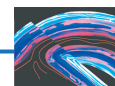


Guidelines

Linee Guida



1. - BACKGROUND

1.1. - RATIONALE

The twelve degrees macroseismic intensity scales, developed since the beginning of XX century, were based on evaluation of the effects on a) humans, b) manmade structures and c) natural environment (fig. 1).

When the first models of macroseismic scales appeared, the Authors intuitively followed the inspired idea of including different types of effects, or effects on different kinds of “receivers”. Without giving a formal definition of this successful methodological approach, DE ROSSI, MERCALLI, CANCANI, OMORI, SIEBERG and their colleagues incorporated in the macroseismic scales effects on humans, on buildings and on natu-

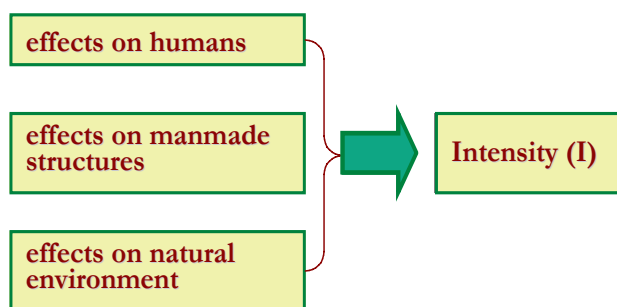


Fig. 1 - According to the original definition of intensity in the twelve degrees scales, i.e., the Mercalli-Cancani-Sieberg Scale (MCS), the Modified Mercalli scale (MM-31 and MM-56) and the Medvedev-Sponheuer-Karnik scale (MSK-64), the assessment of intensity degrees has to be based on humans, manmade structures and natural environment. - Secondo la definizione originale di intensità nelle scale a dodici gradi, quali la scala Mercalli-Cancani-Sieberg (MCS), la scala Mercalli Modificata (MM-31 e MM - 56) e la scala Medvedev-Sponheuer-Karnik (MSK 64), la valutazione del grado di intensità deve essere basata sugli effetti sull'uomo, sulle strutture antropiche e sull'ambiente naturale.

re. In this way, the effects produced by earthquakes at the surface have notably come under close scrutiny, recognizing the fact that they actually result from the cumulated effects of the source (vibrations generated during slip, finite deformations), of the propagation of seismic waves, and, lastly, of local site effects. Later it became clear that by doing this they were able to take into account the whole frequency range of interest, including its static component. Therefore, according to this original and valuable approach, Intensity can be defined as a classification of effects, which allows measuring the earthquake severity in the whole range of frequencies including static deformations and vibrational effects.

However, in the early versions of the twelve degrees scales (cf. DAVISON, 1921), the effects of the earthquakes on the natural environment were scarcely documented. Their presence in the scale was mostly due to the many references to ground cracks, landslides, and landscape modifications, contained in the historical sources.

Later, in the second half of the XX century, these effects have been increasingly disregarded in the literature and in the practice of macroseismic investigation, probably due to their inner complexity and variability requiring specific skills and knowledge, while increasing attention has been paid to the apparently easier to analyze effects on humans and manmade structures (e.g., ESPINOSA *et alii*, 1976a; 1976b; GRUNTHAL, 1998).

In fact, recent studies (DENGLER & MCPHERSON, 1993; SERVA, 1994; DOWRICK, 1996; ESPOSITO *et alii*, 1997; HANCOX *et alii*, 2002; MICHE'TTI *et alii*, 2004; and references therein) have offered new substantial evidence that coseismic environmental effects provide precious information on the ear-

thquake size and its intensity field, complementing, *de facto*, the traditional damage-based macroseismic scales. As a matter of fact, with the outstanding growth of Paleoseismology as a new independent discipline, nowadays the effects on the environment can be described and quantified with a remarkable detail compared with that available at the time of the earlier scales. Therefore, today the definition of the intensity degrees can effectively take advantage of the diagnostic characteristics of the effects on natural environment.

