, a satisfactory matching is obtained among the simulated and observed propagation areas in watershed 1, while in watersheds 2-3, an underestimation is obtained (Fig. 10b). However, with reference to this last area, the observed local breaks of the levees of the Ioffredo torrent are not considered in the numerical analyses, while these phenomena certainly contributed to enlarging the propagation areas, even if with low depths.

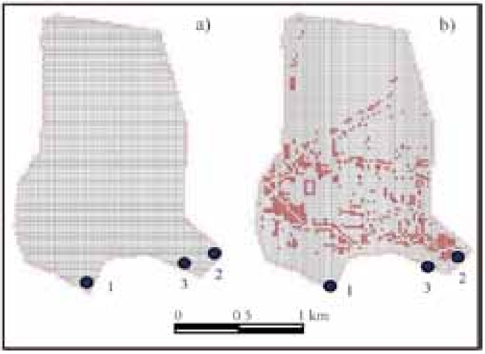

Fig. 9 - Topographic grids (25m x 25m) used as input for the FLO-2D code: a) not considering and b) considering the presence of buildings

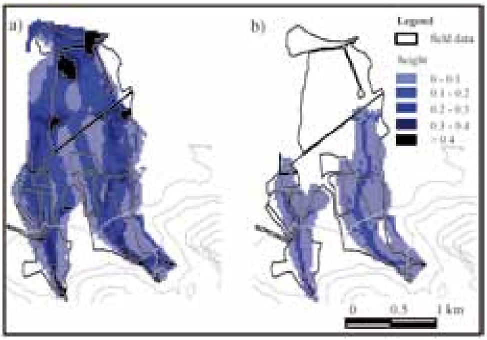

Fig. 10 - Computed propagation areas of debris floods obtained assuming the hydrographs "a" and "b" of figure 7

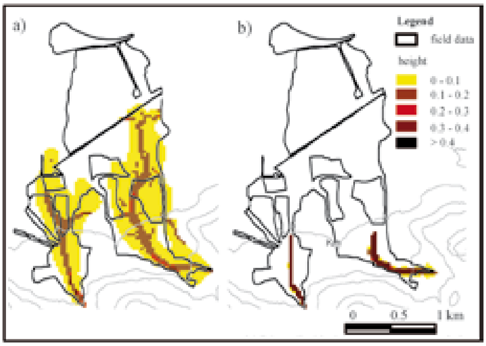

Fig. 11 - Computed propagation areas of debris floods assuming the hydrographs "b" of figure 7b and debris concentrations equal to 0.1 (a) and 0.2 (b)

In order to assess the rheology of the propagating masses, different debris concentrations (by volume) were considered up to 20 %, referring to the hydrograph "b" of figure 7b, with figure 11 showing the simulated propagation areas. It is evident that debris concentrations up to 10% negligibly modify the propagation patterns and the simulated depths, as highlighted by the comparison with figure 10b. Conversely, if the considered debris concentration is higher than 20%, the simulated scenario is completely different, with higher depths of the propagating mass as well as smaller areal extent. Therefore, the December 1999 events must be considered debris floods rather than hyper-concentrated flows since the back- analysed debris concentrations did not exceed 10-20%.

The role of the buildings on the propagation stage of the occurred debris floods was also analysed. The

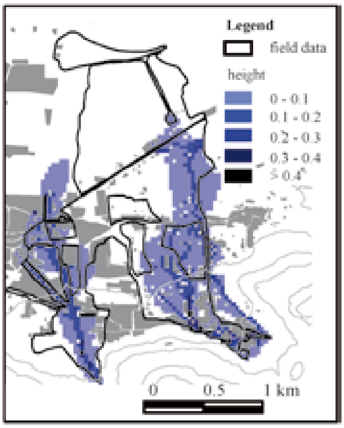

Fig. 12 - Computed propagation areas of the debris floods assuming the hydrographs "a" of figure 7a, absence of sediments and considering the presence of the buildings

