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Analysis and simulation of a rainfall-induced landslide on Enna Area (Italy)

Analyse et simulation des glissements de terrain induits par les précipitations dans la région d'Enna (Italie)

V. Lentini*, K. Pinargote, F. Castelli
Faculty of Engineering and Architecture, University Kore of Enna, Enna, Italy
**valentina.lentini@unikore.it*

ABSTRACT: One of the most dangerous effects of climate change is heavy rainfall, often responsible for the triggering of natural phenomena, such as floods or landslides. In recent years, landslides and alluvial events had a strong impact on the road networks, creating the need to define criteria for management and mitigation of hydrogeological risk related with transport infrastructure systems. The reliability of transport infrastructures plays a key role since, in many cases, their inefficiency has caused serious damage to the anthropic system. In the paper the modelling of a debris flow occurred in the Enna area in the south of Italy is described. The area is prone to landslides, often consisting in shallow movements induced by rainfall. Starting from the study of the geological framework and the historical background for landslides of the Enna district, the research has focused on the causes triggering the landslides. In particular, the real case of 1st-2nd February 2014 which affected Enna city has been modelled. The event caused damage to private buildings and the interruption of the main infrastructure connecting Enna city to the motorway, due to the material on the road. The characterization of soil properties along the slope is based on a detailed geotechnical investigation in addition to a collection of topographical and hydrogeological data. The second part reports the results of the numerical analysis simulating the landslide event to assess the appropriate mitigation works, to reduce the damages to structures and infrastructures located in the area.

RÉSUMÉ: L'un des effets les plus dangereux du changement climatique est la forte pluie, souvent responsable de déclencher des phénomènes naturels tels que des inondations ou des glissements de terrain. Ces dernières années, les glissements de terrain et les événements alluviaux ont eu un impact important sur les réseaux routiers, créant ainsi la nécessité de définir des critères pour la gestion et l'atténuation des risques hydrogéologiques liés aux systèmes d'infrastructures de transport. La fiabilité des infrastructures de transport joue un rôle clé, car dans de nombreux cas, leur inefficacité a causé de graves dommages au système anthropique. Dans cet article, la modélisation d'une coulée de boue survenue dans la région d'Enna, dans le sud de l'Italie, est décrite. La région est sujette aux glissements de terrain, souvent dus à des mouvements superficiels induits par les précipitations. À partir de l'étude du cadre géologique et du contexte historique des glissements de terrain du district d'Enna, la recherche s'est concentrée sur les causes déclenchant les glissements de terrain. En particulier, le cas réel du 1er-2 février 2014, qui a touché la ville d'Enna, a été modélisé. Cet événement a causé des dommages aux bâtiments privés et l'interruption de l'infrastructure principale reliant la ville d'Enna à l'autoroute, en raison des matériaux sur la route. La caractérisation des propriétés du sol le long de la pente repose sur une enquête géotechnique détaillée en plus de la collecte de données topographiques et hydrogéologiques. La deuxième partie présente les résultats de l'analyse numérique simulant l'événement du glissement de terrain afin d'évaluer les travaux d'atténuation appropriés pour réduire les dommages aux structures et aux infrastructures situées dans la région.

Keywords: Landslides; debris flow; geo-hydrological.

1 INTRODUCTION

Landslides can be triggered by various factors, such as meteorological events and tectonic forces. In Italy, frequent landslides, often deadly and economically destructive, are primarily triggered by rainfall.

Evaluating landslide risk involves analysing the spatial and temporal likelihood of specific landslides occurrence. This includes assessing rainfall patterns, triggering factors, event dynamics, propagation areas, and rheology. Efforts over the past decades have focused on developing numerical models to create reliable landslide inventory maps. The information on hazard, elements at risk, vulnerability, as well as geological and geotechnical data is essential.

The aim of this paper is to present the results of the numerical analysis simulated with the model in the FLO-2D (Wu et al., 2013; Stancanelli and Foti, 2015) of the landslide event that struck Enna, Italy, on

February 1st-2nd, 2014, with the goal of evaluating debris flow behaviour.

2 LANDSLIDE INVENTORY IN ENNA AREA

A crucial component of landslide zonation is the creation of a landslide inventory map, which details the information. This inventory serves as a prerequisite for conducting analyses to establish relationships between landslide distribution and various influencing factors. The creation of a comprehensive landslide inventory map, as in Figure 1 (Castelli et al., 2016) in whiche the case study is highlighted in yellow, is pivotal for effective landslide zonation.

In the context of Enna (Sicily – Southern Italy region), a series of landslides triggered by rainfall events (Table 1) were examined and categorized, including the movement data, movement types and soil involved.

