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UPGRADE OF THE CEDIT DATABASE OF EARTHQUAKE-INDUCED GROUND EFFECTS IN ITALY

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EXTENDED ABSTRACT

Il territorio italiano occupa una posizione nel quadro geodinamico dell'area mediterranea che ne giustifica l'elevata attività sismica, soprattutto nel settore appenninico dove, solo nell'ultimo secolo, si è registrato il maggior numero di terremoti con magnitudo superiore a 6.

Lo studio degli eventi sismici che si verificano nella penisola italiana è, pertanto, di fondamentale importanza per la mitigazione del rischio ad essi associato, in quanto potenzialmente dannosi sia per le popolazioni ivi residenti, sia per il patrimonio edilizio, storico ed architettonico, estremamente diffuso nei settori a più alta pericolosità sismica del territorio nazionale. La difesa dai terremoti, per un Paese con una elevata densità abitativa ed un patrimonio storico e artistico non trascurabile come l'Italia, non può limitarsi all'analisi dell'effetto dello scuotimento sismico sulle infrastrutture, ma deve includere le possibili fenomenologie deformative che questo può indurre sul territorio, tra cui le frane ed i processi di liquefazione, che possono causare alterazioni irreversibili nei terreni. L'enorme quantità di testimonianze storiche disponibili in merito ai succitati effetti vede l'Italia in testa a livello internazionale, stanti le fonti documentali esistenti a partire dal XII secolo d.C. Un tale patrimonio conoscitivo sul passato deve essere tenuto in debita considerazione, rivolgendosi al futuro, per la stima dell'indice di vulnerabilità sismica degli edifici oltre che per la valutazione dei livelli di pericolosità sismica, in base a quanto enunciato nel paragrafo 8.5 delle Norme Tecniche per le Costruzioni (NTC 2018).

A tale proposito, il Centro di Ricerca per la Previsione, Prevenzione e Controllo dei Rischi Geologici (CERI) cura da circa dieci anni il Catalogo italiano degli Effetti Deformativi al suolo Indotti da forti Terremoti (CEDIT), una banca dati disponibile in una versione consultabile online, tramite portale web (http://www.ceri.uniroma1.it/index.php/web-gis/cedit/) dall'inizio del 2013, che censisce a scala nazionale gli effetti deformativi sismoindotti al suolo. Il servizio di consultazione del catalogo online è visibile tramite WebGIS sviluppato con interfaccia grafica FLEX in ambiente ArcGIS-Server di ESRI. Il catalogo è esistente dal 1997, con una prima versione ad opera di Delfino & Romeo (1997), in cui sono stati catalogati gli effetti indotti da eventi sismici verificatisi nel territorio nazionale dal 1000 d.C. al 1984. Nel 2012 il catalogo è stato del tutto aggiornato nella sua struttura e nei suoi contenuti (Fortunato *et alii*, 2012; Martino *et alii*, 2012) con l'inserimento degli effetti indotti dai sismi verificatisi fino al 2009.

Poiché il CEDIT è un catalogo macrosismico, cioè basato sulla intensità di un terremoto valutata a partire dagli effetti sui manufatti e sull'ambiente naturale, il database che lo costituisce va inteso come un *work in progress* in termini di aggiornamento ed integrazione; in tale ottica è stato di recente effettuato l'aggiornamento dell'architettura del *geo-database*, qui presentato contestuale all'aggiornamento dei suoi contenuti consistente: i) nell'aggiunta di dati ed informazioni riguardanti eventi sismici che hanno interessato il territorio italiano dal 2009 al 2017 e aggiornamento delle informazioni relative agli eventi sismici già catalogati nella versione precedente; ii) nell'aggiornamento dei valori di intensità macrosismica per ciascuno dei siti in cui sono stati censiti gli effetti deformativi sismoindotti, con quelli presenti nei database CFTI5 e CPTI15 dell'INGV e in Galli *et alii* (2017).

L'ottimizzazione del *geo-database*, ottenuta grazie alla revisione della sua architettura, costituisce, a sua volta, un imprescindibile intervento volto alla futura realizzazione di una versione *on-line* rinnovata, la quale fornirà degli strumenti tecnici che, durante la fase di rilevamento e censimento degli effetti sismoindotti post-evento sismico, ne consentiranno un inserimento automatizzato per velocizzarne la successiva fase di validazione e di inserimento nel catalogo.

Le analisi statistiche, effettuate sui dati contenuti nel catalogo CEDIT aggiornato al 2017, confrontate con le analisi riguardanti la versione precedente (catalogo CEDIT 2012), confermano che la tipologia di effetto sismoindotto prevalente sono le frane, seguite dalle fratturazioni del terreno.

L'analisi sul numero di effetti in funzione dell'intensità macrosismica di sito (I_{MCS}) evidenzia la massima frequenza in corrispondenza della classe 8 di I_{MCS} (I_{MCS}=7.5-8.5), anche se compare un ulteriore picco di frequenza nella classe 7 per gli effetti corrispondenti alla sola categoria della fagliazione superficiale. La distribuzione degli effetti sismoindotti in funzione della distanza epicentrale, descrive un decremento di tutte le tipologie di effetto all'aumentare della distanza dall'epicentro.

ABSTRACT

The database related to the Italian Catalogue of Earthquake-Induced Ground Failures (CEDIT), was recently upgraded and updated to 2017 in the frame of a work-in-progress focused on the following issues: i) reorganization of the geo-database architecture; ii) revision of the earthquake parameters from the CFTI5 e CPTI15 catalogues by INGV; ii) addition of new data on effects induced by earthquakes occurred from 2009 to 2017; iv) attribution of macroseismic intensity value to each effect site, according to the CFTI5 e CPTI15 catalogues by INGV.

The revised CEDIT database aims at achieving: i) the optimization of the CEDIT catalogue in order to increase its usefulness for both Public Institutions and individual users; ii) a new architecture of the geo-database in view of a future implementation of the online catalogue which implies its usability via web-app also to support post-event detection and surveying activities.

Here we illustrate the new geo-database design and discuss the statistics that can be derived from the updated database. Statistical analysis was carried out on the data recorded in the last update of CEDIT to 2017 and compared with the analysis of the previous update outline that:

- the most represented ground effects are the landslides with a percentage of 55% followed by ground cracks with a percentage of 23%;
- the MCS intensity (I_{MCS}) distribution of the effect sites shows a maximum in correspondence of the I_{MCS} class 8 even if a second frequency peak appears in the I_{MCS} class 7 only for surface faulting effects;
- the distribution of the effects according to the epicentral distance shows a decrease for all the typologies of induced ground effects with increasing epicentral distance.

***Keywords**: earthquake-induced ground effects, seismic risk mitigation, CEDIT catalogue*

INTRODUCTION

The high seismicity of the Italian peninsula has to be ascribed to its location in the Mediterranean geodynamic context. The importance of recording and inventorying ground effects connected to earthquakes, is increasing more and more over time. The Italian Catalogue of Earthquake-Induced Ground Failures (CEDIT) just arises from the need to inventory earthquake-induced ground effects, to make them available for scientific and technical applications as in the framework of Seismic Microzonation studies. In fact, following the Indirizzi e criteri per la microzonazione sismica - ICMS (2008) guidelines for Seismic Microzonation in Italy, areas potentially involved in ground instabilities (as for liquefaction and landslides) have to be defined and mapped in 3 level technical products. The first version of the CEDIT catalogue (Delfino & Romeo, 1997) included the earthquake-induced ground effects caused by earthquakes occurred from 1000 until 1984 A.D. In the following, a first update was performed by Fortunato *et alii* (2012) to take into account the ground effects induced by earthquakes occurred after 1984, i.e. up to the L'Aquila earthquake occurred in 2009. The last update of the CEDIT catalogue is reported in Martino *et alii* (2014) and includes a revision of the literature data, as well as time and spatial distribution analyses based on the inventoried dataset. This last upgrade was performed also considering recent literature reviews on ground effects induced by the 1805, 1930 and 1980 earthquakes (Galli, 2000, Porfido *et alii*, 2007; Serva *et alii*, 2007) as well as scientific papers by Prestininzi (1995), Mancini *et alii* (2001), Martino *et alii* (2004), Bozzano *et alii* (2008; 2011) dealing with specific landslide events documented and back analysed through engineering-geological and numerical models.

The here presented version of the CEDIT catalogue includes a reorganization of the geo-database architecture besides the update of its contents to 2017. The latter encompassed a revision of: i) the coordinates of the earthquake epicenters, moment magnitude (M_W), epicentral intensity values from the most recent versions of the databases Catalogo Parametrico dei Terremoti Italiani 2015 - CPTI15 and Catalogo dei Forti Terremoti in Italia v. 5 - CFTI5 (by INGV); ii) the values of macroseismic intensity (I_{MCS}), according to the CFTI5 and CPTI15 catalogues; iii) the ground effects occurred during the 2016-2017 seismic sequence of the Central Apennines and during the 21st August 2017 earthquake at Ischia Island. A statistical analysis was performed based on the CEDIT updated database and the results are here reported.

NEW ARCHITECTURE OF THE CEDIT 2017 DATABASE

The CEDIT 2012 database was implemented for an online publication which made it possible to consult it remotely. However, for the here presented upgrade it was necessary a reorganization of the geo-database architecture, in view of the restyling of the online catalogue which is planned for the next future and for the implementation of a web-app suitable for field surveying in case of future earthquake occurrences.

Such a restructuration was performed by changing the old table-based structure into a more advanced relation-concept based one.

Conceptual model for the new architecture of the CEDIT 2017 database

To generally design a single-administration geo-database it is advisable to follow a step-by-step methodology that allow to:

- define the phases in which the design activity is structured;
- provide criteria for choosing between different alternatives;
- support the database structure by representation of the basic conceptual model;

- guarantee a broad usability of the database, based on flexibility-to-updating and easy-to-use concepts.

