DOI 10.4430/bgta0205

Extensive application of seismic microzoning in Italy: methodological approaches and socio-political implications

D. Albarello

Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università degli Studi, Siena, Italy

(Received: August 1, 2017; accepted: September 24, 2017)

ABSTRACT Italian scientific and technical communities are developing an integrated feasible approach to seismic hazard assessment based on the strict cooperation with local authorities and trained practitioners also operating locally. This approach has a number of implications (technological, pedagogical, and political) and its potential effectiveness (or failure) will also depend on the capability of involved communities (be they small or large) to promote and support preventive actions, taking advantage of the experience acquired in these activities. Without this bottom-up approach involving local communities directly, it will be difficult for our society to cope with future potentially disastrous events.

Key words: microzonation, Italy.

1. Introduction

One of the major goals of seismological research is providing information about future earthquakes and promoting preparedness of local communities (small and large) to cope with their possible effects. Beyond adopting effective rules for anti-seismic design of new buildings, coping with the effects of future earthquake requires:

- planning and supporting building retrofitting, focusing on the most critical situations;
- developing anti-seismic city plans aimed at reducing the level of exposure in the most hazardous areas;
- developing emergency plans tailored to the specific situations in the area of concern.

All these actions are costly (both in terms of direct costs and lack of revenue due to limitations in land use) and require a long time to be completed. To be affordable and sustainable, such activities therefore require the consensus of the local communities, political authorities, and stakeholders involved. This implies that hazard assessment cannot merely be considered a scientific problem and its considerable political and social implications should not be ignored by those scientists and technicians involved in the assessment.

In general, hazard assessment for planning purpose is performed at a "national" scale (Fig. 1). This kind of estimate takes into account the distribution and level of activity of seismogenic sources and of long-range seismic wave propagation patterns. On the other hand, seismic hazard is inherently «local» since events are essentially experienced at the scale of small communities. This is especially true in countries such as Italy, where there are numerous distributed settlements,