This is the goal of the ESI 2007 scale. Its use, alone or integrated with the other traditional scales (see chapter 2), affords a better picture of the earthquake scenario, because only environmental effects allow suitable comparison of the earthquake intensity both:

- *in time*: effects on the natural environment are comparable for a time-window (recent, historic and palaeo seismic events) much larger than the period of instrumental record (last century), and
- *in different geographic areas*: environmental effects do not depend on peculiar socio-economic conditions or different building practices.

1.2. - PRIMARY AND SECONDARY EFFECTS

Earthquake Environmental Effects (EEEs) are any phenomena generated in the natural environment by a seismic event. They can be categorized in two main types:

- primary effects, the surface expression of the seismogenic tectonic source (including surface faulting, surface uplift and subsidence), typically observed for crustal earthquakes over a certain threshold value of magnitude. Being directly linked to the size, hence the energy of the earthquake, these effects in principle do not suffer saturation, i.e., they saturate only for intensity XII, this being an obvious inherent limit of all macroseismic scales.
- secondary effects: phenomena generally induced by the ground shaking. Their occurrence is commonly observed in a specific range of intensities. For each type of secondary effect, the ESI 2007 scale describes their characteristics and size as a diagnostic feature in a range of intensity degrees. Hence, in some cases it is only possible to establish a minimum intensity value. Conversely, the total area of distribution of secondary effects does not saturate and therefore it can be used as an independent tool for the assessment of the epicentral intensity I_0 (par. 3.2).

1.3. - THRESHOLD FOR SURFACE FAULTING IN VOLCANIC AREAS

The focal depth and the stress environment of an earthquake obviously influence the occurrence and the size of the observed effects. Two crustal earthquakes with the same energy but very different focal depths and stress environment can produce a very different field of environmental effects and therefore largely different local intensity values. This is particularly important in volcanic areas, where tectonic earthquakes with low magnitude and very shallow focus (in the order of 1-4 km) can generate primary effects (e.g., AZZARO, 1999). To take this into account, the threshold for surface faulting in volcanic areas has been set at intensity VII, whereas for typical earthquakes (focal depth 5-15 km) primary effects start from intensity VIII.

2. - HOW TO USE THE ESI 2007 SCALE

When suitable EEEs are documented, the ESI 2007 scale allows independent estimates of epicentral and local intensity. Through a straightforward procedure (fig. 2) these values can be used for intensity assessment alone or together with damage-based traditional scales to produce a "hybrid" intensity field. The use of the ESI 2007 scale as an independent tool is recommended when (case A in fig. 2) only environmental effects are diagnostic because effects on humans and on manmade structures are absent, or too scarce (i.e. in sparsely populated or desert areas), or suffer saturation (i.e., for intensity X to XII).

As shown by the processing of many earthquakes worldwide, typically the ESI 2007 used alone can define the intensity degree with an acceptable level of accuracy starting from intensity VII, when environmental effects usually become diagnostic. This accuracy improves in the higher degrees of the scale, in particular in the range of occurrence of primary effects, typically starting from intensity VIII, and with growing resolution for intensity IX, X, XI and XII. Obviously, when environmental effects are not available, intensity has to be assessed by damage-based traditional scales (case B).

If effects are available either on manmade structures and natural environments (case C), allowing to estimate two independent intensities, in general the intensity has to coincide with the highest value between these two estimates. Of course, expert judgment is an essential component in the process of comparing intensity assess-

sed using different categories of “receivers”.

This procedure allows generating a “hybrid field” of local intensities, i.e., derived from the integration of ESI 2007 and other intensity scales. This is deemed to be the best intensity scenario because 1) it takes into account all the effects triggered by the earthquake, 2) it is in agreement with the original definition of intensity, and 3) it allows the comparison of earthquakes in time and in space over the largest chronological and geographic window.

2.1. - PROCEDURE TO USE THE ESI 2007 SCALE AS A SELF INSTRUMENT FOR INTENSITY ASSESSMENT

Evidently the ESI 2007 scale is a tool to assess both epicentral and local intensities.

