Reconstruction and numerical modeling of a flash flood: the event of Atrani 2010

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Study area:
The Dragone basin, Amalfi Coast, Southern Italy. (Fig.1) has an area about 9 km² with a mean elevation of about 105m.a.s.l.; the main river channel is 7km with a W-S orientation (Fig.2a). The upper portion of watershed has a mean slope of about 30° and it is characterized by a channel network mainly developed on right rive slope. In the downstream portion, the catchment becomes a gorge with steep slopes (80°) and rapid losses of elevation (Fig.2b).

Just before the Atrani village, the river is covered and artificially forced to flow underneath roads and squares to flow out to the sea. The channel follows the same path and elevation profile of Via dei Dogi, the main street of Atrani (Fig.2a).

Field surveys:
Information acquired, soon after the event, through the local people interviews and the field measurements significantly contributed to the rainfall event reconstruction and to the characterization of the induced effects. In absence of hydrometric data, the support of the amateur videos (Fig.3c) was of crucial importance for the hydraulic model development and calibration.

Surfaces erosion (~ 90000 m²) and deep channel erosion processes (Fig.3a, 3c), due to the generation of channeled hyper-concentrated flows, occurred. The right left bank, in the upstream areas (Santa Catarina and Santa Maria dei Monti), was particularly affected: field observations attested that the hyper-concentrated flows didn't reached the main river channel, therefore they didn't contributed to the downstream flow in Atrani village.

The flash flood event occurred in Atrani urban area (Fig.5b), outlet of Dragone basin, has been also the consequence of the hydraulic malfunction of the culvert (Fig.4a) that was not able to drain artfully the flood into the sea. In correspondence of the culvert inlet a fraction of the discharge wave (5.9m/s), skimming over the channel cover, invades the street. The channeled flow overpressure involving the breaking of the cover of culvert slab (Fig.6c) and caused a new discharge (20.2m³/s) inlet on the street modifying the downstream flood dynamics.

The solid volume (Fig.3b) concentration of the flood has been assessed not more than 5-6%, which seems to be coherent with video-images proofs. The Cs was much smaller than the value [about 20-30%] that is scientifically considered threshold beyond which the solid component modifies the rheological behaviour of the flow. Therefore it is feasible to approach to the event analysis according with the ordinary hydraulic criteria of sediment transport currents.

Meteorological event:
The September 9th, 2010 a strong weather phenomenon affected the coastal area manifesting with exceptional intensity in extremely confined areas (Castellamare, Scala and Ravello). The cumulative daily rainfall (Ravello rain gauge) 390 m m has been found to be 129.2mm; the maximum precipitation was 94.4mm. The return period, relative to Ravello rain gauge data, has been assessed not more than 5-6%, which seems to be coherent with video-images proofs.

Wave flood reconstruction:
A rainfall-runoff geomorphological model WFIUH - Width Function Instantaneous Unit Hydrograph has been used for the flash flood wave reconstruction basing on a DTN 5x5m. The width function Wm, (Fig.5a) has been extracted by the flow-paths length analysis and rescaled in the temporal width function Wm, (Fig.5b) using the watershed velocity as a scale factor (generated for each grid cell). The watershed velocity has been assessed through the approach proposed by Maidment et al. (1996). The WFIUH has been obtained by the convolution between the Wm, and the rainfall rate data (Fig.5c). The model calibration parameters have been chosen through the mean watershed velocity (Vmean=0.8m/s) and hydraulic diffusivity (D=10^{-6} m²/s) (Mesa & Mifflin, 1998). The model calibration has been done respecting the peak discharge value (98.5 m³/s) and the observed hydrological response time (1hr).

Wave modelling propagation:
Video observations showed three hydraulic phenomenon that characterized the flooding along Via dei Dogi (hydroph. – Fig.5c)

- the transition to a supercritical flow in p1;
- the hydraulic jump in p2 (covering slab breaking point);
- c) the hydraulic jump in p3.

The study of phenomena a) and c) has been useful in order to the discharge assessments. The measurements obtained by the flooding traces left at the walls supports significantly the hydraulic estimations (Fig.4).

An original numerical code, 2D FLATModel (Medina et al., 2007), has been proposed for the wave propagation reconstruction. The code has been tested on unstructured mesh (Fig.7a) that allows the adapting of digital surface to complex urban areas improving significantly the resolution of the simulation results. The simulation is constituted by three different steps, for each one three different condition represent the discharge input and the obstruction state of the lanes (t1, t2, Fig.5c). The discharge fraction of hydrograph that overflows the culvert (5.9m³/s) constitutes the upstream boundary condition (Ctrl-A, Fig.5c). The study supposes an instantaneous breaking of the cover slab and therefore an instantaneous release of the maximum discharge (20.2m³/s) (Ctrl-B, Fig.5c). Fig.7 shows the comparison between two different points, in the upstream and downstream of culvert breaking point, in term of depth water and velocity, between the FLATModel results and the observations.

Conclusions:
The comparison reveals satisfactory results: the code reproduces the effects of the inlet discharge due to the culvert breaking. In the upstream, where the maximum depth water is the only available observation, the code slightly overestimates the peak discharge.

Fig. 1: Geographical location of study area
Fig. 2: a) DTN b) Slope map
Fig. 3: a) Channel erosion b) Sediment fraction c) Eroded surfaces map [Addl Destra Sele, 2011]
Fig. 4: Observed measurements
Fig. 5: a) Wm, width function b) Wm, temporal width c) WFIUH and rainfall data event
Fig. 6: a) Simulation frame at 450s b) Un-structured mesh
Fig. 7: Comparison between results and observations: a) and d) downstream point; b) and c) upstream point

References:
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Medina V., Martinello, M., Brown J., Application of FLATModel, a 2D finite volume code, to debris flows in the northeastern part of the Arno catchment, Italy, Landslides, Springer-Verlag, Ed. 2007, p. 127-142
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Fig. 8: a) Simulation frame at 450s b) Un-structured mesh
Fig. 9: a) Comparison between results and observations: a) and d) downstream point; b) and c) upstream point

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