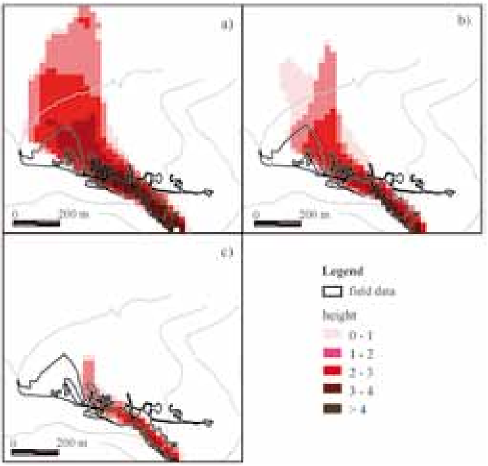

Fig. 13 - Computed propagation areas of the Ioffredo debris flow assuming the same rheological parameter (τ_y = 0.7 kPa, η = 20 Pa·s) while different volumes for the inflow hydrograph available from: a) Budetta & de Riso (2004), b) Revellino et alii (2004) and c) present study

cells of the topographic grid of figure 9 corresponding to buildings were therefore assumed to be not floodable and the obtained results are given in figure 12. Generally speaking, the obtained scenario is quite similar to that of figure 9b even though some local differences can be noted. Specifically, in the simulation of figure 12, a greater correspondence with the in-situ evidence is obtained on the left side for watershed 1 and on the right side for watersheds 2 and 3. However, the presence of buildings does not significantly modify the propagation patterns and depths of this type of phenomena.

NUMERICAL RESULTS FOR THE IOFFREDO DEBRIS FLOW

The propagation stage of the Ioffredo debris flow was initially simulated referring to the 25 m x 25 m Digital Elevation Model of figure 9a in order to: i) obtain a preliminary evaluation of the mobilised volume, ii) investigate the potentialities to reproduce this type of phenomenon with a 25 m x 25 m DEM.

Numerical simulations (Fig. 13) were carried out with three volumes of the inflow hydrograph, respectively equal to 240,000 m^3, 120,000 m^3 and 31,000 m^3, with the first two values being available from literature and the last one assumed in this study. The obtained results clearly show that this last estimated volume is the only one that allows for a better reproduction of the observed propagation area as well as the depths of the debris flow inside the propagation area (Fig. 13). From the obtained results, it is also evident that: i) the accurate evaluation of the mobilised volume is a fundamental step for an adequate assessment of the affected areas, ii) a 25 m x 25 m DEM makes it possible to obtain only a rough estimation of the kinematic and rheological features of the debris flow.

Therefore, further analyses were carried out aimed at adequately assessing: i) the rheology of the propagating mass, ii) the effect of the presence of buildings on the propagation pattern, iii) the relationships between the kinematic features of the debris flow and damage to buildings.

Accordingly, a more detailed 5m x 5m Digital Elevation Model was used and different scenarios were outlined, based on different values of the rheological parameters of the mass (Fig. 14a). The obtained results show that a value of τ_y ranging from 0.5 kPa to 0.7 kPa allows for a satisfactory estimation of the run-out distance of the debris flow, with the last value being the more suitable for adequately reproducing the in-situ evidence (Fig. 15). On the contrary, negligible differences were obtained by changing the parameter h in the range 10 - 20 Pa·s.

In order to further investigate the kinematic features of the Ioffredo debris flow, the presence of buildings was also considered (Fig. 14b). The obtained results show the relevant role played by the obstacles in determining both the flowing directions and the depths of propagating mass (Fig. 15 - 16), especially in the densely urbanized area.

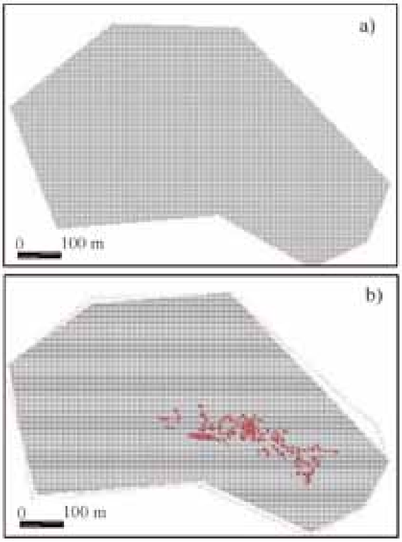

Fig. 14 - Topographic grids (5m x 5m) used as input for the FLO-2D code: a) not considering and b) considering the presence of buildings

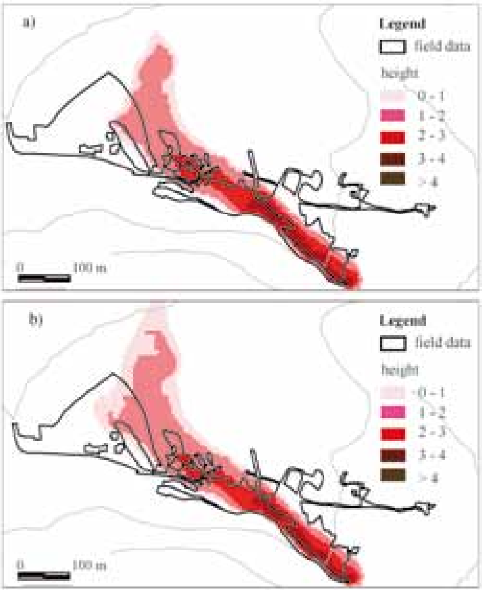

Fig. 15 - Computed propagation areas assuming $\eta = 20$ Pa·s, $\tau_y = 0.7$ kPa (a) and $\tau_y = 0.5$ kPa (b), disregarding the presence of buildings

The computed depths and velocities of the debris flow (Fig. 17) also make it possible to highlight several insights relating to the observed damage.