2.1.1. - *Epicentral intensity* (I_0)

Epicentral intensity (I_0) is defined as the intensity of shaking at epicenter, i.e. what intensity we would get, if there were a locality that matches

the epicenter. Several techniques can be applied to assess I_0 ; for instance, POSTPISCHL (1985) define I_0 as “the value of the closed isoseismal line having the highest degree and including at least 3 different data points”.

Surface faulting parameters and total area of distribution of secondary effects (landslides and/or liquefactions) are two independent tools to assess I_0 on the basis of environmental effects, starting from the intensity VII.

SURFACE FAULTING PARAMETERS: The ranges reported in Table 1 are based on the analysis of surface faulting parameters and intensity data available for more than 400 shallow crustal earthquakes worldwide (SURFIN, SURFace faulting and INTensity database; INQUA scale Project, 2007). The use of this simple table for I_0 assessment requires particular attention when the amount of surface faulting is close to the boundaries between two intensity degrees. In this case it is recommended to choose the intensity value better consistent with the characteristics and distribution of secondary effects.

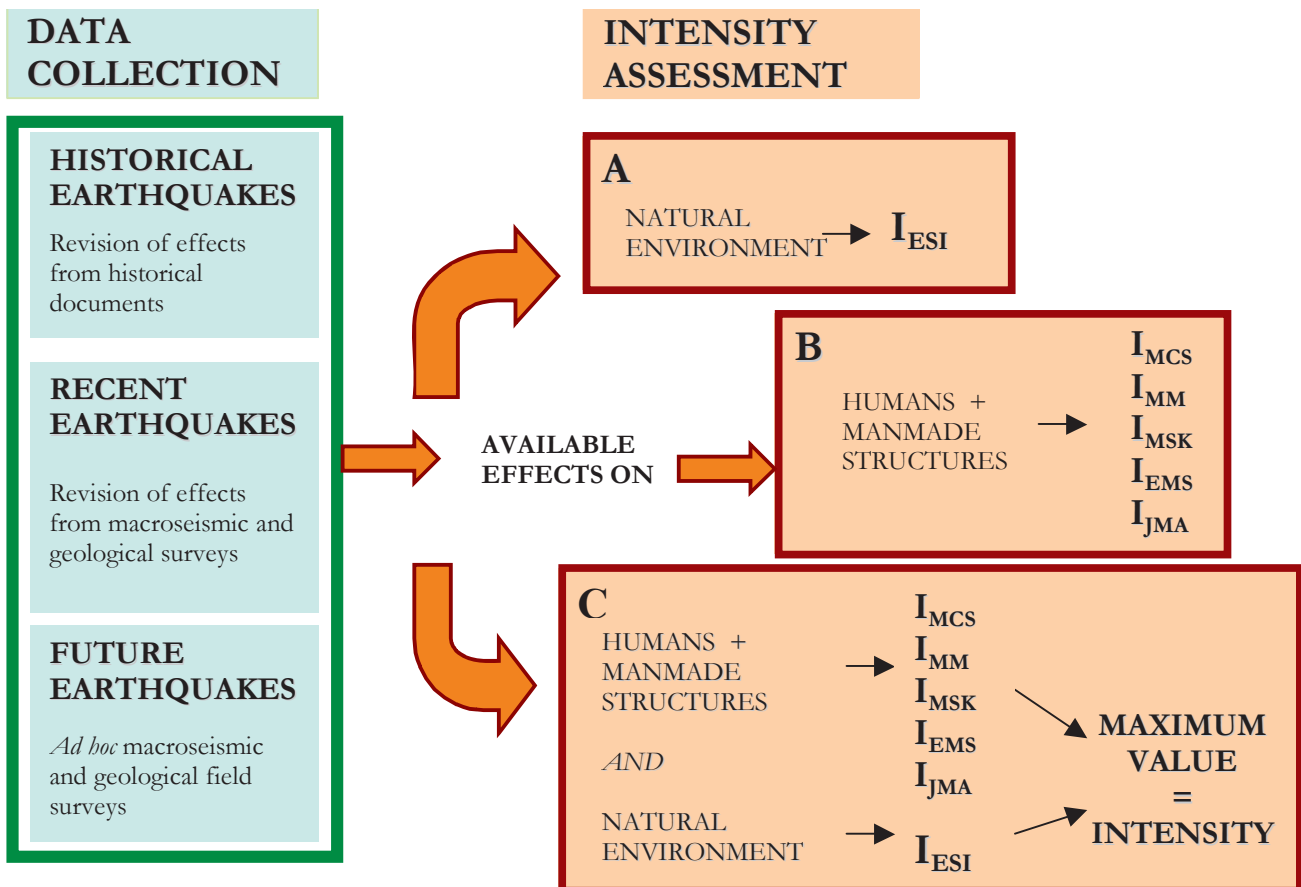


Fig. 2 - Logical scheme for the use of ESI 2007 scale alone or together with damage-based traditional scales. We show only the most commonly used scales, however, any scale can be integrated with the ESI 2007 scale following the same methodological steps.
 - Schema logico per l'utilizzo della scala ESI 2007 da sola o insieme con le scale tradizionali basate sui danni. Qui sono considerate solo le scale maggiormente usate, tuttavia qualsiasi scala può integrarsi con la scala ESI 2007 seguendo un approccio metodologico analogo.

TOTAL AREA OF SECONDARY EFFECTS: Starting from intensity VII, the ESI 2007 scale considers the total area of secondary effects as diagnostic element for I_0 assessment. Even in this case, for each intensity degree table 1 only lists the order of magnitude of the total area, and the chosen value of I_0 has to be consistent with primary effects.

The definition of total area should not include the isolated effects occasionally located in the far field. In fact, the occurrence of these effects is most likely due to peculiar site conditions.