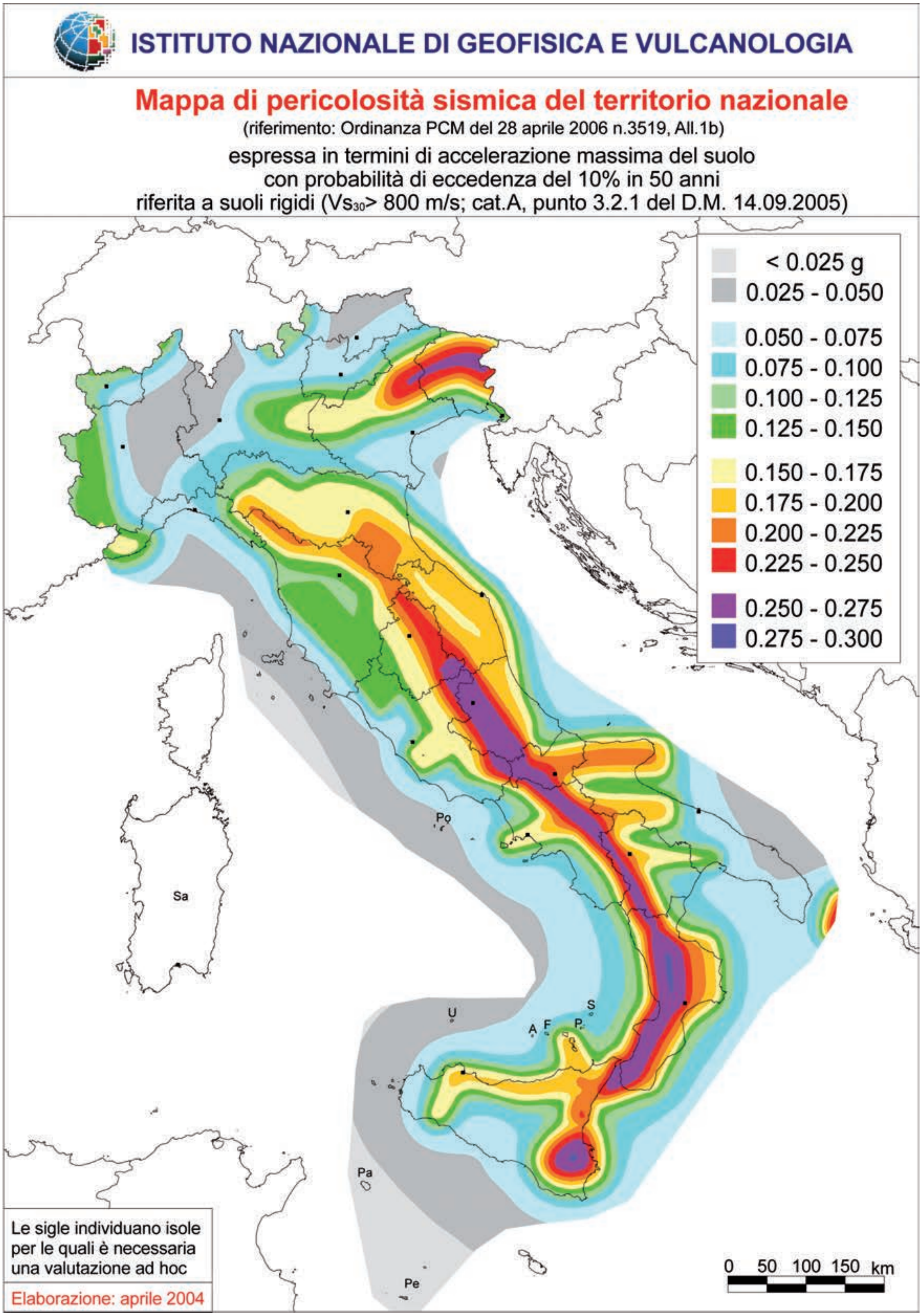

Fig. 1 - Seismic hazard map of Italy (http://zonesismiche.mi.ingv.it/mappa_ps_apr04/italia.html).

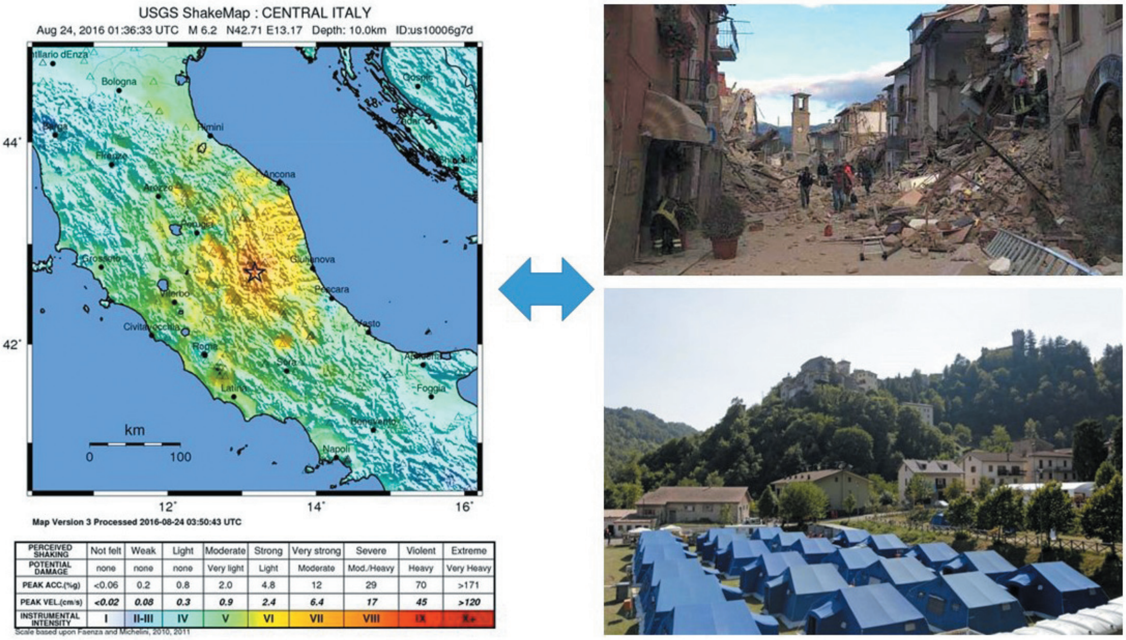

Fig. 2 - Two different scales of views of the same earthquake. On the left: shake map of the first (August 24) strong event of the 2016 seismic sequence in central Italy (https://earthquake.usgs.gov/earthquakes/eventpage/us10006g7d#executive). On the right: images of the 2016 earthquake effects in Amatrice (central Italy).

each being relatively small and having a strong historical identity. This more local perspective on seismic hazard should not be ignored by scientists, who, instead, tend to have a global view of earthquakes (Fig. 2). Along with other issues related to public communication (e.g., Albarello, 2015; Albarello *et al.*, 2015), this may hamper the correct communication of hazard to those communities exposed to future earthquakes.

Recent experiences in Italy have highlighted that hazard is «local» also from the seismological point of view (Fig. 3). It is well known that small-scale spatial heterogeneities in the seismic wavefield are the effect of seismic waves interacting with «local» geo-morphological and seismo-stratigraphical features (e.g., Kramer, 1996). Two groups of effects can be expected respectively in relation to stable and unstable soil conditions. The first group concerns transient phenomena (e.g., seismic resonance) that can enhance the local seismic ground motion. The second group includes induced soil instability, with permanent effects on the ground configuration (landslides, liquefaction, etc.).

Amplification under "stable conditions" is the effect of the interference of seismic waves (mainly V_s phases) trapped within geological bodies bounded by large seismic impedance contrasts (soft soil/bedrock, soil/free surface, etc.) irrespective of the absolute impedance values. The dimension of geological bodies and discontinuities to be analysed for characterizing the relevant phenomena, are of the order of the seismic wavelengths generating resonance effect on man-made structures. For V_s values of a few hundred m/s (typical of shallow subsoil) and natural period of structures of the order of 1 s, the features and volumes with dimensions of the order of hundreds of metres are of main concern. Similar considerations hold for earthquake induced instabilities.

