

Review

History of the Environmental Seismic Intensity Scale ESI-07

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Abstract: This brief note aims to describe the history, from its early original idea, of the new macroseismic scale: The Environmental Seismic Intensity Scale 2007 (ESI 2007). It can be used together with other existing scales or alone when needed for measuring the intensity of an earthquake on the basis of the primary and secondary effects of a seismic event on the natural environment. These effects could be the major sources of earthquake hazards, as recently proved. This note also aims to contribute to the understanding of processes that induced the researcher to develop an idea, to pursue it, and bring it to its end, first through the help of valuable Italian researchers and then through the constructive exchange of ideas with researchers of different cultural backgrounds operating almost everywhere in the world. This note is sponsored and approved by the International Union for Quaternary Research (INQUA), and the Environmental Seismic Intensity scale (ESI-07) was published in 2007 after a revision process of about eight years.

Keywords: earthquake hazards; ground effects; ESI scale 2007; EEE database

1. Introduction

Following the kind invitation of the Editors, herein I introduce some personal considerations on the state of the Environmental Seismic Intensity scale (ESI 2007 scale) [1] starting from its creation to the present and its perspective for the future. This brief note aims to contribute to an understanding of the processes that induced the researcher to develop an idea, pursue it, and bring it to an end, first through the help of valuable Italian researchers and then through the constructive exchange of ideas with researchers of different cultural backgrounds operating almost everywhere in the world.

The Environmental Seismic Intensity scale (ESI 2007 scale) was published in 2007 after a revision process of about eight years as a new intensity scale based only on the Earthquake Environmental Effects (EEEs). This scale integrates the traditional macroseismic scales, of which it represents an evolution, allowing the intensity parameter to also be assessed where buildings are absent and when diagnostic damage-based elements have saturated, exclusively on the basis of environmental effects. Actually, the ground effects have recently proved to be major sources of hazard in addition to vibratory ground motion. In fact, although a serious source of direct damage, the ground motion is not the only parameter to be considered since most damage is due to coseismic geological effects that are directly connected to the earthquake's source or caused by ground shaking. Primary effects such as surface faulting, regional uplift, and subsidence, and secondary effects such as tsunamis, liquefaction, ground failure, and landslides (sensu ESI 2007 scale) must now be taken into account for a more correct and complete evaluation of seismic hazards at both regional and local scales.

The ESI 2007 scale is a 12-degree scale: each degree reflects the corresponding strength of an earthquake and provides a measure of its intensity on the basis of its characteristics. The main

advantage of the ESI 2007 scale is the classification, quantification, and measurement of several known geological, hydrological, and geomorphological features that are associated with each intensity degree, and therefore it allows for the definition of seismic intensity based on the entire scenario of geological ground effects.

The ESI 2007 scale was promoted by several geologists, seismologists, and engineers coordinated by the Servizio Geologico d'Italia of the Institute for Environmental Protection and Research (ISPRA). This scale has been tested worldwide on several modern earthquakes, historical earthquakes, and paleoearthquakes [2–7].

2. History and Considerations on the Scale and Associated EEs Database

In the early 1990s, I was working at the Italian Nuclear Regulatory Commission (ENEA-DISP), responsible for the safety of nuclear power plants (NPPs) regarding the effects of natural phenomena, with special attention devoted to those caused by earthquakes. During those years, I realized that the earthquake intensity parameter—a significant parameter for evaluating the whole set of potential earthquake effects—lacked its initial and fundamental characteristics, mainly because the people in charge of evaluating intensity were not making proper use of the traditional intensity scales (Mercalli–Cancani–Sieberg, MCS; Medvedev–Sponhauer–Karnik, MSK; and Modified Mercalli, MM). In fact, they were steadily neglecting the effects of earthquakes on the ground (and more generally on the natural environment) which, as is now clearly accepted by all (differently from the 1990s), are responsible for quite a large percentage of earthquake damage.

A clear example of this case is the Japanese Fukushima NPP during the 2011 earthquake, where the effects of ground shaking on the built environment were negligible as opposed to the catastrophic tsunami generated by the surface faulting of the ocean bottom [8].