Conceptual models allow the use of datasets by creating the most appropriate architecture to the data management; therefore, these models aim at translating the "ideal concepts" in "real worlds" so representing a very useful tool for designers. The best-known way to represent conceptual models is named Entity-Relationship (E-R) model.

The E-R model aims at identifying the entities and relationships that bind them together. Each E-R model in its basic form (Fig. 1) consists of a rhombus, located at the center, which represents the relationship between the rectangles placed on its right and the left; these rectangles represent the entities of the diagram, and each of them is joined to the central rhombus by a connection line on which there are the "cardinality" indications that define the type of relationship.

For the redesigning of the CEDIT database 2017, the following connections were fixed to generate a E-R model chart:

- earthquake (events) generates ground-effect (effects);
- several sentences can be associated with single effects;
- several sentences can derive from single or multiple bibliographic sources;
- events can be recorded by on site surveys.

The aforementioned cardinality indications define types of relationship that exist between two entities of the database. For the CEDIT they are specifically represented by the following linkages:

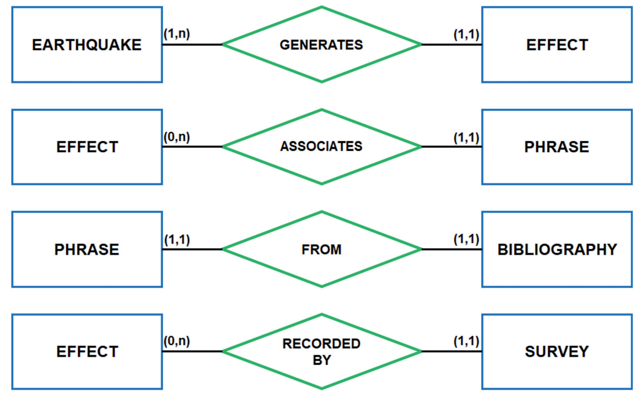

Fig. 1 - Representation of the relationships between the entities of the diagram in the E-R conceptual model

- each earthquake can have from a minimum of 1 to a maximum of n number of effects (relation: 1, n) and each effect can be generated by a single earthquake (relation: 1,1);
- each effect can be associated with 0 or n sentences (relation: 0, n) and each sentence, if any, can be associated with a single event (relation: 1,1);
- each sentence comes from a bibliographic source (relation: 1,1) and each bibliography has only one sentence (relation: 1,1);
- each effect can be recorded by performing, if possible, on site surveys (relation: 0, n) and each effect is associated with a single survey (relation: 1,1).

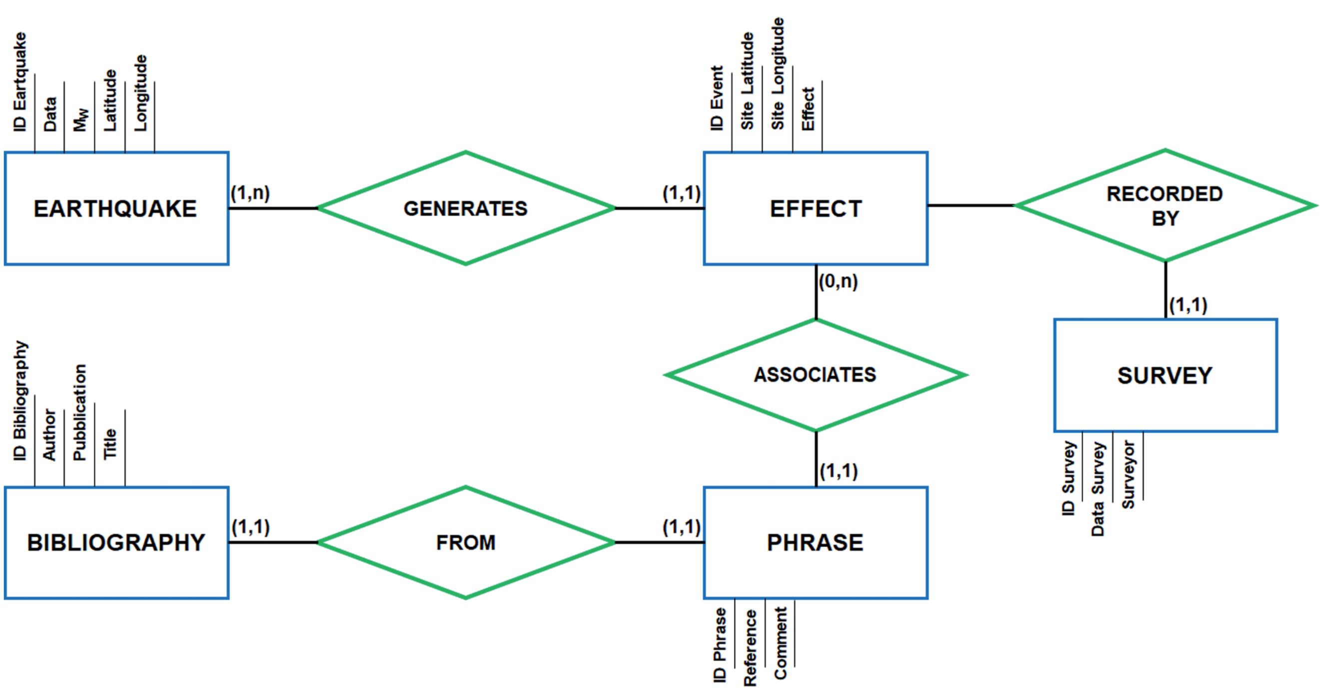

Fig. 2 - E-R model chart with cardinality indications

Once the E-R model (Fig. 2) has been built, it shows all the entities and all the relationships existing among them; such an E-R model can be validated, verifying that all the necessary requirements are satisfied and that the structure respects the requirements for which the database was built.

Each entity is characterized by a set of informations that unequivocally identifies it and determines its belonging to one class rather than another. These information set allow to make up the entities (i.e. the fields reported in the attribute tables).

The attributes for each entity, which are reported on the tables, can be multiple even if it is usually preferred to insert only some of them (i.e. the most relevant ones) to simplify the readability of the E-R chart, to avoid unnecessary complexities.

Logical scheme of the new architetture of the CEDIT 2017 database

The logical scheme is a fundamental tool for designing databases. In fact, it identifies the database in all its parts and is one of the main technical documents which support the customers.

From a logical scheme not only emerges the structure of the various objects that compose the database, but also all the connections that regulate the logic links within the database itself.

The first step for the construction of the logical scheme is the representation of the entities (i.e. the tables that collect the information related to each field). Information within fields of attributes constitute the database itself.

Figure 3 shows that each table consists of three columns: left, middle and right. The left column identifies the type of field that can be composed of letters (abc), numbers (123) or date (dates). The middle column reports the names of all the components of the entity. The right column reports the domain each field belongs to; if the field is numeric, it indicates whether the number is integer or decimal (e.g. Year is an integer consisting of 4 digits int (4)); if it is of alphabetic characters it is indicated with the abbreviation "var" followed by the maximum number of letters that can be inserted (e.g. EpicentralArea var (40)).

In each three-column table are present up to n keys (blue characters in Figure 3) which are fundamental in such a relational database since the same key allows to relate two tables each other as it can be found in both the tables. For instance, the Earthquake table has IDEarthquake as its primary key (<PK>); this field will also appear in the Effect table as an external key (<FK>) and this allows the link between the two tables. English has been chosen as the language to define the names of tables and fields, for international customers.

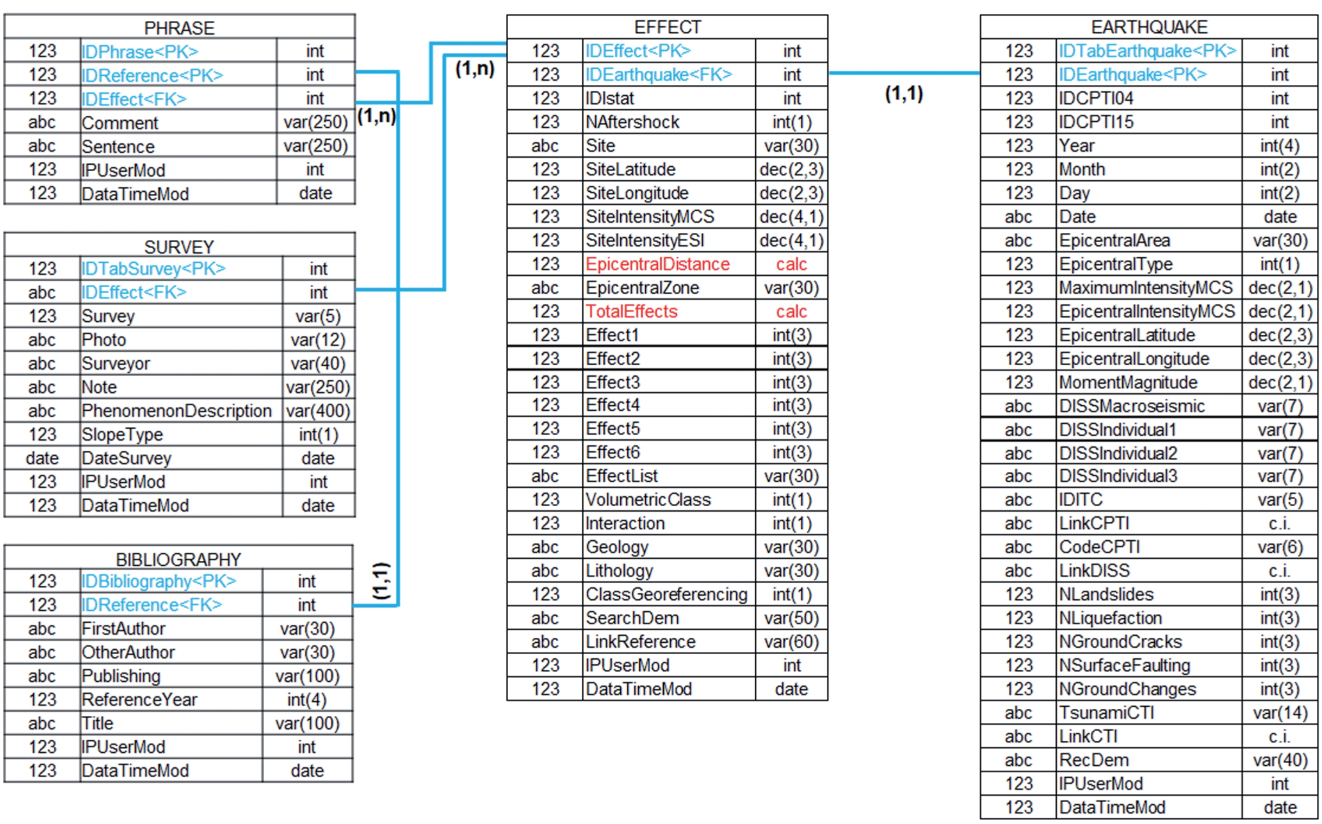

Fig. 3 - Diagram of the E-R model of CEDIT database updated to 2017

Table structure

In the following, we report the detailed structure of each table constituting the CEDIT 2017 geo-database.