Thus, to be useful, hazard assessment should focus on the huge number of small-medium sized villages (thousands of inhabitants) and small towns (less than a hundred thousand inhabitants)

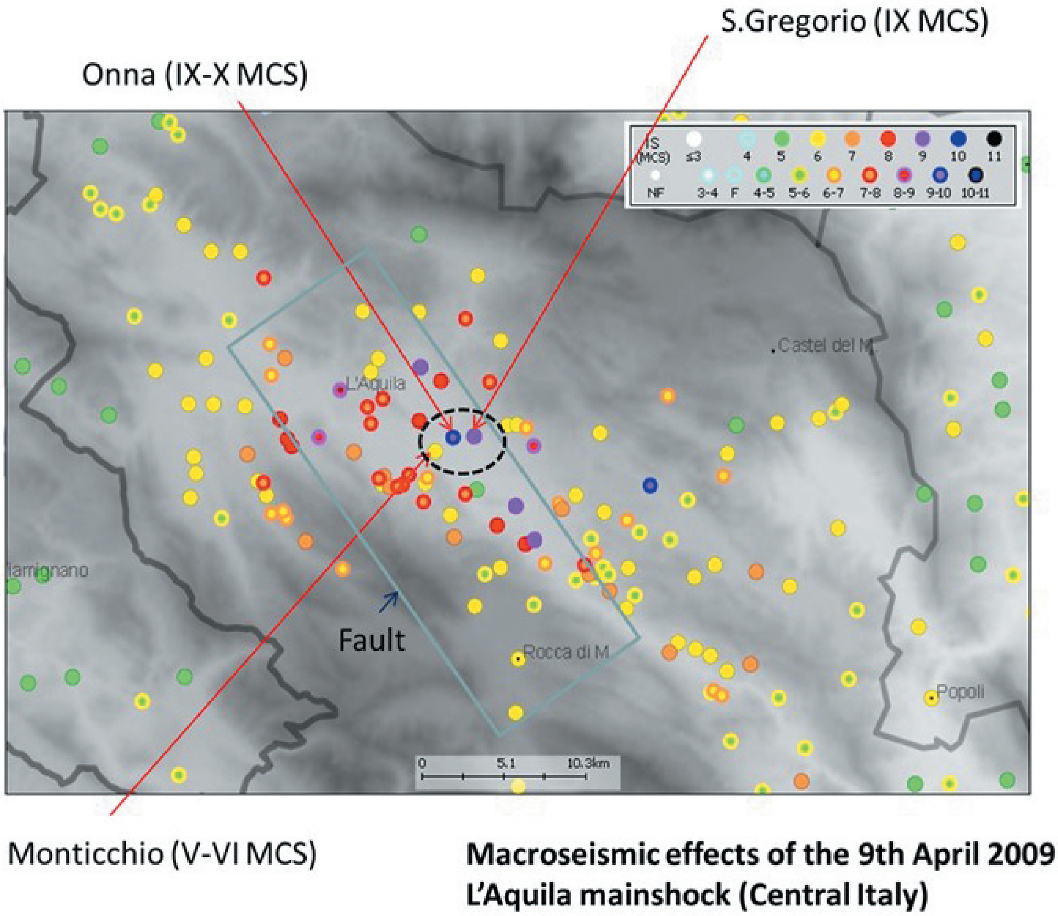

Fig. 3 - Macroseismic effects of April 9, 2009 L'Aquila (central Italy) earthquake (modified from Kouris *et al.*, 2010). The grey rectangle indicates the surface projection of the fault presumably responsible for the earthquake. Arrows indicate three sites (very close with respect to the source dimension) where significantly different levels of damage were observed despite a similar vulnerability level of local buildings.

that characterize the Italian (and European) territory. The basic political and administrative "unit" of these settlements is the municipality (more than 8100 in Italy): at this scale, prevention actions can be managed only if local residents are directly involved and made aware of the actual hazard level. It is worth noting that such a «local» hazard assessment (Seismic Microzoning) is inherently different from the typical Seismic Response Analysis of seismic codes (e.g., EC8, 2003; NTC, 2008). In fact, Seismic Microzoning is extensive in nature since it focuses on entire settlements (while Seismic Response Analysis is intensive, focusing on single buildings). On the other hand, Seismic Microzoning represents a basic tool for planning prevention activities and land management and does not aim (at least not primarily) to support the design of single structures. This suggests that Seismic Microzoning requires specific methodologies and approaches to warrant its feasibility and effectiveness. In particular, it must:

- be cost effective (to be applied over wide areas);
- be operated by experts professionals and public authority/municipal technicians (one cannot expect that Academic and Research institutions should be responsible for this task when thousands of settlements are involved);