As a consequence of this bad approach, the publication of the European Macroseismic Scale (EMS-98) [9] appeared, where the ground effects were relegated to an appendix of no real value. As stated above, the non-utilization of ground effects resulted in a complete alteration of the meaning and value of the intensity parameter. For example, assessing intensity without considering ground effects would have made it impossible to compare the intensity associated with past earthquakes to the intensity assigned to recent ones, and this could have led to erroneous conclusions about the seismic hazard in a given territory and therefore for the facilities located therein, with a special emphasis on NPPs. At that time, these intensity evaluators claimed that the use of the ground effects was not possible due to their extreme variability in both time and space, and the absence of a proper ground-effects database from which to derive a reliable description of the effects for each intensity degree. This was partly true considering the incompleteness of the database, but in my opinion was completely wrong with regard to the great variability of the effects, because this was fully comparable to that of man-made structures. Furthermore, the great variability of the ground effects enables the proper estimation of the strongest earthquakes (mainly intensities between X and XII degrees where in most cases the effects on built structures saturate).

It is important to remark that between 1980 and 1990, paleoseismology was developing considerably all over the world, and I was lucky to meet Professor D. Burt Slemmons, one of the few great fathers of earthquake geology, in 1982 when I was engaged in a training course at the United States Nuclear Regulatory Commission in Washington, DC (USNRC). He was a teacher at the Mackay School of Mines in Reno (Nevada, USA). We became good friends and accomplished many missions together in several countries for the International Atomic Energy Agency (IAEA). Through contact with him and his assistants, in particular with Robert E. Whitney, I started, as a pioneer in Europe, to study and publish papers on paleoseismology [10–22]. These papers, some of which are in Italian [10–12,16,17], show how throughout the years the study of paleoseismicity and its application to Italian earthquakes have grown with the aim of carrying out seismic hazard assessments from paleoseismic evidence. The pathway goes from the first studies concerning the Rieti basin [18,19] or the Fucino Plain [20] to the evidence

of strong seismic paleoevents in the “aseismic” zone of Pollino [21], proving the state-of-the-art of paleoseismology in those years.

I also need to say that my interest in paleoseismology was facilitated by the lessons of Giorgio Magri, my Italian supervisor at the Comitato Nazionale Energia Nucleare/Direzione Sicurezza e Protezione (CNEN-DISP). He always repeated to me that it is better to say that mountains grow because of earthquakes as opposed to tectonics.

With the support of paleoseismology, I decided to adopt the approach of producing something useful for the proper reuse of ground effects in intensity evaluation and restoring the intensity parameter to its proper meaning.

The first step was the production of two articles [22,23]. The first was published in *Terra Nova*. In that article, I made an extraction of the ground effects according to the various degrees as reported in the MCS, MSK, MM, and Japanese scales. The main goal was to remind the intensity evaluators that ground effects are massively included in the historically most-applied intensity scales (MCS, MSK, and MM) from the beginning of their conception. The second one was written to present the idea to a very broad international audience during the special session of the International Union of Geological Sciences (IUGS) Congress held in Beijing in 1996. The simple database, presented in [22], was the “seed” of the huge plant that later gave rise to the ESI scale. I must remind current users that it should be used in conjunction with one of the other traditional scales in order to avoid the same mistake made in the 1990s by the intensity evaluators concerning built structures, that is, the lack of consideration for the entire set of earthquake effects when assessing intensity. It can be used alone only for higher degrees and in the case of sparsely populated areas. It can also be used to verify the intensity of past earthquakes in cases where the intensity was evaluated not using the ground effects properly. As said above, the seeds started to sprout, and the two roadmaps were the initial drafts of the ESI scale and the construction of the associated database.

Regarding the ESI scale, the steps have been as follows:

1. The collection and careful reading of published and unpublished papers and documents dealing with the same objective, first among them: [24]. I think we have to be very grateful to these authors because they opened the road for using ground effects in earthquake intensity evaluation.
2. The presentation of the drafted ESI content at conferences at national and international levels (i.e., [25–28]) and the continuous discussion of the content at national and international levels with the involvements of numerous well-known international experts, to whom I am truly grateful. Among them, special mentions (also due to our friendship) are to be given to:
 - Bagher Mohammadioun and his wife Jody. Bagher is a well-known seismologist [27] who for many years headed the Bureau d’Évaluation du Risque Sismique pour la Sûreté des Installations Nucléaires at the Institut Radioprotection Sureté Nucléaire (IPSN) of France;
 - Ruben Tatevossian (seismologist) and Eugene Roghozin (geologist)—two well-known Russian scientists with great experience concerning macroseismic data and paleoseismology [24];
 - Aybars Gurpinar, a civil engineer who for many years has been the Director of the Nuclear Installation Safety Division at the IAEA, with great worldwide experience on seismic hazards in relation to NPP sites [29];
 - Frank Audemard, a Venezuelan paleoseismologist with great experience, mainly in seismically-active South American countries [30];
 - Shmulik Marco, a well-known Israeli paleoseismologist and author of significant papers on the subject [31];
 - James McCalpin, author of the international benchmark book titled *Paleoseismology* [32];
 - Nils-Axel Mörner, a Swedish geologist with a broad field of experience, including in paleoseismology [33];
 - John Clague, a Canadian authority in quaternary and environmental earth sciences [34];

- Yoko Ota, also a geologist with great knowledge of the earthquake geology of Japan [35];
- Takashi Azuma, a geologist with significant knowledge of paleoseismology in Japan [35].