Earthquake table

Except for the ID attributed for the CEDIT inventory, the EARTHQUAKE table contains information related to the event (earthquake) which are available in literature and/or reported in other official catalogues. In particular, the table includes the name that identifies a single Record (first column), the description of each Record (second column), and a check of updating carried out on 2017 (third column).

EARTHQUAKE		
Record	**Description**	**Last update**
IDTabEarthquake	event code	2017
IDEarthquake	earthquake identification number	2017
IDCPTI04	CPTI catalog code of 2004	2017
IDCPTI15	CPTI catalog code of 2015	2017
Year	year	2017
Month	month	2017
Day	day	2017
Date	date yyyy/mm/dd	2017
EpicentralArea	place of the epicenter	2017
EpicentralType	type of epicenter	2012
MaximumIntensityMCS	maximum intensity	2017
EpicentralIntensityMCS	intensity at epicenter	2017
EpicentralLatitude	latitude	2017
EpicentralLongitude	longitude	2017
MomentMagnitude	M_W	2017
DISSMacroseismic	database code of seismogenic source	2012
DISSIndividual1	database code of seismogenic source	2012
DISSIndividual2	database code of seismogenic source	2012
DISSIndividual3	database code of seismogenic source	2012
IDITC	database code of Italian tsunami	2012
LinkCPTI	link to CPTI catalogue	2012
CodeCPTI	Source catalogue	2012
LinkDISS	link to DISS catalogue	2012
NLandslides	number of catalogue	2012
NLiquefaction	number of liquefaction	2012
NGroundCracks	number of ground cracks	2012
NSurfaceFaulting	number of surface faulting	2012
NGroundChanges	number of ground changes	2012
TsunamiCTI	documented tsunami	2012
LinkCTI	link to CTI catalogue	2012
RecDem	earthquake data summary	2012
IPUserMod	IP address of last updating user	2012
DataTimeMod	date of last update	2012

Tab. 1 - EARTHQUAKE table

- IDTabEarthquake: is a sequential number, automatically assigned, of earthquakes;
- IDEarthquake: is the identification code of the earthquake which includes the year, month, day and time when the earthquake occurred;
- IDCPTI04 and IDCPTI15 are the codes respectively belonging to the CPTI catalogue of 2004 and to the 2015 one;
- Year, Month, Day: they are respectively the year, the month and the day in which the seismic event occurred;
- Date: indicates the date yyyy/mm/dd in a compact way;
- EpicentralArea: indicates the place where the earthquake occurred;
- EpicentralType: indicates whether the epicenter is macroseismic or not;
- MaximunIntensityMCS: maximum intensity observed in the MCS scale;
- EpicentralIntensityMCS: epicentral intensity in the MCS scale;
- EpicentralLatitude, EpicentralLongitude: indicate the latitude and longitude of the site where the earthquake occurred take place;
- DISSMacroseismic, DISSIndividual1, DISSIndividual2, DISSIndividual3: correspond to "Database of Individual Seismogenic Sources" that is a georeferenced database in which are reported informations on paleoseismicity, tectonic and fault systems throughout the country;
- IDITC: it is the code that belongs to the Catalog of Italian Tsunami;
- LinkCPTI: this is the hyperlink to the site of the parametric catalog of Italian earthquakes;
- CodeCPTI: identifies the catalog to which it belongs;
- LinkDISS: it is the hyperlink to the site of the database of individual seismogenic sources;
- NLandslides, NLiquefaction, NGroundCracks, NSurfaceFaulting, NGroundChanges: represent the total number of landslides, liquefaction, soil fractures, faultings and total topographic variations for the considered earthquake;
- TsunamiCTI: indicates whether or not there is documentation of the phenomenon;
- LinkCTI: this is the hyperlink to the Catalog of Italian Tsunami;
- RecDem: is the synthetic datum on date, place and moment magnitude of the seismic event.

Effect table

The EFFECT table contains information related to the effects (earthquake-induced ground effects) which are collected in the CEDIT based on data available in literature and/or reported in other official catalogues as well as specifically inventoried by the CERI research team for the CEDIT database. In particular, the table includes the name that identifies a single Record (first column), the description of each Record (second column), and a check of updating carried out on 2017 (third column).

- IDEffect: identification code of each event;
- IDIstat: identification code of the site where the event occurred;
- NAftershocks: indicates, through an appropriate code, if the relative effect has been triggered by a foreshock (# 2) or by an aftershock (# 1). Secondary shocks were considered since they also contribute to producing effects on the ground. This is due to the fact that some phenomena (such as landslides) can be brought under conditions close to the limit equilibrium by the main shock, but then triggered following a lower

EFFECT		
Record	**Description**	**Last update**
IDEffect	effect code	2012
IDEarthquake	earthquake identification number	2017
IDIstat	ISTAT identification number	2012
NAftershock	identification number of main shock	2012
Site	locality	2012
SiteLatitude	latitude of effect site	2017
SiteLongitude	longitude of effect site	2017
SiteIntensityMCS	MCS site intensity	2017
SiteIntensityESI	ESI site intensity	2012
EpicentralDistance	epicentral distance automatically computed	2017
EpicentralZone	epicentral zone	2012
TotalEffects	computed code of effects	2012
Effect1	effect code number 1	2012
Effect2	effect code number 2	2012
Effect3	effect code number 3	2012
Effect4	effect code number 4	2012
Effect5	effect code number 5	2012
Effect6	effect code number 6	2012
EffectList	description of the effects	2012
VolumetricClass	volume (m^3) of the effect	2012
Interaction	interaction with roads or infrastructures	2012
Geology	geology	2012
Lithology	lithology	2012
ClassGeoreferencing	accuracy of georeferencing process	2012
SearchDem	earthquake data summary	2012
LinkReference	link to CERI site	2012
IPUserMod	IP address of last updating user	2012
DataTimeMod	date of last update	2012

Tab. 2 - EFFECT table

energy event, such as an aftershock. However, for most of the events whose aftershocks are also documented, it is not possible to make a clear distinction between the effects on the ground produced by the main shock or the subsequent ones if not explicitly reported by the historical source;
- Site: indicates the site where the event occurred;
- SiteLatitude, SiteLongitude: are the site latitude and longitude, respectively;
- SiteIntensityMCS: intensity of the MCS scale at event site;
- SiteIntensityESI: intensity of the ESI scale at event's site. ESI is a new scale of seismic intensity based on the effects that earthquakes produce on the environment and not only on buildings and infrastructures. A tool that allows a better knowledge and assessment of earthquakes and that can be used to prevent and mitigate the effects caused by these on the environment, preparing more accurate territorial planning, with the prospect of reducing human losses and reducing economic damage;
- EpicentralDistance: indicates the distance between the earthquake epicenter and the site in which the ground effect occurred;
- EpicentralZone: identifies a subdivision into zones of Italy;
- TotalEffect: within the catalog it is not rare to have multiple effects for the same event. This necessitated a combination of the coding of the already existing effects;
- Effect1, Effect2, Effect3, Effect4, Effect5, Effect6: identify the effects on the ground produced by the corresponding seismic event, in a given location, each one represented by a particular code. Six fields are considered since, in some cases, there has been a combination of more sismo-induced effects for the same location;
- VolumetricClass: indicates the quantity of material (expressed in m^3) that is mobilized by the event;
- Interaction: indicates the presence or absence of interference with the road network and other infrastructures;
- Geology, Lithology: indicate the geology and lithology of the land where the event took place;
- ClassGeoreferencing: indicates the accuracy of the coordinates that can be: regional, municipal, regional, locality or site coordinates;
- SearchDem: is a summary of the date, place and moment magnitude of the seismic event;
- LinkReference: hyperlink to the CERI website.

Phrase table

The PHRASE table contains information related to the sources (sentences reported in historical documents) which are collected in the CEDIT based on data available in literature and/or reported in other official catalogues. In particular, the table includes the name that identifies a single Record (first column), the description of each Record (second column), and a check of updating carried out on 2017 (third column).

PHRASE		
Record	**Description**	**Last upadate**
IDPhrase	phrase code	2012
IDReference	reference identification number	2012
IDEffect	effect identification number	2012
Comment	comments	2012
Sentence	sentences	2012
IPUserMod	IP address of last updating user	2012
DataTimeMod	date of last update	2012

Tab. 3 - PHRASE table

- IDPhrases: identification code of each sentence;
- IDReference: reference identification code;
- Sentence: reports the original sentences, extracted from historical sources, which describe the effects on the ground. Each quote refers to a single location and can describe one or more phenomena; moreover, various phrases by various authors have been reported, describing the same effect to obtain a more detailed picture of the phenomenon; for recent earthquakes reference is made directly to the scientific text;
- Comment: in this field the interpretation of the effects on the ground and additional information such as the size of the phenomenon, the type of mechanism, the trigger time delay with respect to the seismic event are extrapolated from the "Sentence".