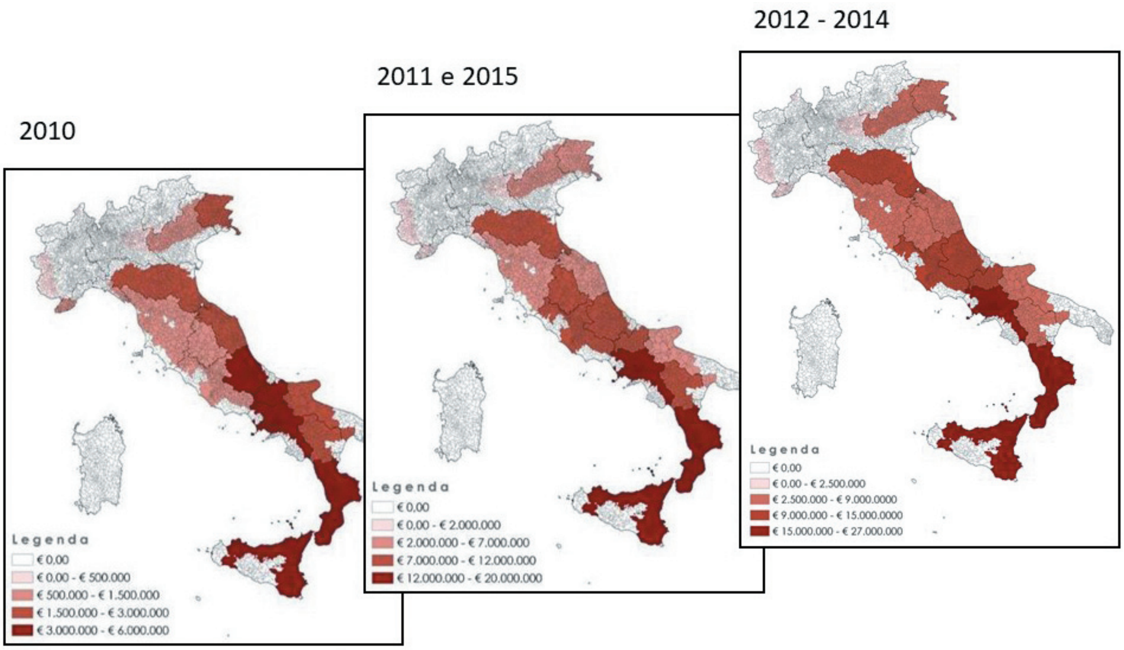

Fig. 4 - Allocation of funds (in Euros) supporting local authorities in providing Seismic Microzoning Studies in different years (courtesy of the Italian Civil Protection Department).

- be technically effective (main expected phenomena must be determined in the analysis);
- provide outcomes that are useful for seismic risk reduction and effectively applicable in city management and emergency planning.

In 2010, the Italian Government promoted a large multiannual project to improve the resilience of Italian settlements. The basic idea combines a top-down financial support to stimulate a bottom-up approach to seismic defense involving local authorities. Extensive seismic microzoning of a large part of the Italian territory, i.e., the development of numerous local hazard maps at the scale of the single municipalities, is the key tool of this project. Assuming that the safety of all citizens deserves the same attention, the project does not focus on major settlements alone, but adopts a generalized approach by supporting all local communities interested in the project.

2. The Italian Seismic Microzoning Program

The project is characterized by five basic elements. First, each single municipal administration is considered institutionally responsible for seismic microzoning. This local institution is the backbone of Italian historical identity and, above all, rules land use, provides city planning and emergency organization. Furthermore, since in the overall organization of the Italian Republic this institution is the closest to citizens, entrusting local government (the municipality) with microzoning activity ensures a more direct participation of inhabitants in prevention activities also by improving their awareness about seismic risk. This also implies that microzoning will be performed by local technical bodies or trained practitioners working in the area.