The first version of the new macroseismic scale was published in 2004 [36], and the second in 2007 [1]. The scale was very well accepted worldwide, and a huge number of papers dealing with the use of this scale have been produced since then across the five continents [1–7,37–48].

Thanks to the kind insistence of my collaborators, the version integrated with three historical cases and with my name as the first author was published in 2015 [49]. Therefore, based on several years of worldwide application in the field, in this paper: (a) we introduced the ESI scale to the community of earth scientists (geologists, geophysicists, and seismologists) and civil engineers as a survey instrument to better characterize a seismic event, also in terms of local effects and attenuation with distance, and (b) we provided insurers, civil protection agencies, and administrators with an integrated tool to assess the potential damage deriving from geological effects during a future earthquake in an area, to be added to the damage directly associated to seismic shaking. Presently, this scale is also going to be used officially by some institutions (e.g., in Georgia) dealing with seismic hazard evaluation, and I hope this practice will also be adopted by other institutions. In fact, a seismic hazard is often underestimated because it is based on lower intensities than the ground environmental effects (e.g., earthquakes of $M_w > 7$ have been associated to $I = X$), which are instead considered in the ESI scale.

I also think it is important to remark that seismic hazard assessment (SHA) would benefit from a comprehensive consideration of all earthquake-related effects, including environmental ones. The key role of the ESI scale use to SHA is the improved intensity assessment. It is also necessary in order to preserve the consistency between the source parameters assessed for historical earthquakes and for recent ones. The basic message is that despite the advent of magnitude, earthquake intensity persists as a fundamental seismic parameter for reliable SHA, especially when EEEs are properly taken into account.

The EEE Catalogue is a database containing information on earthquake effects on the environment [50]. Such information includes the effects of recent earthquakes but also data derived from historical and paleo-earthquakes. The objective of this database is to procure data to be used for the present and future updating of the ESI scale. This worldwide database was initially created in the framework of the International Union for Quaternary Research (INQUA) activities. The web infrastructures were developed by ISPRA—the Geological Survey of Italy. In 2007, the first access-type database including around 20 events was created. This first online structure was presented in the Bern (Switzerland) INQUA Congress in 2011 [50]. Thanks to its online structure, recent, historical, and paleo-earthquakes' environmental effects data were subsequently uploaded to this database, provided by worldwide authors. It currently includes data on around 200 events (http://193.206.192.211/wfd/eee_catalog/viewer.php). Since 2012, the EEE catalogue has been accessible online on the websites of the IAEA and the International Seismic Safety Center (ISSC). It is important to note that the IAEA, in the wake of the disastrous Tohoku 2011 tsunami, has recommended that member states should carefully consider earthquake ground effects—and, more generally, paleoseismological data—in order to achieve a better definition of the seismic hazards in areas where nuclear installations are already installed.

Finally, it is important to recall the numerous papers published worldwide recognizing the importance of this catalogue. Among them is the ISPRA volume published in 2015 [51], a significant monograph that reports the description of the ESI scale in ten languages (English, Italian, Spanish, French, German, Japanese, Russian, Greek, Dutch, and Korean).

Currently, the Italian National Institute of Geophysics and Volcanology (INGV) has also finally recognized the importance of the environmental effects induced by earthquakes by including them in their new seismic catalogs [52].

Together with the EEE database, the Italy HAZards from Capable faults (ITHACA) database born from an idea of Eutizio Vittori. It includes the current knowledge on capable faulting in Italy, to which

paleoseismological studies widely contribute. At present, this continuously updated catalogue is used for the revision or planning of new infrastructure and microzonation purposes in the whole territory of Italy [53,54].

It is important to underline that, globally, there are very well-organized similar catalogues of active faults, such as the one proposed for the USA by the United States Geological Survey (USGS) (<https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=5a6038b3a1684561a9b0aadf88412fcf>) and another for Central Asia organized by the University of Tübingen (<https://esdynamics.geo.uni-tuebingen.de/faults/>).

In conclusion, I strongly hope that the institution where I worked (currently named ISPRA) will continue our efforts to maintain the databases quoted above and soon release an update of the ESI scale based on the wealth of information gathered in recent seismic events worldwide.

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