Bibliography table

The BIBLIOGRAPHY table contains information related to the literature sources (i.e. technical or historical reports, scientific papers) which are collected in the CEDIT based on data available in literature and/or reported in other official catalogues. In particular, the table includes the name that identifies a single Record (first column), the description of each Record (second column), and a check of updating carried out on 2017 (third column).

BIBLIOGRAPHY		
Record	**Description**	**Last update**
IDBibliography	bibliography code	2012
IDReference	reference identification number	2012
FirstAuthor	author	2012
OtherAuthor	other authors	2012
Publishing	publication	2012
ReferenceYear	reference year	2012
Title	title	2012
IPUserMod	IP address of last updating user	2012
DataTimeMod	date of last update	2012

Tab. 4 - BIBLIOGRAPHY table

- IDBibliography: identification code of the bibliography;
- FirstAuthor, OtherAuthor: indicate the name of the authors reported on the source;
- Publishing: indicates the magazine, the archive or the newspaper in which the consulted works are contained;
- ReferenceYear: year of publication of the work;
- Title: title of the source from which the information is derived.

Survey table

The SURVEY table contains information related to the surveying activities carried out by the CERI research team for the database updating after each earthquake. In particular, the table includes the name that identifies a single Record (first column), the description of each Record (second column), and a check of updating carried out on 2017 (third column).

SURVEY		
Record	**Description**	**Last update**
IDTabSurvey	survey code	2017
IDEffect	effect identification number	2017
Survey	survey identification number	2017
Photo	photo identification number	2017
Surveyor	name of the surveyor	2017
Note	field notes	2017
PhenomenonDescription	description of ground effect	2017
SlopeType	type of the slope	2017
DateSurvey	date	2017
IPUserMod	IP address of last updating user	2017
DataTimeMod	date of last update	2017

Tab. 5 - SURVEY table

- IDTabSurvey: identification code of the surveys;
- Survey: survey code consisting of two letters (which correspond to the initials of the surveyors' surname) and the progressive number of recordings;
- Photo: name or number of the photo of the recorded event;
- Surveyor: name of those who carry out the survey;
- Notes: these are annotations that the surveyors acquire during the field survey;
- PhenomenonDescription: is a description of what is analyzed on site;
- SlopeType: indicates the type of slope that can be natural or anthropogenic;
- DateSurvey: indicates the date in which the survey is carried out.

Dictionaries

Dictionaries have been included in the revised CEDIT 2017 database (Fig. 4) to allow an univocal driven compilation of the tables of attributes, facilitating future updating or editing.

The dictionaries defined for the CEDIT 2017 database are:

- Registry: it is a register containing the data of the people who have access to the database (administrators, personnel in charge, other users);
- Diz_Istat: all the Italian locations are listed, with the codes of the regions, provinces and municipalities to which they belong;
- Diz_Georeferencing (Tab. 6): this dictionary allows you to certify the accuracy of the coordinates that are entered. They can be coordinates of site, location, capital, municipality or geographical area;

1	coordinates of the geographical area
2	coordinates of municipality
3	coordinates of chief town
4	coordinates of locality
5	coordinates of the site

Tab. 6 - Dictionary of geo-referencing

- Diz_Interaction (Tab. 7): indicates the presence or not of a possible interaction of the induced effect with the road network or with other infrastructures;

1	not interferent
2	possible interference
3	interferent
4	damage on infrastructures

Tab. 7 - Dictionary of interaction between ground effects and infrastructures

- Diz_Macroeffect (Tab. 8): the effects that can occur for an event are of different type. This dictionary has allowed the grouping of the effects into 6 macro-categories: landslides,

REGISTRY		
123	IDRegistry	sequential number
abc	Name	name
abc	Surname	surname
123	Phone	phone number
abc	Email	mail address
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_ISTAT		
123	IDIstat	sequential number
123	CodReg	regional code from 1 to 20
123	Loc2001	locality code 2001
abc	Loc2010	composite number
abc	DenomLoc	locality denomination
123	CodPro	province code 103
123	CodCom	municipality code 103
123	Loc2010	composite number
123	CodPro2010	province code 110
123	CodCom2010	municipality code 110
123	ProCom	province of the municipality
123	Loc	locality identification number
123	CentroCl	centre 0 1
123	Altitudine	altitude of the locality
123	Populat2001	population to 2001
123	TipoLoc	values from 1 to 4

DIZ_GEOREFERENCING		
123	IDGeoref	sequential number
abc	Georef	accuracy of georeferencing process
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_INTERACTION		
123	IDInteraction	sequential number
abc	Description	interaction with roads or infrastructures
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_MACROEFFECT		
123	IDMacroeffect	sequential number
abc	Legend	six macro effects
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_MACROSEISMIC		
123	IDMacroseismic	sequential number
abc	Legend	macroseismic epicenter or not
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_LAST_CATALOG		
123	IDLastCatalogue	sequential number
abc	CodeCatalog	list catalog
abc	LinkCatalog	link to the catalog
123	Updating	updating
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_CODE_EFFECT		
123	IDCodeEffect	sequential number
abc	DescriptionEffect	effect identification number
123	ClassEffect	code of the category of the effect
abc	DescriptionClass	description of category
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_COMBINED_EFFECTS		
123	IDCombinedEffect	sequential number
abc	TypeEffect	combination of effects
abc	DescriptionEffect	description of the combinations
abc	Legend	explanation of the combinations
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_VOLUME		
123	IDVolume	sequential number
abc	Dimension	$<1m^3$ - $1<m^3<5$ - $>5m^3$ or n.a.
abc	ClassVolume	m^3 mobilized class: a, b or c
123	IPUserMod	IP address
123	DataTimeMode	data

DIZ_TYPE_SLOPE		
123	IDTypeSlope	sequential number
abc	Legend	natural or anthropic slope
123	IPUserMod	IP address
123	DataTimeMode	data

Fig. 4 - Scheme of the dictionaries included in the CEDIT 2017 database

1	landslides
2	ground cracks
3	liquefaction
4	surface faulting
5	ground changes

Tab. 8 - Dictionary of macro effects on ground

soil fractures, liquefaction, faulting, topographic variations;

- Diz_Macroseismic (Tab. 9): indicates if an earthquake's epicenter is macroseismic or not;

1	epicenter is macroseismic
2	epicenter is not macroseismic

Tab. 9 - Table regarding the dictionary of macroseismic epicenter

- Diz_Last_Catalog (Tab. 10): indicates the last version of the Parametric Catalog of the Italian Earthquakes in which the considered earthquake is present;

1	CPTI04	http://emidius.mi.ingv.it/CPTI04/
2	CPTI15	https://emidius.mi.ingv.it/CPTI15-DBMI15/

Tab. 10 - Dictionary of macroseismic epicenter

- Diz_Code_Effect (Tab. 11): this dictionary lists all the effects that can be generated by an event and each has been assigned an encoding. The code consists of three digits. The right column indicates the macro-category it belongs to;

100	landslides	1
110	rock fall	1
111	rock topple	1
112	rock slump	1
113	rock slide	1
114	rock spread	1
115	rock avalanche	1
116	rock wedge slide	1
117	rock topple	1
120	debris fall	1
121	debris topple	1
122	debris slump	1
123	debris slide	1
124	debris flow	1
125	debris avalanche	1
126	soil creep	1
130	earth fall	1
131	earth topple	1
132	earth slump	1
133	earth slide	1
134	earth spread	1
135	earth flow	1
137	mud flow	1
200	ground cracks	2
210	fractures with gas or fire emission	2
220	fractures related to slides	2
230	ground cracks related to slides	2
300	liquefaction	3
310	water ejection	3
311	sand boils	3
320	water ejection from fissures	3
321	water and sand ejection from fissures	3
400	surface faulting	4
500	ground changes	5
510	subsidence	5

Tab. 11 - Dictionary of effects

- Diz_Combined_Effect (Tab. 12): the occurrence of effects, related to the different macro-areas, made it necessary to create a code that clearly and unequivocally explained the belonging to the different categories. It was therefore decided to use the first identifying number of each effect and to insert it in ascending order within the identification field of the event. For example, the earthquake occurred in Ferrara on 11/17/1570 which has the effect of 200, 310, 321, and 500 has as codification 235;
- Diz_Volume (Tab. 13): indicates the cubic meters that are mobilized by the event;
- Diz_Type_Slope (Tab. 14): indicates the type of slope, that can be natural or anthropogenic, in which the ground effect occurs;

In Figure 5 is shown the diagram of the E-R model that fully represents the entire database to be implemented.

The following tables (Tab. 15 and Tab. 16) report the consistency of the attributes for the seismic events and related ground effects, expressed as percentage respect to the total inventoried records, in the 2012 and 2017 version of CEDIT database.

DATA ANALYSIS FROM THE LAST UPDATED VERSION OF THE CEDIT

The above described architecture of the CEDIT database, whose content was updated to 2017, represents a major innovation respect to the previous release of the database dating back to 2012 (Fortunato *et alii*, 2012). The main surveying criteria, based on which the ground effects are inventoried, have already been presented in Martino *et alii* (2017) with respect to field activities carried out after the earthquakes occurred in 2016-2017 Central Apennines seismic sequence.