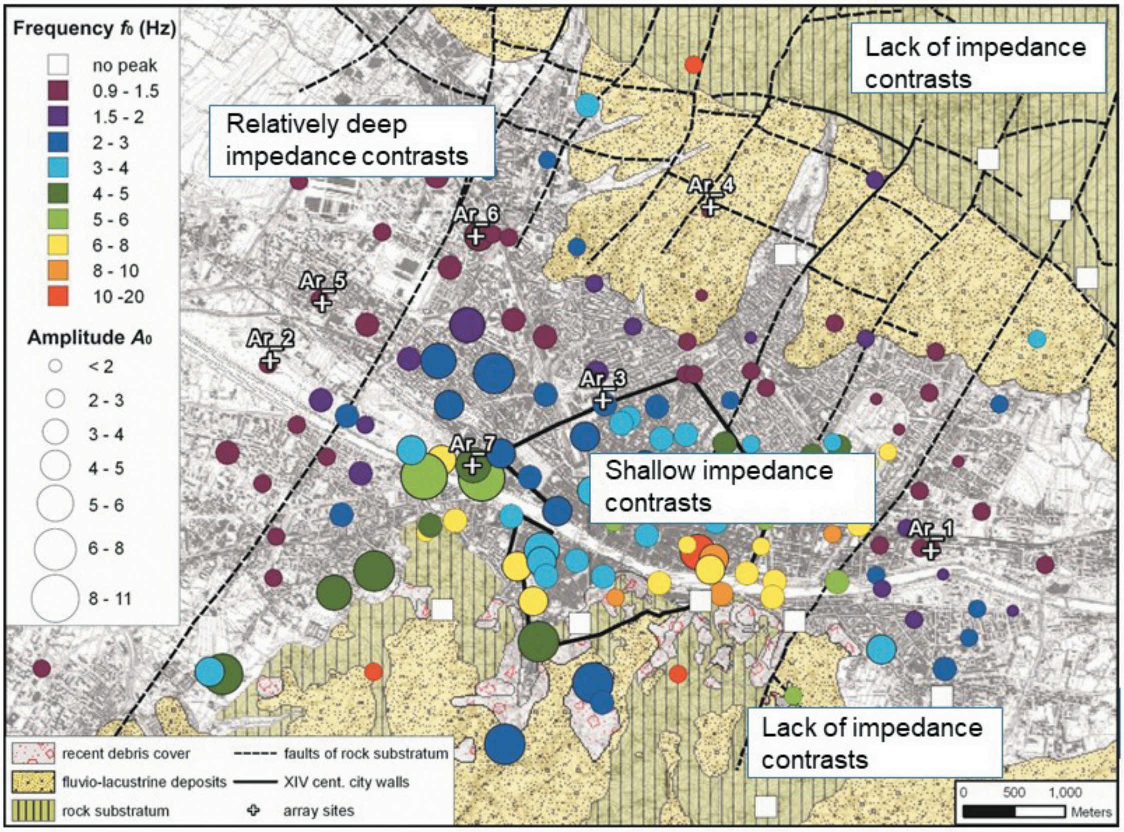

Fig. 5 - An example of H/V survey in the Florence municipality (modified from D'Amico *et al*., 2008).

Second, a multi-year (7 years) financial program (about 10^9€ as a whole, including contributions for retrofitting) has been allocated by the central government to co-finance microzoning activities of single municipalities. Financial allocation of resources is graduated by taking into account the seismic hazard level of the Italian area (Fig. 4). This financial organization represents the top-down lever for stimulating local communities to participate in prevention activities. On their side, local administrations are requested to contribute financially to this action by drawing funds from the local budget or from funds made available by regional administrations (higher-level administrative structures providing general rules for land use to be adopted by municipal authorities). These funds can be used only in the case that outcomes of seismic microzoning are actually implemented in city planning and land use rules. In the global 7-year plan (2010-2016), 3896 municipalities where preliminary identified as of upmost importance based on the reference hazard map. The actual distribution of funds among the single municipalities, however, is negotiated with regional authorities.

Third, high-level scientific institutions are identified and coordinated in the frame of a single 'Centre for Seismic Microzoning and Applications' (https://www.centromicrozonazionesismica.it/) that is responsible for training and assisting practitioners and local administrations in performing and checking microzoning studies.

Fourth, common guidelines are defined by central administration and implemented by regional authorities to be used by trained practitioners in charge of field activities. These "Guidelines" represent the technical component of the plan and resulted from a general agreement among National (Civil Protection Department) and regional authorities, scientific community (research centres, universities) and national associations of practitioners (geologists, engineers, architects). These were first released in 2008 and then integrated in 2010 and 2011 with adjustments resulting from ongoing experiences (WGSM, 2008; WGSMLA, 2010; Various Authors, 2011). The key element of these guidelines is the multi-level nature of planned microzoning activities. In particular, three levels are identified, each characterized by growing complexity and commitment (and financial efforts). Specific outcomes are expected from each level. This organization allows graduating field activities with respect to available resources, specific goals and possible presence of local criticalities. Some details concerning the structure of these guidelines are reported in the following section.

Fifth, all microzoning studies including the relevant database of collected information, are evaluated by the National Civil Protection that also certifies their scientific validity before their implementation in local land use rules. This implies that a large public database of geological, geotechnical and seismological information is established where the relevant information is collected and stored permanently. This database will represent an important basis for future and more advanced studies that can take advantage of the extensive collection of previously dispersed data.

3. The practice of seismic microzoning

As above mentioned, and in line with other experiences (e.g., TC4, 1999), a key element of these guidelines in the multi-level character of planned activities.This organization allows graduating field activities as a function of available resources, specific goals and possible presence of local criticalities. Aims and outcomes of each level is shortly outlined below (see, also Albarello *et al.*, 2015).

3.1. Level I: propaedeutic

The aim is to construct a reference geological model that is specifically oriented to seismic phenomena. Fundamental is the use of low cost extensive prospecting tools (small-scale geological/geomorphologic surveys, ambient vibration measurements, etc.) and the thorough exploitation of data stored in national and municipal archives (drillings, geologic maps from city plans or single building design, etc.).

The main outcome of this first level is a digital database of retrieved data and a map where the zones characterized by the expected occurrence of similar co-seismic phenomena are identified (Seismically Homogeneous Microzones). In particular, three possible situations are of major concern:

1. stable areas where no ground motion amplification effect is expected;
2. stable areas where stratigraphical or morphological amplification effects are expected only: these areas are then differentiated in relation to the local stratigraphic log;
3. unstable areas where permanent soil deformations are considered as possible (liquefaction, landslides, surface faulting, etc.).