Evidently, only a sound professional judgment can establish which effects should be included/excluded in the definition of total area.

TAB. 1 - Ranges of surface faulting parameters (primary effects) and typical extents of total area (secondary effects) for each intensity degree.

- Valori di riferimento per ciascun grado di intensità relativo ai parametri di fagliazione superficiale (effetti primari) e all'area totale degli effetti secondari.

I_0 Intensity	PRIMARY EFFECTS		SECONDARY EFFECTS
	SURFACE RUPTURE LENGTH	MAX SURFACE DISPLACEMENT / DEFORMATION	TOTAL AREA
IV	-	-	-
V	-	-	-
VI	-	-	-
VII	(*)	(*)	10 km ²
VIII	Several hundreds meters	Centimetric	100 km ²
IX	1- 10 km	5 - 40 cm	1000 km ²
X	10 - 60 km	40 - 300 cm	5000 km ²
XI	60 – 150 km	300 –700 cm	10000 km ²
XII	> 150 km	> 700 cm	> 50000 km ²

(*) Limited surface fault ruptures, tens to hundreds meters long with centimetric offset may occur essentially associated to very shallow earthquakes in volcanic areas.

2.1.2 . - Local intensity (I_L)

The local intensity is essentially assessed through the description of secondary effects. However, even the local expression of primary effects, in terms of maximum displacement of a fault segment, may contribute to its evaluation.

The evaluation of local intensity can be done in two different ways:

LOCALITY - SITE: this approach is recommended when the descriptions of environmental effects are not homogeneously surveyed over the territory, which is common for historical earthquakes. The main advantage of this procedure is that it allows the comparison with local intensities deriving from traditional macroseismic scales.

According to this approach, a Site can be defined as any place where a single environmental effect has occurred. The description of one effect has to be done at this level.

One Locality may include several sites and presents a level of generalization, to which intensity can be assigned. It can refer to any place, either inhabited or natural. It has to be small enough to keep separated areas with significantly different site intensities, but large enough to include several sites and consequently to be representative for intensity assessment. Therefore, the locality has to be defined by expert judgment.

