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COMPARISON OF 2D MODELS FOR THE SIMULATION OF THE OCTOBER 1954 DEBRIS FLOW AND FLOOD EVENT AT MAIORI (CAMPANIA REGION, ITALY

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ABSTRACT

The Campania Region (southern Italy) is characterized by a frequent occurrence of volcaniclastic debris flows causing extreme loss of life and property damage where a large population occupies alluvial fans. In 1954 the small town of Maiori was struck by several debris flows initiated as soil slips triggered by prolonged rainfalls. Historical sources report seaward shift of the coastline of some tens of metres during major flood events, also documented by air photographs taken soon after the disaster. The 1954 event has been simulated using two commercially available models, DAN-W and FLO-2D. DAN-W is a program used to model the post-failure motion of rapid landslides such as debris flows and suitable for estimating their runout behaviour. The same 1954 event has been further simulated by means of FLO-2D, whose sensitivity to different routing conditions was tested by varying several critical input data as the shape of flow hydrograph and the volume mobilised. The rheological parameters of the model have been assigned assuming a Bingham behaviour for the debris flow, based on other works available in literature. The results obtained with both programs have been then critically commented, with the aim of assessing their capability to reproduce the studied event and, more generally, to help in the specific hazard zoning and mapping.

Key words: *debris flows, flood event, back-analysis*

INTRODUCTION

On October 25-26, 1954 a wide territory in the Campania region (Italy) including the municipalities of Salerno, Vietri sul Mare, Maiori, Minori, was struck by a huge flood event which caused about 300 victims and severe damage to urban centres and primary infrastructures. The event, triggered by a short duration, high intensity rainfall was also characterized by the detachment of a great number of mass movements, mainly of the slide-flow type, which mobilized loose pyroclastic deposits. The 1954 is, up to now, the worst episode of a long series, which, from that year onward, hit the Campania region and which has known a further, tragic peak on May 5, 1998. On that occasion five foothill towns (Sarno, Bracigliano, Quindici, S. Felice a Cancello and Siano) were invaded by some extremely rapid flow-like movements, again involving the local volcaniclastic covers: as main consequence, 160 persons lost their lives.

The events occurred in the last decades clearly evidenced the intrinsic vulnerability of the Campanian territory, where more than 3000 km^2 (ca. 22% of the regional extension) are exposed to a very high hazard related to fast-moving (> 10 m/s), long-runout (3-4 km) slide-flows in pyroclastic sediments.

In the case of fast-moving landslides such as flow-like movements, the assessment of their runout is of paramount importance for both researchers and administrators, when a thorough evaluation of the related hazard is required, e.g. for the implementation of urban planning strategies. Multiple approaches can notoriously be applied to the assessment of the maximum travel distance of phenomena such as debris flows, debris avalanches, hyperconcentrated flows: empirical, statistical, process-based methods can in fact be used, whose drawbacks are tackled by culturally competent researchers. As concerns debris flow modelling, two approaches are possible: two-phase model and single-phase model. A two-phase model treats separately the solids and the fluid. It is very useful to simulate the entrainment and deposition processes through the movable bottom line, and, therefore, is suitable to face problems where the morphological evolution is to be determined. The state of art for describing the interaction effects between the two phases is insufficient (Takahashi, 2007). As an alternative to separating the stress contributions of solid and fluid constituents and their interactions, many investigators use lumped-rheology models or calibrated resistance formulas to model the effects of the stress on a debris flow (Iverson, 2005). The mixture of fluid and solids is considered as a kind of continuous fluid whose properties implicitly reflect the fluid-particles interaction effects.

From a scientific point of view the one-phase model appears obsolete and recent debris flow theories tend to select the two-phase model. However, for practical applications one-phase approach is usually preferred. Therefore we believe that systematic comparisons of debris flow models with well-documented field cases are of value.

In recent years, several runout prediction methods have been developed (e.g. RAMMS, RASH3D, SHWCIN, TITAN2D, etc.), including innovations that have significantly advanced our ability to mimic debris flows' behaviour (McDougall *et alii*, 2008). However, while studies are promoted to improve the existing approaches, also mutuating hints from different fields (cellular automata, fractal logics, neural network, etc.), there is an urgent need to make assignment on robust and trustworthy models, essential to perform a landslide hazard and risk assessment both at region- and slope-scale. Accordingly, a major effort has to be devoted not only to search more reliable predictive models, but also to validate the existing procedures, trying to overcome uncertainties and shortcomings which actually limit our capability to diagnose a basin or a slope behaviour.