Particularly, the most damaged buildings “a”, “b”, “c” and “e” correspond to simulated velocities 12 m/s < V < 21 m/s, while the buildings “d” and “f” are as-

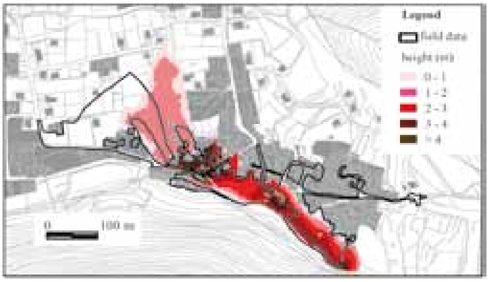

Fig. 16 - Computed propagation areas assuming ($\tau_y = 0.7$ kPa, $\eta = 20$ Pa·s) and considering the presence of buildings

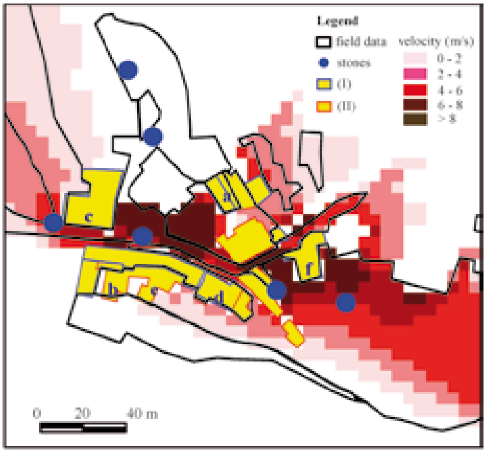

Fig. 17 - Buildings destroyed (I) and severely damaged (II) compared to the computed velocities of the propagating mass using the same rheological parameters of figure 16

sociated to 8 m/s < V < 12 m/s. These results match the results of Faella & Nigro (2003) which estimated velocities ranging from 14 m/s to 21 m/s as necessary for the column collapse of concrete buildings, while lower velocities, within the range 3 - 19 m/s, may cause the failure of external walls.

CONCLUDING REMARKS

This paper deals with flow-like mass movements which occurred in December 1999, causing 6 victims inside an area of about 4.70 km^2 of the municipality of Cervinara (Southern Italy).

For this event, the temporal occurrence was firstly reconstructed based on the available information on damage to structures and infrastructures as well as the eyewitness accounts of local inhabitants and the available dataset.

The analysis of the available data outlines different types of flow-like movements which occurred during the 1999 disaster: i) debris floods originated in three mountain basins that affected a large propagation area, ii) three hours later, a huge debris flow originated in a small watershed and propagated independently from the previous phenomena.

For both the aforementioned debris floods and debris flow, a numerical modelling of the propagation stage was carried out using a commercial FLO-2D code, referring to i) inflow hydrographs evaluated by using different methods depending on the typology of phenomena, ii) rheological parameters assessed on the basis of the back-analysis of the observed propagation areas.

In the three analysed watersheds, the numerical results confirm that debris floods rather than hyperconcentrated flows occurred, since the debris concentrations is lower than 10 - 20%. For these phenomena, the inflow hydrographs estimated referring to the measured rainfall of the 15-16 December 1999 rainstorm allow for a satisfactory back-analysis of the propagation area. On the contrary, the hydrographs computed referring to a rainfall characterised by a return period equal to 100 years give an overestimation of the propagation areas. Finally, it has been demonstrated that the buildings play a negligible role on the extent and depths of the propagation area of the observed and modelled debris floods.

For the occurred debris flow, the back-analysed volume matches the in-situ evidence, with it being in agreement with one of the studies in current literature. Moreover, it has been highlighted that a quadratic rheological law is appropriate in order to obtain a satisfactory simulation of the propagation area. Finally, taking into account the role played by the buildings on the kinematics of the debris flow, the simulated depths of the debris flow match those observed in-situ; moreover, velocities seem to be strictly related to the type and severity of the recorded damage to buildings.

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