REGULAR GRID: in case a systematic field survey of the affected area provides a homogeneous distribution of environmental effects, which is still uncommon for modern earthquakes but highly advisable for future earthquakes, it is recommended to divide the territory into a regular grid with a cell size that depends on the scale of the field survey. It should be possible to assign a local intensity to each cell. The resulting distribution of local intensities allows to define the map of isoseismals. However, with this approach the comparison and integration with “standard” macroseismic intensity values may become quite difficult.

2.2. - CORRELATION BETWEEN ESI 2007 AND TRADITIONAL MACROSEISMIC SCALES

In principle, the correlations of intensity scales, degree by degree, should be never allowed because each scale classifies the effects in a different way. Hence, for the comparison of two earthquakes it should be advisable to use the same intensity scale, even if it is necessary to reclassify all the effects. For instance, in the MSK64 scale the concepts of “typical” damage and building types are used. As a result this is a scale of constant intervals. The MCS and Modified Mercalli scales, based on maximum effects, are scales of order. As a consequence intensity VIII is much easier to get in original Mercalli than applying MSK64.

Indeed, the “classic” twelve degrees scales, though they included environmental effects, were not able to differentiate intensities above IX, because (a) they did not make difference between primary and secondary effects, (b) they did not use quantitative approach for the effects on nature. Therefore, it is expected that when we deal with the strongest earthquakes the application of the ESI 2007 scale will yield an intensity value that is different, and more physically meaningful, from that obtained with the others scales. That is exactly the reason why it is necessary to develop this new intensity scale.

As a matter of fact, in the practice of macroseismic investigation, very often one is obliged to compare earthquakes intensities classified with different scales. This has promoted the use of conversion tables, such as those proposed by KRINITZSKY & CHANG (1978), REITER (1990), and PANZA (2004). On the other hand, the application of such kind of tables has often caused the introduction of additional uncertainties, such as the use of half-degrees or fractional degrees.

In order to avoid these inconveniences, the correlation among the most important intensity scales has to be simply based on one-to-one relationships. As discussed in MICHETTI *et alii*, (2004), due to the level of uncertainty inherent in the structure itself of the macroseismic scales, and in case a conversion between scales is a step that cannot be absolutely avoided, the best we can do is to consider all the twelve degrees scales as equivalent. This includes also the Chinese macroseismic intensity scale, which has been originally designed to be consistent with the MM scale (e.g., XIE, 1957; WANG, 2004). Nevertheless, the correlation with the 7-degrees JMA intensity scale (KRINITZSKY & CHANG, 1977; REITER, 1990; HANCOX *et alii*, 2002), and with other scales not based on twelve degrees, inevitably requires grouping of some intensity degrees.

3. - STRUCTURE OF THE SCALE

The ESI 2007 scale has been developed to be consistent with the Modified Mercalli macroseismic scale (MM-31, WOOD & NEUMANN, 1931; MM-56, RICHTER, 1958) and the MSK-64 (Medvedev-Sponheuer-Karnik scale), since these are the most applied worldwide and includes many explicit references to environmental effects.

More in general, the new scale was carefully designed in order to keep the internal consistency of the original twelve degrees scale, as discussed in depth by MICHETTI *et alii*, (2004). A great deal of work in seismic hazard assessment is accomplished in the world, and intensity is a basic parameter in this. Any “new word” in this research field must not result in dramatic changes. The members of the WG are aware that, by definition, the twelve-degree macroseismic scales are based essentially on effects on humans in the range of intensity II to V, on damage in the range of intensity VI to IX, and on natural environment in the range of intensity X to XII. The ESI 2007 scale is therefore really useful only for the assessment of the highest intensities. But, as mentioned above, to avoid any confusion, the classical numbering is kept.