Main aim of the present contribution is to cross-verify the feasibility of two well-known commercial codes (DAN-W - Hungr, 1995; FLO-2D - O'Brien *et alii*., 1993) in modelling the October 1954 event, with respect to the Reginna Maior basin, which has been one of the focus areas in terms of damage caused. Such event, although triggered by an extreme rainfall, showed features common to vast areas of the Campania region, where slide-flows in volcaniclastic terrains have repeatedly occurred.

Both models discussed below solve the continuity and momentum equations in both orthogonal flow directions. Only the main features are summarized here, and the appropriate literature is cited for each model. The debris-flow mixture is assumed to be a continuous, homogeneous, and incompressible fluid.

GENERAL SETTING

The Regina (or Reginna) Maior torrent drains a basin of about 33 km^2, which shows a prevailing N-S direction. It crosses the territory of Maiori, a town of about 5700 inhabitants, located some 20 km west of Salerno, the province capitol (Fig. 1). The basin, which culminates at about 1300 m a.s.l. with Mt. Cerreto, is of fifth order, following the hierarchical system proposed by Strahler (1952); the main channel reaches the Tyrrhenian sea after about 6 km.

The geological setting is characterized, on the whole, by the presence of a carbonate bedrock overlain by loose pyroclastic deposits. The bedrock is in fact made up of the basal terms of a carbonate platform sequence, Mesozoic to Tertiary in age, mainly represented by dolostones and dolomitic limestones ascribed to Triassic. Some of these rocks are so pervasively jointed to be termed, in the local geological literature, as floury (farinose).

The bedrock crops out mainly along high-angle scarps or cut-slopes; in the remaining areas, it is mantled by a cover made up of pyroclastic deposits. In the area, such deposits belong to the 79 a.D. Vesuvian eruption, famous for having destroyed Pompeii and Herculaneum. Volcanological studies (Lirer *et alii*, 1973) have evidenced that the 79 a.D. eruption was characterized by a dispersion axis SE oriented, which caused the onset of up to 2.5 m of volcaniclastic products in the Sorrento Peninsula.

For the study area, a 1:5000 scale map is available which shows the areal distribution of the pyroclastic cover and the related thickness (Fig. 2). As evident

Fig. 1 - Location of study area

from Figure 2, a cover thick up to 5 m is present on the slopes, which is the key-element, along with slope angle, accounting for the high susceptibility to mass movements such as slides and slumps, which, albeit initially surficial, can eventually evolve into debris flows. In the footslope areas, along the main draining channels and on the planar surfaces, the cover reaches the highest values, comprised in the 5 to 20 m class.

THE 25-26 OCTOBER 1954 EVENT

The 25-26 October 1954 event, characterized by extreme rainfall values clustered in a few hours, hit an area of more than 500 km^2, mainly falling within the Salerno province. The most notable figures which dramatically synthesize what happened are reported in Table 1: 318 victims, more than 11.000 homeless, 320 buildings destroyed; the overall damage was estimated at about 40 billions of Italian Liras, corresponding to a present-day value of 550 millions of Euro (Esposito *et alii*, 2003b) (Fig. 3).

The municipalities which suffered the worst consequences were all located in the so-called Amalfi coast, west of Salerno, and included the towns of Vietri sul Mare, Maiori, Cava de' Tirreni, Tramonti, Minori. Several hydrographic basins were interested by phenomena such as areal slope denudation, mass movements, overflowing, shore progradation: among them, the Reginna Maior, Regina Minor, Bonea, Cetus, Fusandola and Rafastia basins were the focus of the main ground effects.

On October 25 a weather disturbance which had already caused huge rainfall in northern Italy moved southward, reaching the Campania region and the province of Salerno (Fig. 4). The rainfall lasted about 16 hours, from 1:00 PM on October 25, to 5:00 AM on October 26, with a maximum value of 504 mm and maximum intensity of 150 mm/hour (Frosini, 1954). De Luca *et alii* (2010) defined the 1954 event as a hurricane-like meso-cyclonic vortex, characterized by a return period of about 59.000 years.