The current version of the CEDIT database contains 5 tables that are in relation to each other according to the logical scheme described in Figure 5. The reference catalogues used for updating the Earthquake and Effect tables are the CPTI15, CFTI5Med, DBMI15, ITCver2, DISS 3.2.1 (by INGV). Moreover, the report by Galli *et alii* (2017) referred to MCS intensity values after the 2016-2017 Central Apennines seismic sequence, was also taken into account. The same tables, i.e. the Earthquake and the Effect ones, have been updated with data on new seismic events up to 2017 and with the related induced ground effects, surveyed by the CEDIT Working Group from the CERI Research Centre and from the Earth Sciences Department of Sapienza University of Rome (Martino *et alii*, 2017). Compared to the previous version of the CEDIT catalogue, about 4% of earthquakes and about 47 % of effects have been added. More in particular, the earthquakes added to the database are 7:

- M_W 6.1 Emilia Romagna earthquake occurred the 20/05/2012 with 30 effects surveyed;
- M_W 4.4 central Adriatic earthquake occurred the 22/08/2013 with 3 effects surveyed;
- M_W 6.0 Amatrice (RI) earthquakes occurred the 24/08/2016 with 147 effects surveyed;
- M_W 5.9 Castelsantangelo sul Nera (MC) earthquake occurred the 26/10/2016 with 247 effects surveyed;
- M_W 6.5 Norcia (PG) earthquake occurred the 30/10/2016 with 423 effects surveyed;
- M_W 5.5 Capitignano (AQ) earthquake occurred the 18/01/2017 with 12 effects surveyed;
- M_W 4.2 Casamicciola (Ischia Island) earthquake occurred the 21/08/2017 with 8 effects surveyed.

1	1	landslides
2	2	ground cracks
3	3	liquefaction
4	4	surface faulting
5	5	ground changes
6	12	landslides; ground cracks
7	13	landslides; liquefaction
8	14	landslides; surface faulting
9	15	landslides; ground changes
10	23	ground cracks; liquefaction
11	24	ground cracks; surface faulting
12	25	ground cracks; ground changes
14	35	liquefaction; ground changes
15	45	surface faulting; ground changes
16	123	landslides; ground cracks; liquefaction
17	124	landslides; ground cracks; surface faulting
18	125	landslides; ground cracks; ground changes
20	135	landslides; liquefaction; ground changes
22	134	landslides; liquefaction; surface faulting
23	235	ground cracks; liquefaction; ground changes
24	245	ground cracks; surface faulting; ground changes
25	1235	landslides; ground cracks; liquefaction; ground changes
26	1245	landslides; ground cracks; surface faulting; ground changes
27	34	liquefaction; surface faulting
28	145	landslides; surface faulting; ground changes
29	234	ground cracks; liquefaction; surface faulting
30	345	liquefaction; surface faulting; ground changes
31	1234	landslides; ground cracks; liquefaction; surface faulting
32	1345	landslides; liquefaction; surface faulting; ground changes
33	2345	ground cracks; liquefaction; surface faulting; ground changes
34	12345	landslides; ground cracks; liquefaction; surface faulting; ground changes

Tab. 12 - Dictionary of combined effects

1	a	$< 1\ m^3$
2	b	$1 < m^3 < 5$
3	c	$> 5\ m^3$
4	n.a.	not available

Tab. 13 - Dictionary of mobilized volume

1	natural slope
2	anthropic slope

Tab. 14 - Dictionary of slope type

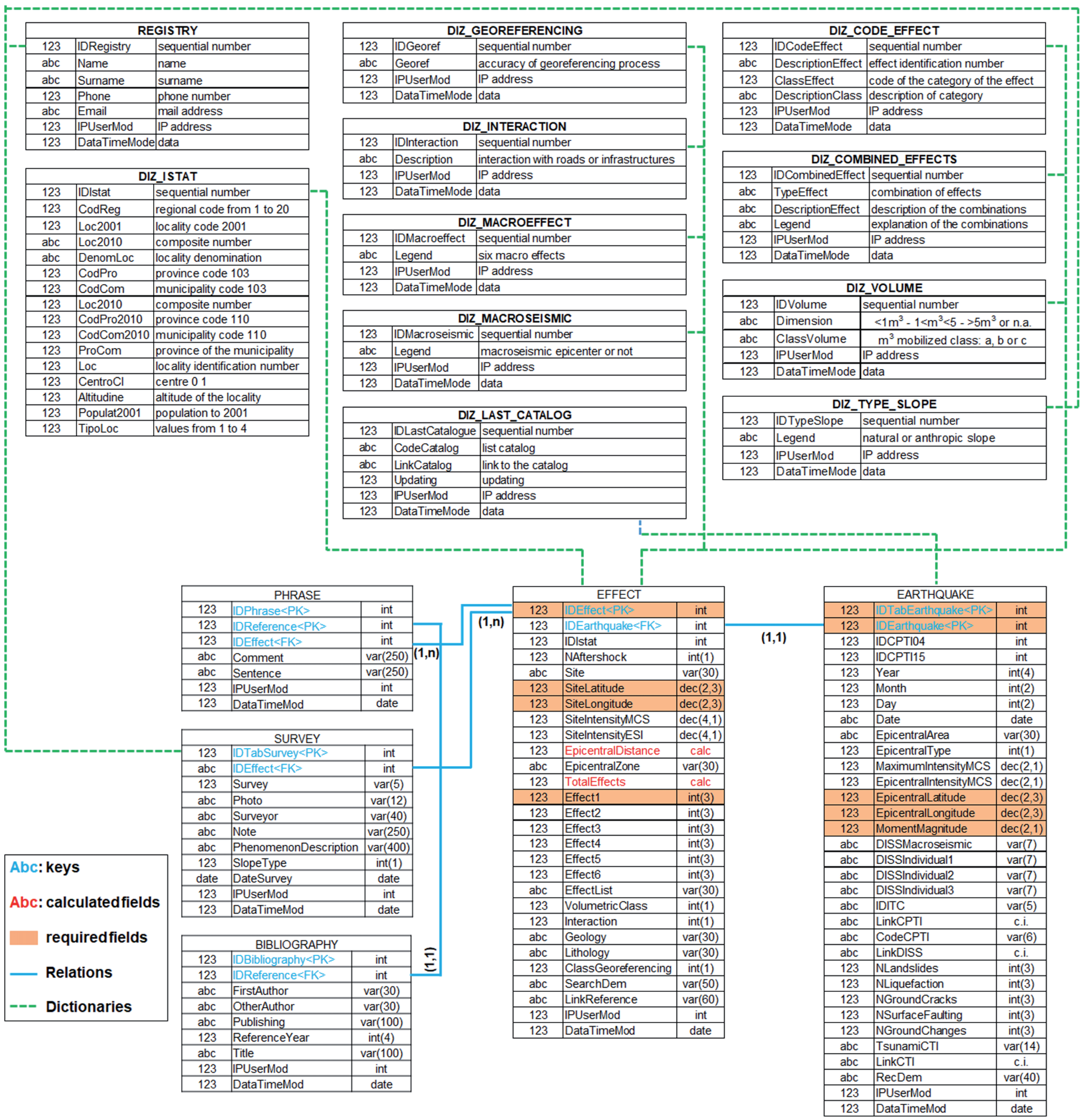

Fig. 5 - Diagram of the E-R model of the CEDIT database updated to 2017 showing the links among Dictionaries and Tables

The surveyed effects were grouped into 5 macro-categories, following the same criteria already used in the previous release of the catalogue. In Table 8 the codes of the macro-categories are reported, and they were also considered for the following statistical analyses. The CEDIT database 2017 contains data about over 170 earthquakes and roughly 3790 earthquakes-induced ground failures occurred in more than 1100 Italian localities. Obviously, absolute values are poorly significant, since the catalogue (just as all macroseismic catalogues) is inevitably subject to continuous revisions and updates (as new studies become available and new seismic events occur). For instance, the current release of the CEDIT database does not

CEDIT 2012			CEDIT 2017		
FIELD	DATA TYPE	% OF DATA	FIELD	DATA TYPE	% OF DATA
ID	automatic numbering	100%	ID	automatic numbering	100%
ID_CPTI04	short text	97%	ID_CPTI04	numeric (int)	100%
ID_Earthquake	numeric	100%	ID_Earthquake	numeric (int)	100%
year	numeric	100%	Year	numeric (int)	100%
month	numeric	100%	Month	numeric (int)	100%
day	numeric	99%	Day	numeric (int)	100%
date	short text	100%	Date	Data	100%
epicentral area	short text	100%	EpicentralArea	short text (30)	100%
maximum intensity_MCS	short text	95%	MaxIntensityMCS	numeric, decimal (2,1)	96%
epicentral intensity_MCS	short text	98%	EpicentralIntensityMCS	numeric, decimal (2,2)	99%
epicentral_latitude	numeric	100%	EpicentralLatitude	numeric, decimal (2,2)	100%
epicentral_longitude	numeric	100%	EpicentralLongitude	numeric, decimal (2,2)	100%
moment magnitude	numeric	100%	MomentMagnitude	numeric, decimal (2,2)	100%
DISS_macrosismico	short text	100%	DISSMacroseismic	short text (7)	100%
DISS_individual_1	short text	100%	DISSIndividual1	short text (7)	100%
DISS_individual_2	short text	100%	DISSIndividual2	short text (7)	100%
DISS_individual_3	short text	100%	DISSIndividual3	short text (7)	100%
ID_ITC	short text		IDITC	short text (5)	
LINK_CPTI04	hyperlink	96%	LINKCPTI04	hyperlink	100%
LINK_DISS	hyperlink	100%	LINKDISS	hyperlink	100%
No_landslides	numeric	74%	NLandslides	numeric (int)	100%
No_liquefaction	numeric	69%	NLiquefaction	numeric (int)	100%

