LANDSLIDES TRIGGERED BY THE AUGUST 24, 2016 (MW 6.0) AMATRICE EARTHQUAKE (ITALY): DATA SURVEY AND INVENTORYING

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Introduction. On August 24, 2016 a strong earthquake (Mw 6.0 – 42.714°N 13.172°E) struck central Apennines (Italy) at 3.36 a.m. (local time), starting a seismic sequence characterized by a Mw 5.4 and thousands of Mw <5 aftershocks. The seismic sequence caused the complete destruction of the historical towns of Amatrice, Arquata del Tronto, Accumoli and Pescara del Tronto but also significant damages to several towns and villages within 20 km from the epicenter. Since the first hours after the mainshock a Working Group coordinated by the Research Centre on Geological Risks (CERI) of the Sapienza University of Rome operated in the field to survey the ground effects induced by the earthquake. More than one hundred landslides have been surveyed. These events include mainly rock falls and rock slides, which are distributed within a distance of about 40 km from the mainshock epicenter. Several landslides involved roads but no severe damages were generally produced.

Field surveys. The field surveys were planned starting from the first hours after the Mw 6.0 earthquake occurrence and were carried out up to 50 km far from the epicenter for 10 days, until the first rainfalls occurred, which triggered further secondary ground effects. These last ones were not inventoried since they were not considered as properly triggered by the earthquake shaking. The surveying criteria were focused on distinguishing the most recent landslides with respect to older ones, as well as to provide a high reliability of the earthquake trigger interpretation. In this regard, in case of rockslides the following evidence has been collected:
- clearly visible source areas of rock falls or slides: clean surfaces, not weathered scarps;
- clearly visible rock mass debris: clean debris, not weathered blocks, blocks over vegetation;
- clearly visible tracks of rolled blocks;
- detectable impact point of blocks.
In case of debris slides the following evidence has been collected:
- remobilized debris: chaotic deposit overlapping the older accumulation surface;
- evidence of perimetral ground cracks (due to the detachment of debris above the bedrock);
- evidence of open ground cracks within debris with fresh vegetation cover.
In case of reactivation of translational or roto-translational slides the following evidence has been collected:
- ground cracks cutting paths, roads or soil and involving fresh vegetation;
- debris accumulation at the landslide toe over roads or paths.

To check the reliability of the above listed evidence, after having checked the national landslide inventory (IFFI Project, ISPRA), the most recent satellite images available on-line were compared to pictures taken during the field surveys to verify that the inventoried effects were not existing before.

**Inventorying.** The CERI’s Italian Catalogue of Earthquake-Induced Ground Failures (CEDIT) stores data about ground failures induced by earthquakes with an epicentral intensity of at least 8 on the MCS scale, which occurred from 1000 AD. The bibliographic sources available for historical earthquakes are reported and cited in the catalogue. On-line reporting (possible by a web-site mail) were also taken into account.

Several recent seismic events in Italy that have produced relevant ground effects (e.g., 1976 Friuli M\textsubscript{w} 6.4, 1980 Irpinia M\textsubscript{w} 6.9, 1997 Umbria-Marche M\textsubscript{w} 6.0, 2009 L’Aquila M\textsubscript{w} 6.2, 2012 Emilia M\textsubscript{w} 6.0), proved that earthquake-induced ground effects can lead to a risk level comparable to the earthquake shaking itself.

The CEDIT database is published online for public access at the URL http://www.ceri.uniroma1.it/index.php/web-gis/cedit/ and hosted on the web server of the Research Centre for the Geological Risks (CERI) of the Sapienza University of Rome (Fortunato et al., 2012). The WebGIS system has been developed by using the Flex interface of ArcGIS (ESRI™) server technology. The system provides a geo-database consulting and querying interface with graph or table outputs.

The CEDIT database reports approximately 2000 localities where ground failures were triggered by 166 earthquakes that occurred in the last millennium in Italy for which information about the occurrence of ground effects can be retrieved from historical documents. The ground effects collected in the database fall into five main categories: landslides, ground-cracks, liquefaction, surface-faulting and ground-changes (these last ones including among others: subsidence, relevant morphological changes due to river damming, lake formation and so on). These categories are further divided into sub-categories, specifying the type of effect, such as, for example, the landslide kinematic type.

Summary statistics of the database content (Martino et al., 2014) indicate that 14% of the Italian municipalities have experienced at least one earthquake-induced ground effect and that landslides are the most common (approximately 45%), followed by ground-cracks (32%) and liquefaction (18%). Among landslides, approximately 40% can be ascribed to Keefer’s (1984, 2002) type-1 category of landslides triggered by earthquakes (falls and disrupted slides), 22% to type-2 (coherent slides), 6% to type-3 (lateral spreads and flows) and a considerable number

![Fig. 1 – Examples of surveyed landslides, triggered by the August 24, 2016 earthquake and distribution of earthquake-induced landslides in the municipalities struck by the August 24, 2016 earthquake.](image_url)
(approximately 32%) are undefined. Type-3 landslides were distinguished from liquefaction-related effects based on the description given in the historical chronicles, which can be retrieved in the on-line version of the catalogue.

The relationships between ground effects and earthquake parameters such as seismic source energy (earthquake magnitude and epicentral intensity), local conditions (site intensity) and source-to-site distances are also analysed (Martino et al., 2014). The analysis indicates that liquefaction, surface-faulting and ground-changes are much more dependent on the earthquake source energy (i.e., magnitude) than landslides and ground-cracks. In contrast, the latter effects are triggered at lower site intensities and greater epicentral distances than the other environmental effects. The ground effects surveyed after the Amatrice earthquake have been inventoried in the CEDIT catalogue and include 145 landslides, consisting of rock falls, rock slides, debris slides (Fig. 1).

**Preliminary considerations on Amatrice earthquake-triggered landslide distribution.**
The percentage distribution of the inventoried landslides in the involved municipalities is shown in the pie chart of Fig. 1: based on our surveys, the municipalities significantly affected by earthquake-triggered effects are Arquata del Tronto (27%), Norcia (22%), Accumoli (20%) and Amatrice (10%). In the remnant municipalities the percentage of effects respect to the total is lower than 5%.

The inventoried landslides are distributed within an epicentral distance ranging from 4 km up to 41 km; this evidence is in very good agreement with the upper-bound curve by Keefer (1984), which shows that the maximum expected distance for disrupting landslides in case of $M_w$ 6.0 earthquake should be 73 km. Moreover, the maximum distance of the inventoried landslides is very close to the average distribution of distance vs. $M_w$ for Italy, as derived by Martino et al. (2014) from the CEDIT catalogue data (Fig. 2). As it regards the geographical distribution of the landslides triggered by the August 24 earthquake, they are mapped within an area 53 km long in the NW-SE direction and 27 km wide in NE-SW direction. It is worth noting the complementary spatial distribution of the landslides triggered by the August 24 earthquake respect to the distribution of

![Fig. 2 – $M_w$ vs. maximum epicentral distance: comparison of the inventoried data with the upper bound curves by Keefer (1984) and Martino et al. (2014).](image)

![Fig. 3 – Distribution of the landslides inventoried after the August 24, 2016 earthquake (violet symbols) with respect to the 1997 Umbria-Marche (to the NW) and 2009 L’Aquila (to the SE) earthquakes (blue symbols).](image)
ground effects due to the 1997 Umbria-Marche and to the 2009 L’Aquila earthquakes reported in Fig. 3.

References