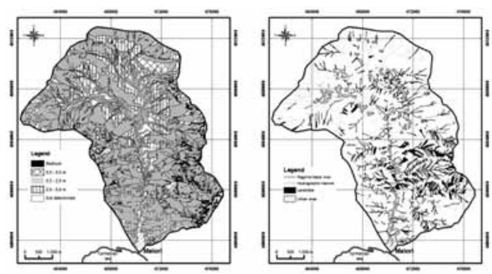

Fig.2 - Reginna Maior basin: Pyroclastic cover thickness map (on the left); 1954 Landslide-inventory map (on the right). Data provided by the Destra Sele Regional Basin Authority

Fig. 3 - Effects of the October 1954 event at Maiori

Among the main consequences, a huge number of mass movements occurred (Lazzari, 1954; Penta *et alii*, 1954), initially detached as slides or slumps and eventually evolved as debris avalanches along open slopes or channelled debris flows: within the Reginna Maior basin, more than 110 landslides have been mapped (Fig. 2). The landslides were fed by the pyroclastic cover mantling the carbonate bedrock and mainly ascribable to the 79 a.D. products.

An extensive collection of eyewitnesses accounts is available for the 1954 event (see Esposito *et alii*, 2004 and references therein). According to such accounts, it has been possible to extract the following information, valuable with respect to the present study:

- on October 26, the Reginna Maior torrent passed through Maiori with three successive flood waves, each of which higher than the preceding one; the waves occurred at 20:30, 21:00 and 22:00, respectively. The last wave was responsible for the major urban damage, and for the sudden opening of a sinkhole;
- the debris invaded seven buildings, located along the

Municipality	Destroyed buildings	Damaged buildings	Damaged industries	Victims	Homeless
Salerno	11	15	412	108	7127
Vietri sul Mare	309	269	60	117	1929
Maiori	14		214	34	939
Cava de' Tirreni			38	31	690
Tramonti			18	25	127
Minori			156	3	337

Tab. 1 - Damages and victims caused by the 1954 event (modified after Esposito *et alii, 2003a)*

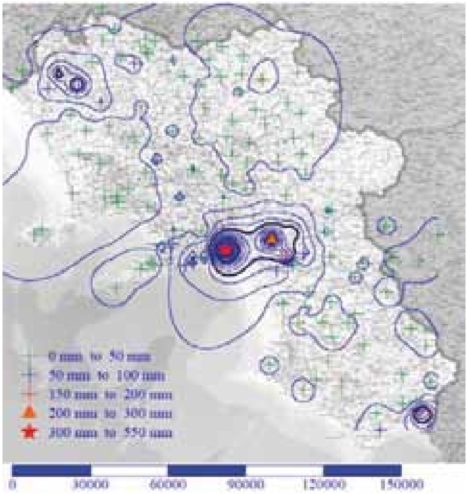

*Fig. 4 - Rainfall field of the October 1954 event (*De Luca *et alii, 2010)*

main street of Maiori, destroying them completely;

- along the torrent stretch which crosses Maiori the alluvial bed raised of about 3 m, while in a couple of sections located about 2.3 (Ponte Primario) and 1.5 km (Ponte Vecite) upstream of Maiori, debris deposition caused a bed elevation of about 14 m;
- the Maiori beach prograded seaward of about 50 m and, at the mouth of the Reginna Maior, a temporary fan delta was built, whose maximum width reached 100 m from the pre-existing shoreline. It is interesting to notice that the 1954 fan-delta was still visible from airphotos taken about one year after the 1954 event (Fig. 5);
- the beach of the nearby town of Minori, a small pocket beach normally constrained by headlands, prograded to such an extent that it was possible to reach Maiori by walking along the shore.

BACK-ANALYSES OF THE 1954 EVENT

DAN-W: MODEL AND INPUT DATA

The maximum runout of single debris flows moving along channels tributary to the Reginna Maior has been carried out using DAN (Dynamic ANalysis - Hungr, 1995), in its latest version DAN-W, a numerical model which allows to estimate the post-failure motion for debris flows and avalanches.