Tab. 15 - Data related to Earthquakes table

CEDIT 2012			CEDIT 2017		
FIELD	DATA TYPE	% OF DATA	FIELD	DATA TYPE	% OF DATA
ID_Effect	numeric	100.0%	IDEffect	numeric (int)	100.0%
ID_ISTAT	short text	99.6%	IDIstat	short text	100.0%
ID_locality_ISTAT	short text	19.1%	IDLocalityIstat	short text	19.1%
ID_ISTAT_LOC_TOT	short text	5.5%	IDIstatLocTot	short text	5.5%
ID_Earthquake	numeric	100.0%	IDEarthquake	numeric (int)	100.0%
Total	short text	50.0%	Noaftershocks	numeric (int)	100.0%
site	short text	99.3%	Site	short text (30)	100.0%
site_latitude	numeric	99.2%	SiteLatitude	numeric, decimal (2,2)	99.5%
site_longitude	numeric	99.2%	SiteLongitude	numeric, decimal (2,2)	99.5%
site_intensity_MCS	short text	99.7%	SiteIntensityMCS	numeric, decimal (2,1)	99.7%
site_intensity_ESI	short text	14.5%	SiteIntensityESI	numeric, decimal (2,1)	14.5%
effect_1	numeric	-	Effect1	numeric (int)	-
effect_2	numeric	-	Effect2	numeric (int)	-
effect_3	numeric	-	Effect3	numeric (int)	-
effect_4	numeric	-	Effect4	numeric (int)	-
effect_5	numeric	-	Effect5	numeric (int)	-
effect_6	numeric	-	Effect6	numeric (int)	-
effect	short text	98.5%	EffectList	short text (45)	100.0%
geology	short text	75.1%	Geology	short text (30)	75.1%
lithology	short text	75.1%	Lithology	short text (30)	75.1%
Epicentral_distance	numeric	99.0%	EpicentralDistance	numeric, decimal (3,1)	99.0%
epicentralZone	short text	20.0%	EpicentralZone	short text (30)	100.0%
classeGeoreferenziazione	numeric	98.5%	ClasseGeoreferencing	numeric (int)	100.0%
RicercaDem	short text	100.0%	RicercaDem	short text (50)	100.0%
Link_reference	short text	99.2%	LinkReference	short text (60)	99.2%
VOLUMETRIC_CLASS	short text	25.0%	VolumetricClass	short text (2)	25.0%
RILEVATORI	short text	25.0%	IDSurvay	short text (40)	25.0%
Interaction	short text	25.0%	Interaction	short text (17)	25.0%

Tab. 16 - Data related to Effects table include any data related to the ground effects related to the Molise earthquake (2018), and does not include the I_{MCS} values regarding the Capitignano (2017) and Casamicciola-Ischia (2017) earthquakes as they are not yet available.

Based on the CEDIT database updated to 2017, the distribution of the earthquake-induced ground failures grouped following the 5 macro-categories was obtained (Fig. 6). This distribution evidences a general increase in the number of ground effects inventoried for each macro-category respect to the previously two releases and demonstrates as the macro-category "landslide" is the most represented among all the inventoried ground effects. More in particular, the number of inventoried earthquake-induced landslides increases up to 55% after the 2016-2017 Central Apennines seismic sequence; the most of these newly inventoried landslides are represented by rock-falls and rockslides.

To update up to 2017 the CEDIT database, a complete revision of the macroseismic intensity values (I_{MCS}), assigned to the sites in which the earthquake-induced ground effects were recorded, was also performed. The I_{MCS} values have been obtained by performing a spatial proximity analysis, carried out using QGIS software (Fig. 7), starting from the geographical coordinates of the CEDIT effects and the quotation points of the macroseismic field obtained for the historical earthquakes and reported in the CFTI5Med and CPTI15 catalogues by INGV, as well as in Galli *et alii* (2017) scientific paper, which reports MCS Intensity values related to the August 24 earthquake, October 26 and 30 earthquakes belonging to the 2016-2017 Central Apennines seismic sequence. The spatial analysis performed by the QGIS software allowed to obtain the association of each CEDIT effect with the nearest I_{MCS} value reported for the corresponding earthquake in the macroseismic quotation field.

Figure 7 exemplifies the spatial distribution analysis, carried out by QGIS software, which map the MCS site Intensity (i.e. MCS of the effect sites) from the CEDIT 2017 database. The frames in the figure describe the effects of a couple of significant earthquakes (those of higher magnitude in each of the regions in central and southern Italy), categorized in colour according to the I_{MCS} and as a type of symbol based on the type of effect.

The frequency distribution for the 5 macro-categories of earthquake-induced ground effects inventoried in the CEDIT 2017 database, is reported in Figure 8 and it is compared with the one of the previous (2012) version of the CEDIT database. This distribution confirms that the highest percentage of ground-effects collected in the last release of CEDIT database is related to landslides (55%), followed by ground cracks (23%), liquefaction (13%), surface faulting (5%) and generic ground changes (4%).

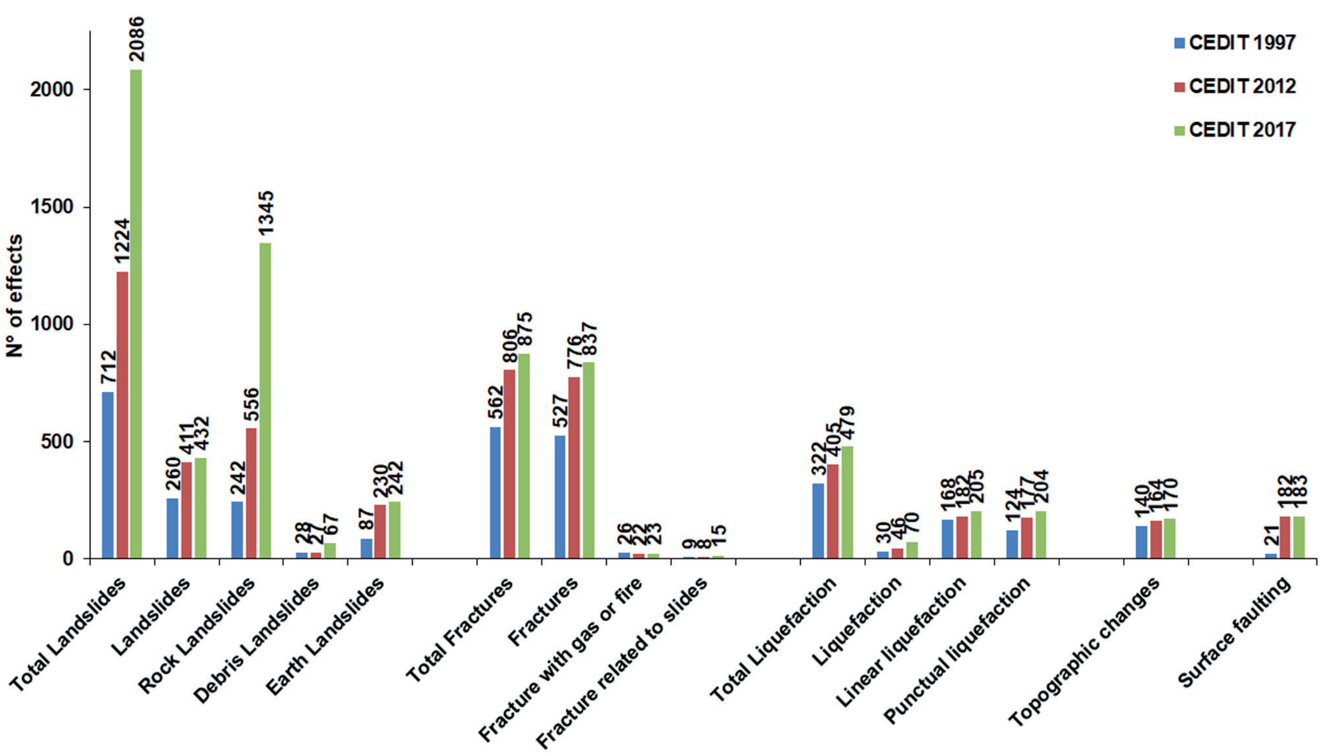

Fig. 6 - Frequency distribution of earthquake-induced ground effects inventoried in the updated CEDIT database and distinguished in subcategories. A comparison with the previous versions of the CEDIT database (i.e. 1997 and 2012, respectively) is also reported