3.1. - MAIN GROUPS OF INTENSITY DEGREES

The ESI 2007 scale starts where environmental effects become regularly observed in favorable conditions, i.e. at intensity IV. The scale is linear and works well up to XII degree. In the first version of the scale, intensity I, II and III were also defined using environmental effects (MICHETTI *et alii*, 2004). It is important to remark that several effects on nature, especially concerning water bodies and hydrogeological phenomena (MONTGOMERY & MANGA, 2003 and references therein), but also instrumentally-detected primary tectonic deformations (permanent fault offset measured at the INFN Gran Sasso, Italy, strainmeter; cf., AMORUSO & CRESCENTINI, 1999), have been observed for very low intensity. Perhaps future investigation will allow a new revision of the scale in order to include environmental effects suitable for intensity assessment in the range from I to III. However, after 4 years of application at a global scale through the INQUA scale project, it was clear that with the knowledge available today, effects on natural environment in this range are not diagnostic.

Therefore, comparing the ESI 2007 with the other 12 degrees scales, we can identify three main subset:

I) From I to III: There are no environmental effects that can be used as diagnostic.

II) From IV to IX: Environmental effects are easily observable starting from intensity IV, and often permanent and diagnostic especially starting from intensity VII. However, they are necessarily less suitable for intensity assessment than effects on humans and manmade structures. Their use is therefore recommended especially in sparsely populated areas;

III) From X to XII: Effects on humans and manmade structures saturate, while environmental effects become dominant; in fact, several types of environmental effects do not suffer saturation in this range. Thus, environmental effects are the most effective tool to evaluate the intensity.

3.2. - TITLE AND DESCRIPTION

The title reflects the corresponding force of the earthquake and the role of environmental effects.

In the description, the characteristics and size of primary effects associated to each degree are reported firstly. Then, secondary effects are described i) in terms of total area of distribution for the assessment of epicentral Intensity (star-

ting from intensity VII); ii) grouped in several categories (see previous chapter and tab. 2), ordered by the initial degree of occurrence.

Text in *Italic* has been used to highlight descriptions regarded as diagnostic by itself for a given degree.

3.3. - DESCRIPTION OF EARTHQUAKE ENVIRONMENTAL EFFECTS

It is possible to collect the characteristics of earthquake environmental effects in two different ways:

- the ESI 2007 Form, designed to be used during the emergency phase after an earthquake (Appendix II);
 - the EEE Database, designed to be used for the revision of historical reports and for final archiving.
- Both these documents can be downloaded from http://www.apat.gov.it/site/en-GB/Projects/INQUA_Scale/Documents/

The structure of the ESI 2007 Form and EEE Database is similar. Thus, it is possible to migrate from the former to the latter without difficulties.

3.3.1. - *Primary effects*

The size of primary effects is typically expressed in terms of two parameters: i) Total Surface Rupture Length (SRL) and ii) Maximum Displacement (MD). Their occurrence is commonly associated to a minimum intensity value (VIII), except in case of very shallow earthquakes in volcanic areas. Amount of tectonic surface deformation (uplift, subsidence) is also taken into account.

3.3.2. - *Secondary effects*

Secondary effects can be classified into eight main categories (tab. 2). While some descriptions are considered diagnostic (*in Italic*), others are susceptible to be changed after the implementation of the database which correlates characteristic features of secondary effects and intensity degrees.

Nevertheless, in order to provide a reasonable value for the total area of secondary effects, it is recommended to describe and map the whole distribution of secondary effects, including those not yet incorporated in the description of intensity degrees (e.g., karst collapses).

A - Hydrological anomalies

Hydrological anomalies show up from intensity III and saturate (i.e. their size does not increase) at intensity X.

They can be divided in two groups:

- Surface water effects: 1) Overflow; 2) Discharge variation; 3) Turbidity of rivers;
- Ground water effects: 1) Drying up of springs; 2) Appearance of springs; 3) Temperature changes; 4) Anomaly in chemical component; 5) Turbidity of springs.

Further useful information might be: the amount and rates of variation in temperature and discharge, the presence of anomalous chemical element, the duration of the anomaly, and the time delay.

B - Anomalous waves/tsunamis

In this category are included: seiches in closed basins, outpouring of water from pools and basins, and tsunami waves. In the case of tsunamis, more than the size of the tsunami wave itself, the effects on the shores (especially runup, beach erosion, change of coastal morphology), without

TAB. 2 - *Diagnostic range of intensity degrees for each class of environmental effects.*

- Intervallo di gradi di intensità diagnostico per ciascuna classe di effetti ambientali.