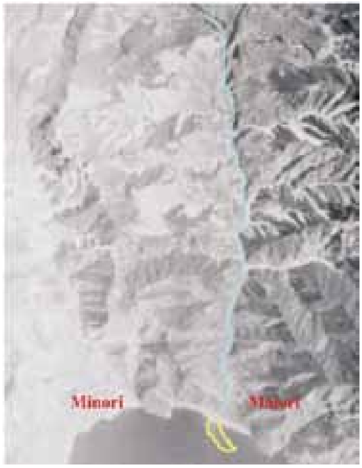

Fig. 5 - Airphoto of the study area taken on July 1955. Blue line: Reginna Maior Torrent; yellow line: submarine fan-delta

The model is based on an explicit Lagrangian solution of equations of unsteady non-uniform flow moving in a shallow open channel (Saint Venant's equations). The input data to start the model are: a) trigger volume, b) topographic profile of the slope (2D), c) width of the channel, and d) a constant erosion thickness. Moreover, the program includes an open rheological kernel, so that a variety of constitutive behaviours can be implemented (Hungr, 2003).

The rheological relationship selected for the analysis is the Voellmy (1955) model, as modified by Hungr (1995):

$$\tau = \gamma H\left(\cos\alpha + \frac{a_c}{g}\right)\mu + \gamma\frac{v^2}{\xi}$$

where τ:is the resisting stress at the base of the flow, α is the slope angle,γ is the unit weight of the flowing material (approximately 15 kN/m^3), H is the flow depth, ξ the dynamic friction coefficient of the material, ac is the centrifugal acceleration resulting from the vertical curvature of the flow path, μ is a turbulence coefficient with dimensions of m/s^2, g is the gravity acceleration and v is the velocity of the flow.

The choice of the Voellmy rheology was suggested by the good results obtained by previous authors in similar settings (Revellino *et alii*, 2004; Scotto di Santolo & Evangelista, 2009; Calcaterra *et alii*. 2010). In fact, in the Campanian Apennines, the velocities obtained with the frictional as well as Herschel-Bulkley models proved to be excessively high, even in the zone close to the arrest point, with respect to the data available from the literature (Faella & Nigro 2003; Scotto di Santolo & Evangelista, 2009). The Voellmy model differs significantly, with considerably lower and more realistic velocities than for the other two models. Such observations confirm what was observed by Hungr (1995), who noted that, by using the frictional model, the velocities were significantly overestimated. Moreover, the Voellmy model has been widely confirmed in similar contexts (Hungr & Evans 1996; Fiorillo *et alii*. 2001; Revellino *et alii*. 2004) by also using three-dimensional geometric models (McDougall & Hungr 2005) in terms of both distances travelled and velocities. In the papers by Revellino *et alii* (2004) and Scotto di Santolo & Evangelista (2009), in particular, by means of Voellmy-based back-analyses, a calibration of relevant input parameters (dynamic friction coefficient of the material, μ, and turbulence coefficient, ξ was achieved. The obtained values of μ= m/s^2 and ξ= 0.07 allowed to properly simulate the behaviour of the real events.

The flow paths have been reconstructed on a 1:5.000 scale map. No observed data were available as regards runout distances and final landslide debris thicknesses, so the input parameters were not adjusted to the selected rheology.

DAN-W: RESULTS

The volumes of pyroclastic deposits initially detached for each of the 1954 landslides were assessed by means of a GIS-based procedure (Fig. 6), through consecutive overlay operations. The procedure consisted in setting a buffer area (1 m) for the landslide perimeter, giving a weighted average thickness (T_{wa}) of sediments for each landslide (based on the pyroclastic cover thickness map of Figure 2), and then in multiplying the obtained value by the areal extent of the landslide.The Twa value was hence calculated by means of a weighted average of the different thickness classes of pyroclastic deposits included in the buffer area:

$$T_{wai} = \frac{\sum t_{in} * a_{in}}{a_i}$$

where: t_{in} is the central value of the thickness class of the n-th element in which the buffer area, of the i-th landslide, is divided; ain is the area of the n-th element in which the buffer area, of the i-th landslide, is divided; a_i is the area of the whole buffer area ($\sum a_{in}$).