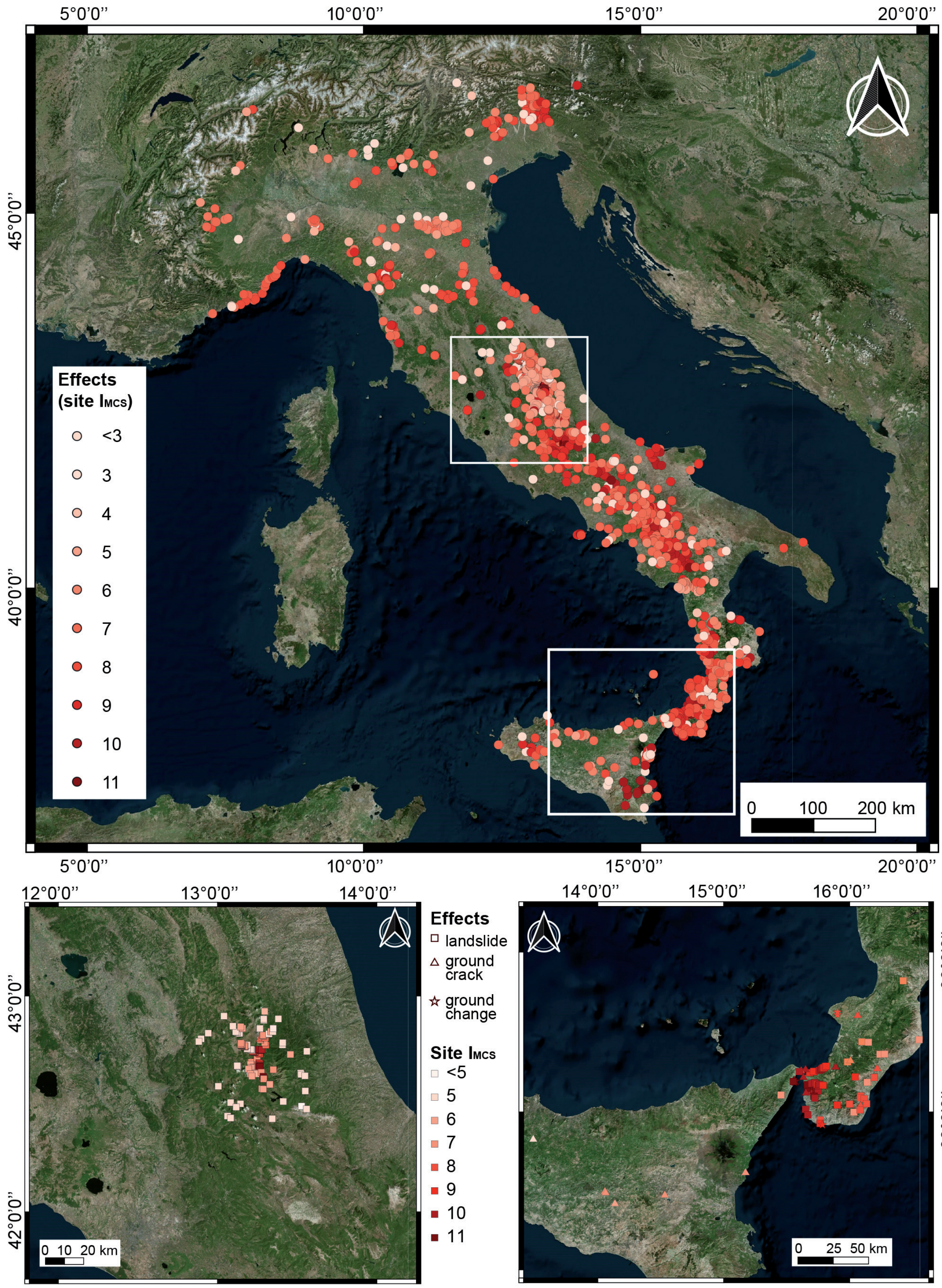

Fig. 7 - Projection of the site intensity MCS values extracted from the CEDIT database updated to 2017. Two frame highlight the site intensity MCS value for the ground effects related to the M_W 6.0 24/08/2016 Amatrice Earthquake (bottom left frame) and the M_W 7.1 28/12/1908 Messina Earthquake (bottom right frame)

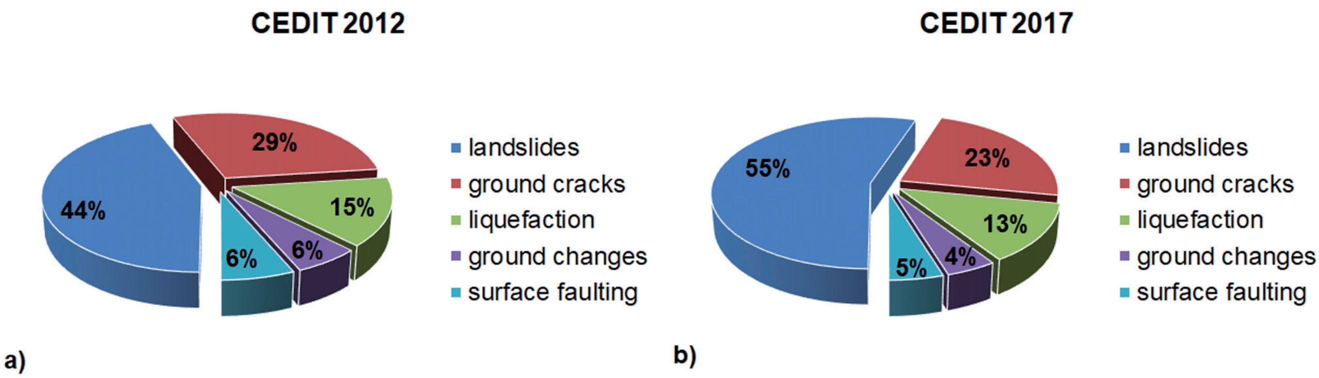

Fig. 8 - Frequency distribution of earthquake-induced ground effects distinguished for macro-categories and derived from: a) the CEDIT 2012 database and b) the CEDIT 2017 database

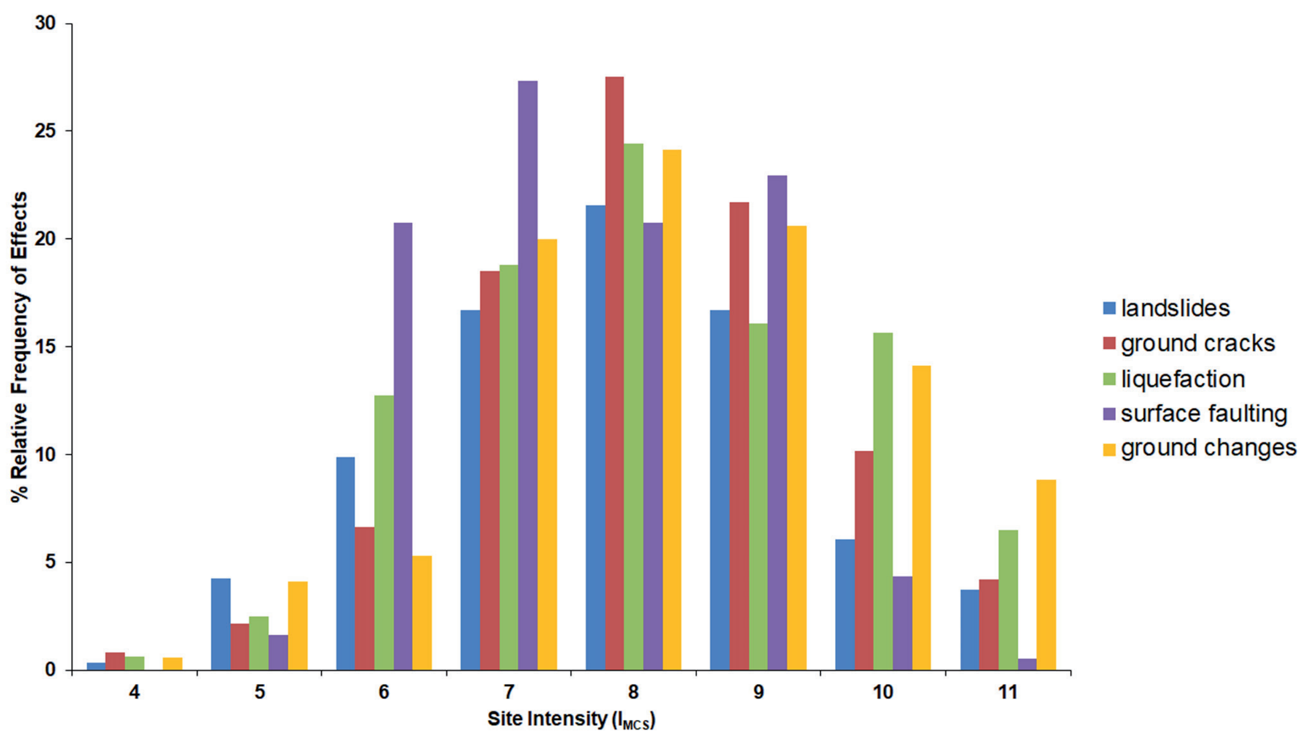

Fig. 9 - Relative frequency of ground failures due to seismic event vs. local macroseismic intensity (MCS scale) reported in the CEDIT database updated to 2017

Figure 9 shows the relative distribution of the earthquake-induced ground effects with respect to to the local macroseismic intensity. Consistently with the results already obtained from the 2012 version of CEDIT database, the maximum frequency (modal value) occurs for I_{MCS} class 8 for landslides, ground cracks, liquefaction and ground changes, while regarding the surface faulting the maximum frequency occurs for I_{MCS} class 7. In here presented version of the CEDIT database there is a further frequency peak in the I_{MCS} class 9 even not extended to all types of effects but only to the "surface faulting" category. The trigger threshold of I_{MCS} is between 5 and 6 for landslides and ground crack, while it is higher for other macro-categories of ground effects.

The not available datum (value -9999) was entered into the CEDIT database for I_{MCS} values extrapolated from points having distances higher than 5 km from the effect site, as they were not regarded as reliable. Table 17 describe how the I_{MCS} class are subdivided and merged regarding the construction of the histogram reported in Figure 9.

Figure 10 shows the absolute frequency of earthquake-induced ground effects as a function of MCS epicentral intensity obtained as the ratio between the number of effects for each macro-category and the number of earthquakes of a specific epicentral intensity class that induced them. The general trend shows an increase of frequency with the epicentral intensity values, with the exception of landslides macro-categories that presents a peak at 10 epicentral I_{MCS} values because of the large number of effects recorded during the 2016-2017 Central Apennines seismic sequence (epicentral I_{MCS} value equal to 10 for all the mainshocks).

Table 18 shows the criteria adopted for grouping the epicentral IMCS values to obtain the distribution diagram of Figure 10.

The attenuation of the earthquake-induced ground effects with distance from the earthquake epicenter is shown in Figure 11 as it results after the last updating of the CEDIT database. According to the results obtained from the previous statistical analysis carried out in the older release of CEDIT (Fortunato *et alii*, 2012), an almost exponential decay of the numbers of effects with distance is evident for all the 5 considered macro-categories of effects. The decrease is evident for epicentral distances greater than 25 km, although for this class the "surface faulting" and "ground changes" macro-categories show a more pronounced decay if compared to the same macro-categories in the lower epicentral distance class (class 15 km). Such a trend indicates that the presence of these two macro-categories of effects is more influenced by the epicentral distance than the other macro-categories of effects.