This map (an example is given in Fig. 6) is generally accompanied by geological sections

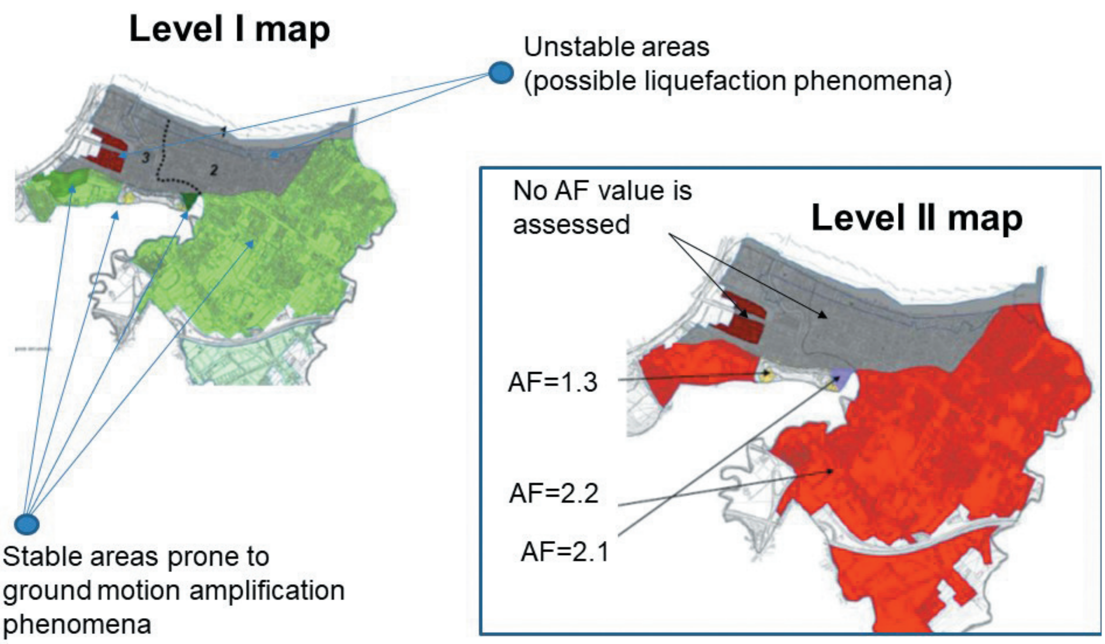

Fig. 6 - Typical outcomes of Level I (on the left) and Level II (on the right) microzoning studies by following the Italian guidelines of seismic microzoning (WGSM, 2008). AF indicates the amplification factor (see text for details).

where major buried seismic impedance contrasts are tentatively identified. The basic tools for developing Level I maps are:

- intensive reappraisal of available information (borehole data, geological mapping, etc.) to be standardized and stored in the comprehensive geographical database;
- targeted/Planned/Specific geological/geomorphological surveys (1:5000-1:10000);
- "fast and cheap" geophysical surveys.

In this last context, single station ambient vibration measurements (NHV technique) play a major role in detecting the presence of possible resonance phenomena and roughly estimating the depth of resonant interfaces. Very rough semi-qualitative estimates are supplied to geologists by results allowing to check the presence of resonance phenomena, and roughly evaluating the importance and depth range of impedance contrasts that are potentially responsible for them (Fig. 5). The end result is not a "true" microzoning but in any case represents a mandatory step for planning more accurate investigations where necessary and discard other areas (Levels II and III). These maps are checked by the central authority (Civil Protection Department) and then implemented by local administrations.

3.2. Level II: simplified quantitative evaluation of expected effects

This level aims at improving Level I maps by adding quantitative estimates of expected amplification effects. These values only concerns areas where 1D stratigraphical amplification phenomena or morphological effects are expected. These numerical values are supplied in the form of integral spectral parameters [amplification factors (AF)] relative to fixed frequency ranges and cannot be used for planning (Fig. 6).