After calculating the source volumes for each landslide, a total value of about 1.3 million cubic metres was obtained (Tab. 2). Owing to the high number of individual mass movements occurred (about 110 within the Reginna Maior basin), the source volumes introduced in the DAN-W back-analyses were considered as the sum of all landslides occurred in every tributary basin of the Reginna Maior torrent (Tab. 2). The resulting source volumes were then transformed into a debris slab of constant width, length and thickness (the latter ranging from 2 to 10 m), for each tributary basin, numbered from 1 to 15 (Fig. 7 and Tab. 2). Moreover, an average constant thickness of pyroclastic deposits (from 1 to 2 m, depending upon the map of Figure 2) was assumed to be eroded along each flow path.

As shown in Table 2, a final detached volume of about two million cubic metres has been calculated, with runout distances comprised between 900 and 2800 m from source. In nearly all the analyzed profiles the simulated flow passed over the confluence between the tributary basin and the main stream, coming to a halt from 100 to 500 m downstream, along the Reginna Maior. The predicted maximum flow velocities were in the order of 25-30 m/s, which decrease down to 2-4 m/s in the terminal stretches of the streamlines. Here, the front height showed values from 1 to 8 m.

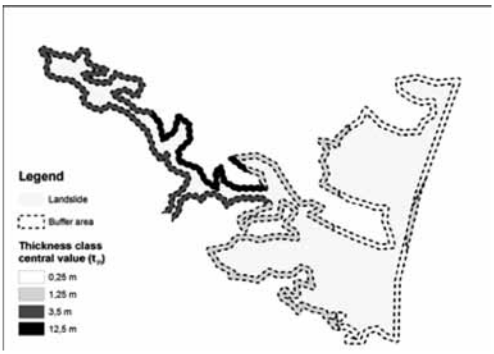

Fig. 6 - Graphical procedure adopted to estimate the initial volume detached for each 1954 landslide (see text)

Fig. 7 - Cross sections and points of maximum runout for the analyzed streamlines

Profile	Volume (m^3)		Runout distance (m)	
	Source	Final	Confluence	Final
1	105.000	130.000	1.700	1.900
2	55.000	80.000	1.400	1.800
3	7.500	25.000	1.400	1.700
4	30.000	55.000	1.800	1.900
5	71.000	110.000	2.400	2.800
6	120.000	160.000	850	1.100
7	300.000	380.000	1.800	2.300
8	85.000	130.000	1.600	1.700
9	180.000	300.000	1.600	2.000
10	72.000	100.000	800	1.100
11	55.000	100.000	1.800	2.000
12	52.000	70.000	600	900
13	57.000	70.000	750	1.000
14	18.000	55.000	1.500	1.600
15	140.000	205.000	1.400	1.400

Tab 2 - Source and final volume, confluence and final runout for each tributary basin

FLO-2D: MODEL AND INPUT DATA

In order to predict and to compare the runout distance and the velocity of the debris flows observed in the study area, the two-dimensional FLO-2D model (O'Brien *et alii*., 1993) has been applied. The FLO-2D simulation code solves the governing equations using a finite difference method on a fixed rectangular grid. The governing equations include the continuity equation

$$\frac{\partial h}{\partial t}+\frac{\partial hV_x}{\partial x}+\frac{\partial hV_y}{\partial y}=0$$

and the two-dimensional equations of motion:

$$S_{fx}=S_{ox}-\frac{\partial h}{\partial x}-\frac{V_x}{g}\frac{\partial V_x}{\partial x}-\frac{V_y}{g}\frac{\partial V_x}{\partial y}-\frac{1}{g}\frac{\partial V_x}{\partial t}$$

$$S_{fy}=S_{oy}-\frac{\partial h}{\partial y}-\frac{V_x}{g}\frac{\partial V_y}{\partial x}-\frac{V_y}{g}\frac{\partial V_y}{\partial y}-\frac{1}{g}\frac{\partial V_y}{\partial t}$$

where h is the flow depth, V_x and V_y are the velocity components, S_{fx} and S_{fy} are the friction slope components and Sox and Soy are the bed slopes.

The basic equation for the total friction slope S_f considers a combination of yield, viscous, collision and turbulent stress components. Based on the so-called quadratic rheological model of Julien & Lan (1991), the total friction slope Sf is expressed as:

$$S_f=\frac{\tau_B}{\rho gh}+\frac{K\mu_B V}{8\rho gh^2}+\frac{n^2V^2}{h^{4/3}}$$

where τ_B is the Bingham yield stress, ρ is the mixture density, g is the gravitational acceleration, μ_B is the Bingham viscosity, *V* is the mean flow velocity, *K* is the laminar flow resistance coefficient.