	Environmental effects	Diagnostic range of intensity degrees	
	<i>SURFACE FAULTING AND DEFORMATION</i>	VIII (*)	XII
<i>A</i>	<i>HYDROLOGICAL ANOMALIES</i>	IV	X
<i>B</i>	<i>ANOMALOUS WAVES/TsunamiS</i>	IV	XII
<i>C</i>	<i>GROUND CRACKS</i>	IV	X
<i>D</i>	<i>SLOPE MOVEMENTS</i>	IV	X
<i>E</i>	<i>TREE SHAKING</i>	IV	XI
<i>F</i>	<i>LIQUEFACTIONS</i>	V	X
<i>G</i>	<i>DUST CLOUDS</i>	VIII	VIII
<i>H</i>	<i>JUMPING STONES</i>	IX	XII

(*) For intensity degree VII, limited surface fault ruptures, tens to hundreds meters long with centimetric offset may occur essentially associated to very shallow earthquakes in volcanic areas.

neglecting those on humans and manmade structures, are taken as diagnostic of the suffered intensity.

Effects may already occur at intensity IV, but are more diagnostic from IX to XII. The definition of intensity degrees has taken advantage from the tsunami intensity scale proposed by PAPADOPOULOS & IMAMURA (2001), and from many descriptions of the aforementioned effects worldwide (e.g., LANDER *et alii*, 2003).

C - Ground cracks

Ground cracks show up from intensity IV and saturate (i.e. their size does not increase) at intensity X.

Diagnostic parameters are lithology, strike and dip, maximum width, and area density.

D - Slope movements

Slope movements, including under water landslides, have been grouped in:

1) Rock fall; 2) Debris fall; 3) Toppling; 4) Rock slide; 5) Debris slide; 6) Avalanche; 7) Mudslide; 8) Debris flow; 9) Earth flow; 10) Mud flow; 11) Slow slide; 12) Slow earth flow; 13) Slow mud flow; 14) Lateral spread; 15) Sackung; 16) Complex (two or more concurrent types).

They show up at intensity IV and saturate (i.e. their size does not increase) at intensity X.

The total volume is diagnostic for intensity assessment. It can be roughly estimated on the basis of the landslide area when the depth of sliding mass can be reasonably estimated. The uncertainties introduced with this procedure do not appear to significantly influence the intensity evaluation.

Further information: maximum dimension of blocks, area density, amount of slip, humidity and time delay.

E - Trees' shaking

Trees' shaking is reported from a minimum intensity IV. It is important to record the occurrence of broken branches and the morphologic characteristics of the area (flat, slope). The definition of intensity degrees basically follows these provided by DENGLER & MCPHERSON (1993).

F - Liquefactions

Liquefactions occur from intensity V. The diagnostic features for liquefactions are the diameter of sand volcanoes and the lithology. Saturation (i.e. their size does not increase) occur at intensity X. Other useful characteristics are shape, the time delay, the depth of water table and the occurrence of water and sand ejection.

G - Dust clouds

Dust clouds are reported since intensity VIII, typically in dry areas.

H - Jumping stones

Jumping stones have been reported from minimum intensity IX. The size of stones and their imprint in soft soil are considered as diagnostic parameters for intensity evaluation.

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PUBLICATIONS WITHIN THE INQUA SCALE PROJECT

In the frame of the "INQUA Scale Project" activities, numerous papers, reports and abstracts have been published. In this section is reported a preliminary list.

PAPERS AND REPORTS (PUBLISHED OR IN PRESS).

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- GUERRIERI L., TATEVOSSIAN R., VITTORI E., COMERCI V., ESPOSITO E., MICHETTI A.M., PORFIDO S. & SERVA L. (2007) - *Earthquake environmental effects (EEE) and intensity assessment: the INQUA scale project*. Boll. Soc. Geol. It. (Ital. J. Geosci.), **126**, No. 2, Roma.
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