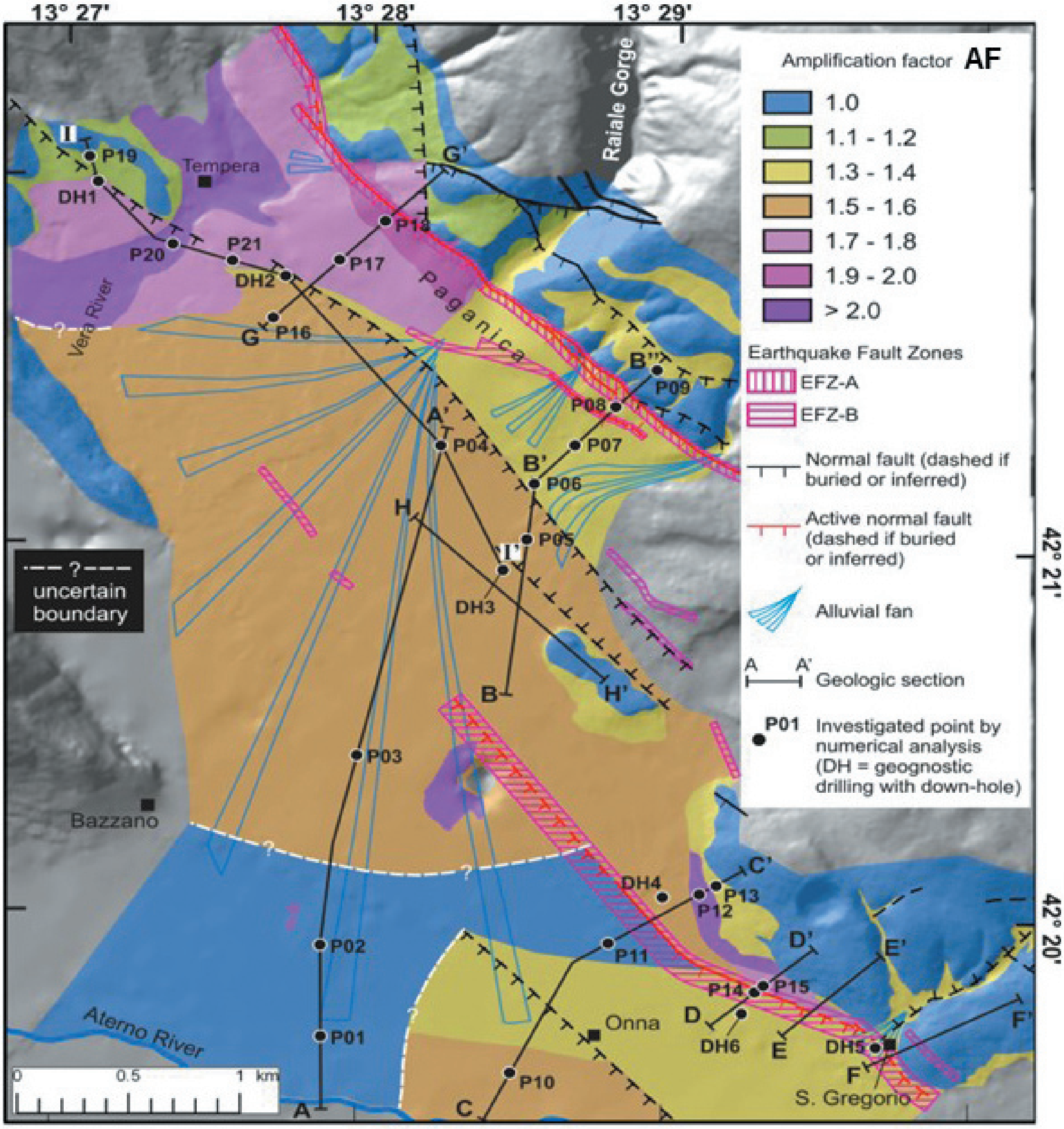

Fig. 7 - Typical outcome of Level III microzoning by following the Italian guidelines for seismic microzoning (WGSM, 2008).

The evaluation of AF values would need 1D numerical modelling accounting for non-linear behavior of soils. These computations are expected to require extensive borehole sampling and laboratory analyses that individual municipalities cannot currently afford with the resources actually available. To face this difficulty, regional administrations (governing several municipalities) provide (with the help of research centres) specific tools (abacuses) allowing practitioners to compute AF values on the basis of a restricted set of parameters that can be obtained by relatively cheap surface measurements. In this frame, the key element of Level II microzoning is the estimate of the average V_s values of the shallowest geological bodies (tens of metres) inside the microzones where 1D seismic amplification effects are expected (see, e.g., Peruzzi *et al.*, 2016).

Seismic prospecting techniques both in active ("light" SH refraction, MASW) and passive (ESAC, SPAC, etc.) techniques (see, e.g., Foti *et al.*, 2011) are of major concern along with more expensive (and thus less applicable) borehole measurements (Down-Hole or Cross-Hole). However, since average Vs values are of concern only, simplified approaches can also be defined that do not require troublesome inversion procedures providing weakly constrained Vs profiles (see, e.g. D'Amico *et al.*, 2008; Albarello and Gargani, 2010; Albarello *et al.*, 2011). Abacuses (also determined via intensive numerical simulations) are also supplied to evaluate morphological effects.

3.3. Level III: complex situations

This level of analysis concerns two kinds of specific situations (both detected at the previous levels of analysis) relative to a portion (hopefully small) of the considered area where:

1. abacuses are not applicable because the local situation is not contemplated or where the presence of sharp and strong lateral seismic impedance contrasts the application of 1D abacuses unreliable;
2. permanent deformations are expected due to landslides, liquefaction, surface faulting etc.