The laminar flow resistance coefficient K equals 4000 has been considered in relation with roughness and irregular cross section geometry (as suggested in FLO-2D Reference Manual, 2009). The Bingham parameters τ_B and μ_B are defined as exponential functions of sediment concentration (Coussot, 1994; Martino, 2003) which may vary over time; they have been inferred from the rheology of debris samples collected in another basin of Campania Region, measured by a coaxial viscometer (Martino, 2003). The pseudo-Manning's resistance coefficient (n=0.02) accounts for both collisional (inertial grain shear) and turbulent frictional losses.

The simulations have been developed for several values of solid concentration (0.3-0.6) and for two different variations of input discharge with respect to time: single surge input hydrograph or a succession of hydrographs generated from multiple events of debris flow (multisurge input hydrograph). The input hydrograph was reconstructed on the basis of debris volumes reported in Table 2. The surface topography was discretised into square-grid elements, and each one was assigned an elevation and a roughness factor. The detail and accuracy of a simulation are related to grid size: the sensitivity analysis showed that the quality of the simulations is higher when using the finer grid (small-sized cells).

FLO-2D: RESULTS

The debris flow event occurred on 1954 had a duration of 16 hours after an intense rainfall and reached the sea depositing there a volume of solid materials that permitted to reach by walking the village of Mi-

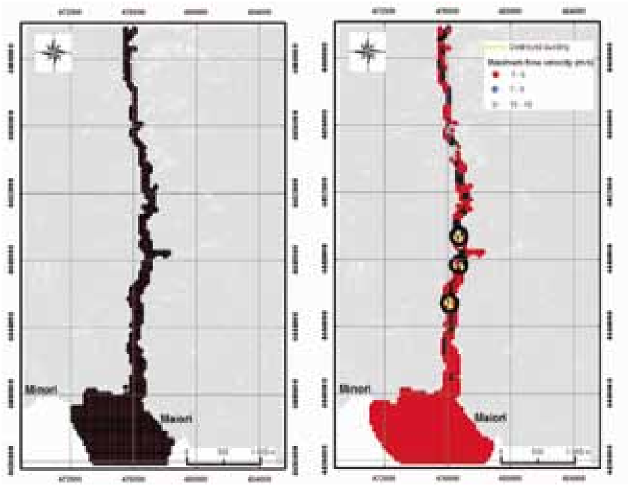

Fig. 8 - Distribution of deposit (on the left); maximum velocities predicted (on the right)

nori "almost without getting wet" as reported by eyewitnesses. The flow spread on the alluvial fan where several buildings were damaged. The procedure to optimize the model parameter consisted in obtaining the best agreement with the field observations: the comparison between field and numerical results has been developed taking into account the volume deposited in the sea and the velocities reached in correspondence of the buildings destroyed, where presumably they reached values higher than 6-7 m/s (Federico & Amoruso, 2008) (Fig. 8).

Starting from these event data, a reasonable agreement of the maximum depositional extent can be obtained for a value of solid concentration equal to 0.6 and a multiple hydrograph: these choices more closely match the depositional area in the sea and the high maximum velocities in the cells with the buildings destroyed (indicated with circles in Figure 8).

DISCUSSION AND CONCLUSIONS

Previous authors have already performed a comparison between DAN-W and FLO-2D, generally achieving good and intercomparable results, which, in turn, resulted in good agreement with the findings of the present study, considering the differences among the simulated events.

Among the most recent papers, Armento *et alii* (2008), Bertolo & Bottino (2008), Calcaterra *et alii* (2010) found that DAN-W gives a more accurate representation of the documented events in terms of velocity and runout distances using the Voellmy rheology, while FLO-2D, requiring a high-resolution DEM, represents more precisely the terminal flooded area. Moreover, Calcaterra *et alii*. (2010), who simulated a landslide-flood event occurred on November 2009 on the Ischia Island, Campania region, Italy, suggested a potential complementarity between DAN-W and FLO-2D in allowing to simulate a mixed landslide-flood event. In fact, the differences in the results obtained (DAN-W runout distance shorter than FLO-2D one) can be considered as a proof of the different behaviour of the unstable masses during their downslope movement. The Ischia event, in fact, started as a gravity-driven phenomenon, represented by some soil slides evolved into a channelled debris flow, whose mobility was strongly controlled by the local slope breaks (max runout distance = 1100 m). The debris flow eventually underwent a further evolution into a low-viscosity debris mixture (an hyperconcentrated flow, according to Pierson & Costa, 1987), which, favoured by the relevant water discharge, was able to reach the shoreline after a further travel of about 1500 m.