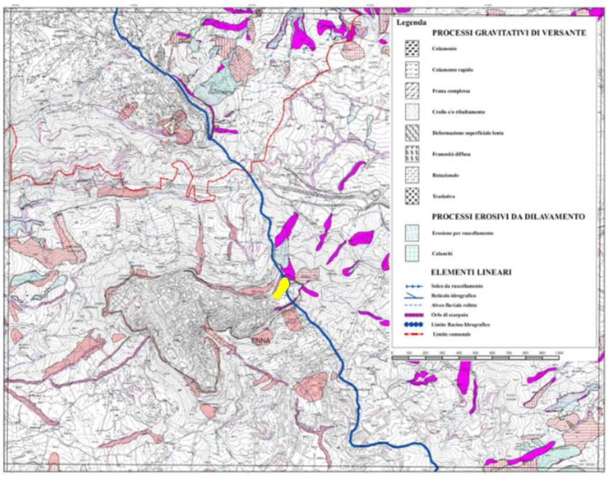

Figure 1. Landslide inventory map in the area of Enna, Sicily (Castelli et al., 2016).

Table 1. Cumulative rainfall, critical value and alert period for the landslides analysed and classified.

Event	Date of occurence
1	13/10/1991
4 - 5 - 6 - 7	08/09/1999
9 - 10	16/10/2003
12 - 13	12/12/2003
14 - 15′- 15′′ - 15′′′ - 16 - 17	06/03/2005
18 - 19	12/04/2005
20	15/01/2010
24	31/01/2011
25	02/02/2014

3 CASE STUDY OF ENNA

Italy, particularly Sicily (Castelli and Lentini, 2013) is marked by a complex landscape and geology that results in a variety of potential instabilities. Enna, situated in the heart of Sicily, exhibits steep hill slopes (Castelli et al., 2016). The geological composition comprises the Numidian Flysch and Holocene-age river alluvium (Castelli et al., 2017). On the night of February 1st to 2nd of 2014, Enna experienced a heavy downpour that resulted in significant damage to structures. It took place in a basin covering 0.158 km², leading to a debris flow. The impact of the rainfall event can be assessed by comparing photos taken before and after the event (Figure 2).

(a)

(b)

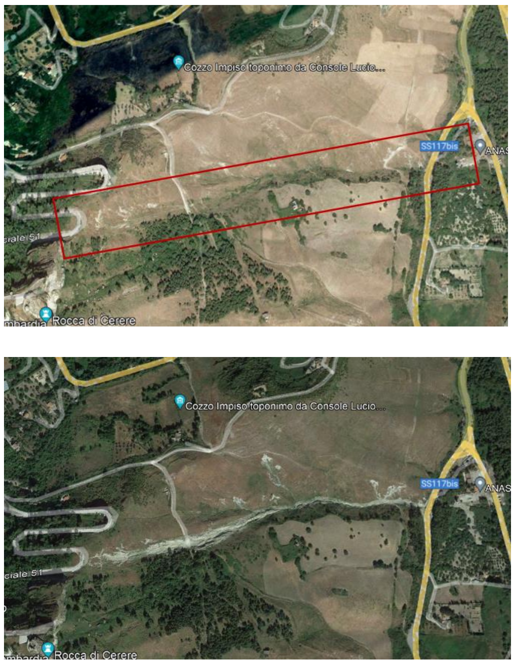

Figure 2. (a) the area before the debris flow; (b) the area after the debris flow.

4 RAINFALL DATA

The focus is on identifying rainfall thresholds as potential triggers for landslides, and their significance in mitigating geo-hydrological risks. By continuously monitoring meteorological, hydrological, and geotechnical parameters and combining them with predefined threshold values.

Information of rainfall data collected by Enna Meteorological Station was used. Figure 3 presents the rain intensity of the event on February 2, 2014 in Enna. The landslide associated with this event was initiated after intense rainfall, with precipitation exceeding 116.6 mm in less than one hour.

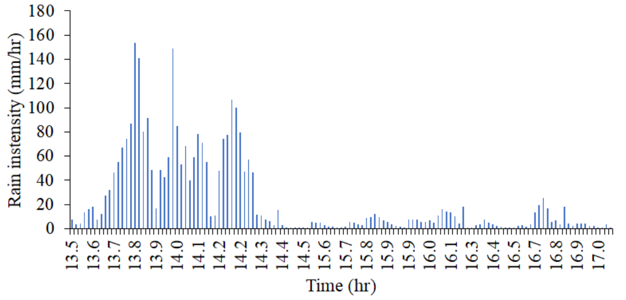

Figure 3. Rain intensity of the event of the 1st – 2nd February 2014 in Enna.

5 GEOTECHNICAL CHARACTERIZATION

The characterization of the foundation soil is an important key in the geotechnical study. That´s why the geotechnical parameters of silty clay (unsaturated soil), such as soil unit weight γ *(kN/m³)*, water content $w_{n\ (\%)}$, strength parameters in terms of friction angle $\phi'(°)$, cohesion $c'(kN/m^2)$, and undrained cohesion c_u (kN/m^2) were obtained from in-situ tests and geotechnical laboratory tests, which have been used to subsequently define the geotechnical properties such as the consistence index I_C, presented in Table 2 (Castelli et al., 2017).