CLASSES I_{MCS}	RANGE OF VALUES
CLASS 4	I_{MCS} <4.5
CLASS 5	4.5>=I_{MCS} <5.5
CLASS 6	5.5>= I_{MCS} <6.5
CLASS 7	6.5>= I_{MCS} <7.5
CLASS 8	7.5>= I_{MCS} <8.5
CLASS 9	8.5>= I_{MCS} <9.5
CLASS 10	9.5>=I_{MCS} <10.5
CLASS 11	I_{MCS} >=10.5

Tab. 17 - Description of I_{MCS} classes adopted in Figure 9

CLASSES EPICENTRAL INTENSITY (MCS)	RANGE OF VALUES
5	I_{MCS} <5.5
6	5.5 >= I_{MCS} < 6.5
7	6.5 >= I_{MCS} < 7.5
8	7.5 >= I_{MCS} < 8.5
9	8.5 >= I_{MCS} < 9.5
10	9.5 >= I_{MCS}< 10.5
11	I_{MCS} >=10.5

Tab. 18 - Criteria used for distinguishing the epicentral intensity classes adopted to obtain the diagram of Figure 10

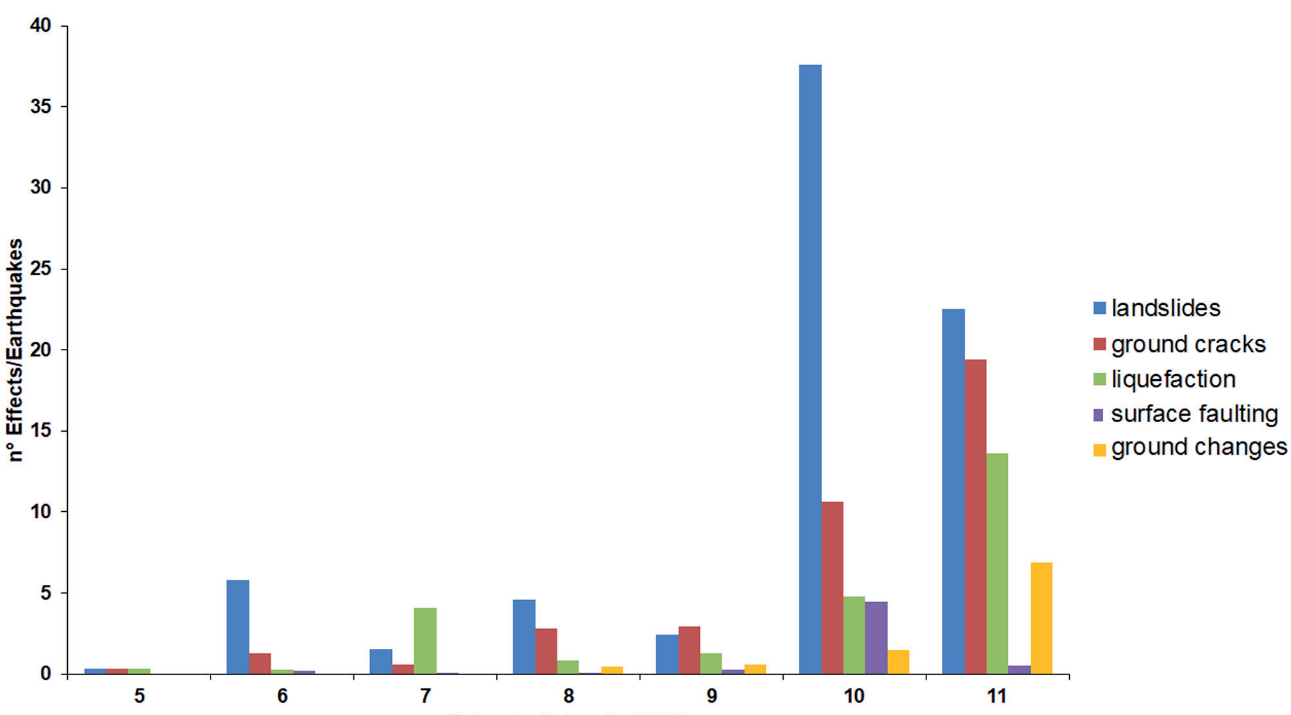

Fig. 10 - Absolute frequency of ground effects due to seismic event vs. epicentral macroseismic intensity (MCS scale) as it results from the CEDIT database updated to 2017

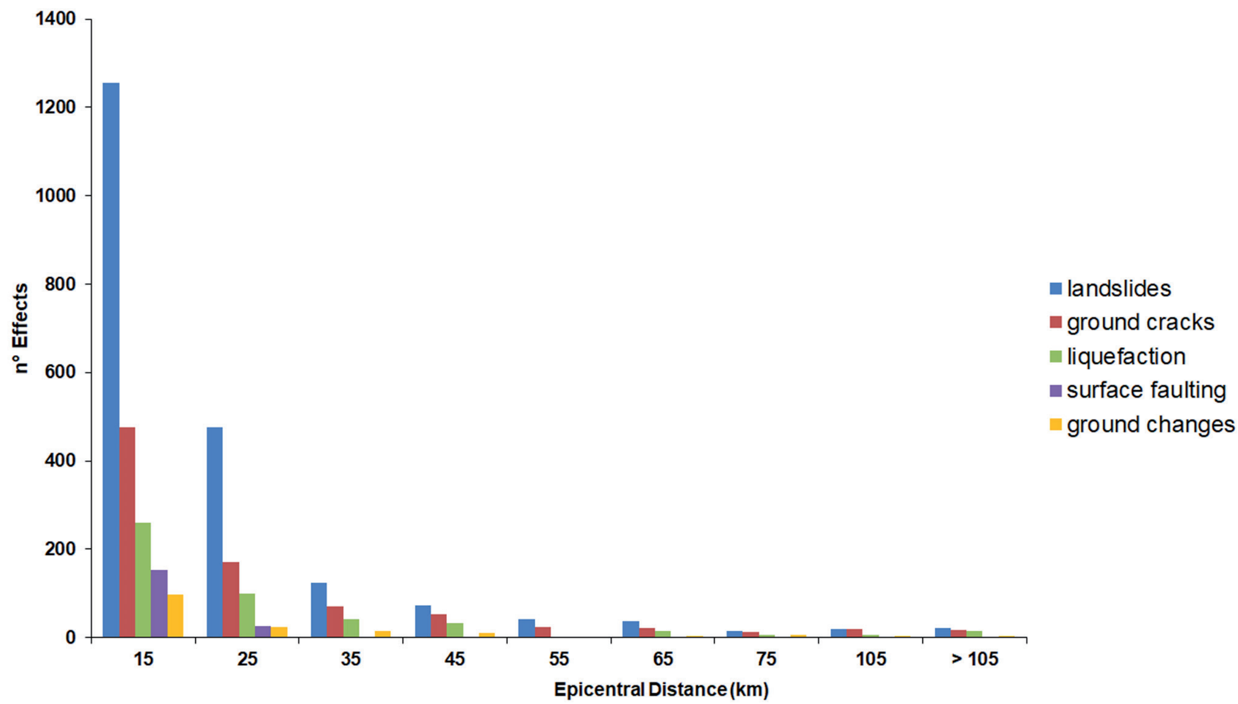

Fig. 11 - Distribution of earthquake-induced ground failures vs. epicentral distance from the earthquake reported in the CEDIT database updated to 2017

CLASSES OF EPICENTRAL DISTANCE (km)	RANGE OF VALUES
15	< 15 km
25	15 >= km < 25
35	25 >= km < 35
45	35 >= km < 45
55	45 >= km < 55
65	55 >= km < 65
75	65 >= km < 75
105	75 >= km < 105
>105	>= 105 km

Tab. 19 - Description of epicentral distance classes (expressed in km) adopted for the distribution diagram of Figure 11

Table 19 shows how the epicentral distance (expressed in km) values have been grouped and merged to derive the distribution diagram of Figure 11.

CONCLUSIONS

The Italian catalogue of ground effects induced by strong earthquakes (CEDIT) inventories the ground effects induced by strong earthquakes occurred in Italy since the year 1000 A.D. The first release of the CEDIT, edited by Romeo & Delfino (1997), included the main earthquakes up to 1984, successively updated up to 1997 and then up to the 2012 Emilia earthquake by Fortunato *et alii*, 2012 and Martino *et alii*, 2014.

The latest update of the CEDIT database, up to 2017, is here presented. The database was also re-designed and a new architecture, based on a modern relation-concept, was adopted which is here reported in an E-R model with related logic scheme, attribute tables and dictionaries.

To update the CEDIT database, the effects induced by the earthquakes occurred in the Central Apennines on 2016-2017 and at Ischia Island on 2017 were added in the new database and all the events and effects were checked accordingly to the recent CFTI5Med and CPTI15 catalogues by INGV. To associate a macroseismic intensity value (I_{MCS}) to the effect sites, a spatial analysis was specifically carried out through the QGIS software starting from the macroseismic quoted field available in literature and updated to the last seismic sequence of the Central Apennines.

According to the updated CEDIT database, the frequency distribution of category of effects shows that landslides are the most represented ground effect corresponding to almost 55% of the entire dataset. Moreover, the I_{MCS} threshold for earthquake triggering of ground effects grouped in macro-categories ranges from 5 to 6 for all the considered categories of effects while their spatial distribution reveals an almost exponential decrease of the inventoried number of effects with increasing epicentral distance, with the most of the effects located within 25 km corresponding to a percentage of 80%. The updating and the new architecture of the CEDIT database will allow the upgrade of the online catalogue in the next future and the design of a specific web-app to manage future surveys for new inventorying.

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