The results deriving from the simulation of the debris flow – flood event occurred at Maiori in 1954, obtained with the DAN-W and FLO-2D models, were here compared. In our case-study, an extreme, mixed event was back-analyzed, characterized by very long runout distances (5-6 km from source) and by the mobilization of about 2 million cubic metres of pyroclastic deposits, values unusually large for the Campanian Apennines (Calcaterra *et alii*, 2004).

As regards runout distances, the noticed disagreement between the two models' output is not necessarily a critical evidence. In fact, the lower values obtained with DAN-W (900-2800 m) can be explained, following CALCATERRA *et alii* (2010), as essentially controlled by the morphology of the flowpaths, where the main slope breaks found along the profiles and the low-angle channel of the Reginna Maior are responsible for the sudden slowdown of the gravity-driven flow. To this respect, it must be evidenced that individual soil slips moved from source areas showing slope angles between 29° and 43°. The main break at the slope base caused a reduction of 10° to 30°. Slope angles further decrease at the confluence between tributary channels and the main course of the Reginna Maior: the latter shows an average seaward dip of about 12°. In addition, if the 1954 landslide events are compared with similar phenomena occurred in the same geographical setting (Sorrento Peninsula), it can be evidenced that the debris flows known for the above area have displayed a maximum runout in the order of 800-900 m (CALCATERRA *et alii*, 2004). Runout distances comparable to those calculated by DAN-W for the 1954 events are typical of different Campanian settings, such as Mt. Pizzo d'Alvano, the carbonate relief involved in the May 1998 landslide event (DEL PRETE *et alii*, 1998; CALCATERRA *et alii*, 1999): on that occasion the foothill towns of Sarno, Bracigliano, Quindici and Siano were invaded by some channelled debris flows, which attained a maximum travel distance of 3500-4000 m (CALCATERRA *et alii*, 2004). Hence, the 1954 runout distances obtained with DAN-W, even though underestimated with respect to the total distance travelled by the low-viscosity flow along the Reginna Maior streamline, at the same time should be considered as the debris flow characterized by the highest mobility in the Sorrento Peninsula, thus confirming the exceptional conditions under which the 1954 landslides have occurred.

Flow velocities obtained with DAN were, as already pointed out by previous authors, higher than reasonably expected. In our case, following CALCATERRA *et alii* (2010), it could be explained with the high source volumes assumed in the simulations.

The key to the accuracy of simulation obtained with FLO-2D is the size of inundation in the sea that permitted to reach by walking the village of Minori. The values of the maximum predicted velocities revealed that they are compatible with the damage occurred on the buildings during the event. Moreover, while DAN-W cannot reproduce the contemporary trigger of multiple events, this effect can be simulated with FLO-2D assigning, in the hydrographical inputs, a succession of hydrographs, each one generated from a single event.

In conclusion, our study evidenced that, despite the noticed differences, the combined application of DAN-W and FLO-2D is useful to back-analyze with a reasonably accurate representation debris flow and flood events, even in the case of "extreme" episodes such as that occurred at Maiori and surrounding areas in 1954. The above differences, especially as regards the maximum runout, can be explained by means of the presumably different behaviour of the simulated phenomena, which, in their initial stages, have been prevailingly controlled by gravity (surficial slides evolved into channelled debris flows), and eventually transformed into low-viscosity debris mixtures (hyperconcentrated flows), owing to the significant water discharge. In any case, for both models, it is of paramount importance the definition of the rheological model, notoriously difficult to be a-priori defined if not by means of accurate laboratory experiments. Hence, both DAN-W and FLO-2D can be considered as useful tools to predict debris flow and flood hazard especially when detailed input data are not available, and their back-analysed parameters can be conveniently adopted for other settings, where similar boundary conditions can be found.

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