Table 2. Geotechnical parameters (Castelli et al., 2017).

Sample	γ $\left(\frac{kN}{m^3}\right)$	w_n (%)	c' $\left(\frac{kN}{m^2}\right)$	φ' (°)	c_u $\left(\frac{kN}{m^2}\right)$	I_c
S1C1	20.1	21.0	-	-	-	-
S1C2	20.9	20.4	39.44	25	-	1.50
S1C3	19.5	20.0	-	-	223.0	1.23
S1C5	20.2	26.0	25.36	24	255.0	0.67

6 NUMERICAL MODELLING AND RESULTS

The primary aim of the present numerical analyses is: to assess the ability of computational models to replicate the dynamics of debris flow.

To model the debris flows, it is required: a digital terrain model (DTM), hydrological data, and the rheological properties. The DTM was constructed using a grid system in FLO-2D, developed by O´Brien (1986). For this case, it assumed a single-phase modeling approach. The hydrological input was applied where the debris flow initiation was observed (Armanini et al., 2009).

In the simulations based on the literature reference (O´Brien and Julien, 1988; Bertolo and Wieczorek, 2005; Boniello et al., 2010; Wu et al., 2013) utilizing the FLO-2D model, specific parameter values of the rheological coefficients have been chosen from those available in the literature of Stancanelli and Foti (2015) that are closely resembling of the geomorphological and lithological characteristics of the study area α1= 0.006032, β1= 19.9, α2= 0.000707, and β2= 29.8.

A reconstructed representation of the area was yielded (Figure 4). The following important data were obtained:

- The maximum flow depths observed during the event, derived from the FLO-2D simulation, are presented in Figure 4a, with the highest predicted flow depth reaching approximately 1.10 meters.
- Figure 4b illustrates the final flow depths, with the highest predicted value at around 0.20 meters.
- Furthermore, Figure 4c displays the predicted maximum velocities, indicating that the greatest velocities were recorded in the upper regions of the basins, where the slopes were steeper, ranging from 4 to 6 m/s.

(a) *(b)* *(c)*

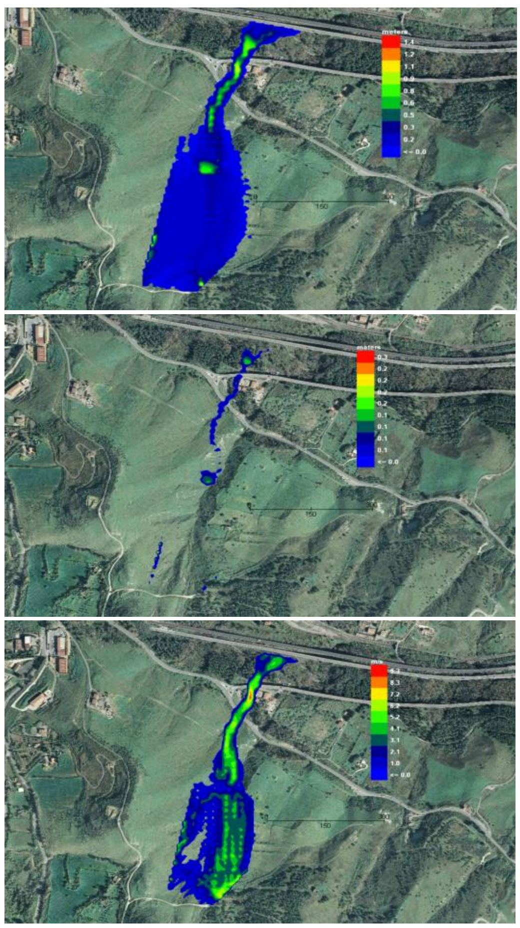

Figure 4. The simulation model carried out with the FLO-2D: (a) maximum flow depth; (b) final flow depth and (c) maximum velocity.

7 CONCLUSIONS

The results presented from a geological, geomorphological, and geotechnical survey of a real case in Enna, demonstrating that predicted values align closely with observed data and were reported in terms of the maximum flow depth, final flow depth and maximum velocity.

The study utilizes FLO-2D to simulate the case of the 1st-2nd of February 2014 create reliable numerical models for debris flows (Figure 4), which aid in assessing the set of variable direct infiltration of intense rainfall and runoff into cover materials. Likewise, was also possible to appreciate the key role that pore water pressure plays for the propagation stage, making dispersion patterns more complex. Ultimately, a precise representation of the topography in the system being a needed step to obtain a rational replication of the observed deposition patterns and to be able to carry out specific mitigation work for the area.

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