In these cases, new geotechnical information is required along with a detailed reconstruction of 2D-3D geometries in the subsoil. Fast-and-cheap approaches become unfeasible and detailed numerical analyses are required along with intensive (and expensive) laboratory testing of drilled samples. High-level expertise is required and specialists coming from research institutions or major geotechnical engineering companies come into play. It is worth noting, however, that these analyses (representing a "true" seismic response analysis) should concern small portions of the inhabited areas. As an example, according to Italian legislation, the presence of active landslides actually prevents the use of the considerable areas for housing or industrial plants. The application of Level III studies complete the seismic microzoning of the relevant municipality (Fig. 7). This information is implemented in land use plans and city plans that are the basis for preventive actions (re-location of critical facilities, identification of structures most prone to possible damage and urgently requiring retrofitting, etc.).

4. Conclusion

In the global 7-year plan (2010-2016), 3896 municipalities were preliminary identified as of upmost importance based on the reference hazard map (PGA≥0.125 g for a 10% exceedance probability in 50 years). As at September 1, 2016, 2097 studies have been planned**,** 1115 studies have been completed (mostly Level I)**,** and 982 studies are currently underway (Fig. 8). Beyond these outcomes, dependent also from the heterogeneities of management capability of local administrations, important results have been however obtained.

First of all, a large number (several hundreds) of regional and municipal authorities and experts have been involved in microzoning and the communities were made aware of seismic hazard in their village or town. Moreover, several hundreds of practitioners (mainly professional geologists) and volunteers have been trained in microzoning studies and seismic hazard assessment. These now more aware citizens and technicians represent a well-distributed "presidium" that will prove of great help in supporting activities devoted to seismic risk reduction.

Furthermore, a coherent methodological protocol (Guidelines for Seismic Microzoning) has been established and tested in the field. New field procedures and experimental tools have been developed and (more importantly) disseminated. This outcome has been the result of a permanent and close cooperation between academic and non-academic technical bodies, allowing the fruitful match between scientific knowledge and real application: both research and practice will be able to take advantage of this major methodological effort. A key element of the adopted microzoning approach is its gradualism. This has ensured its widespread applicability but has also meant that, in most cases, only Levels I and II (at most) assessment have been performed. This may be considered unsatisfactory due to the qualitative or semi-qualitative nature of these studies. However, what is best? Having a detailed quantitative knowledge about local hazard for a few important towns or providing rough but effective hazard evaluations that are well distributed over hundreds of settlements? Which has the greatest potential impact?

Finally, these studies allow gathering countless pieces of standardized information that are currently dispersed in a number of local archives (both public and private). The implementation of these data in a geographic database (as required in the Level I microzoning) to be transmitted to Civil Protection Department responsible for their validation, enables creating a large public repository of georeferenced geological/geophysical/geotechnical data that will represent a resource of great importance for future studies.

REFERENCES

Albarello D. and Gargani F.; 2010: *Providing NEHRP soil classification from the direct interpretation of effective Rayleigh waves dispersion curves*. Bull. Seism. Soc. Am., **100**, 3284–3294, doi: 10.1785/0120100052.

Albarello D., Cesi C., Eulilli V., Guerrini F., Lunedei E., Paolucci E., Pileggi D. and Puzzilli L.M.; 2011: *The contribution of the ambient vibration prospecting in seismic microzoning: an example from the area damaged by the 26th April 2009 l'Aquila (Italy) earthquake*. Boll. Geof. Teor. Appl., **52**, 513-538, doi: 10.4430/bgta0013.

Albarello D., Socco V.L., Picozzi M. and Foti S.; 2015: *Seismic hazard and land management policies in Italy: the role of seismic investigations*. First Break, **33**, 87-93

Albarello D.; 2015: *Communicating uncertainty: managing the inherent probabilistic character of hazard estimates*. In: Peppoloni S. and Di Capua G. (eds), Geoethics: the role and responsibility of geoscientists, Geological Society, London, Special Publications, 419, pp. 111–116, http://dx.doi.org/10.1144/SP419.9.

D'Amico V., Picozzi M., Baliva F. and Albarello D.; 2008: *Ambient noise measurements for preliminary site-effects characterization in the urban area of Florence*. Bull. Seism. Soc. Am., **98**, 1373–1388, doi: 10.1785/0120070231.

EC8 (Eurocode 8); 2003: *Draft prENV 1998-1 Jan 2003, Design of structures for earthquakes resistance. Part 1: general rules, seismic actions and rules for buildings (draft no 4)*. European Committee for Standardization, Brussels.

Kouris L.A.S., Borg R.P. and Indirli M.; 2010: *The L'Aquila earthquake, April 6th, 2009: a review of seismic damage mechanisms,* COST ACTION C26: Urban Habitat Constructions under Catastrophic Events, Proceedings of the Final Conference, pp. 16-18.

Kramer S.L.; 1996: *Geotechnical earthquake engineering*. Prentice Hall, New York, 653 pp.

NTC; 2008: *Norme Tecniche per le Costruzioni*. DM 14 gennaio 2008. Gazzetta Ufficiale, n. 29 del 4 febbraio 2008, Supplemento Ordinario n. 30. Istituto Poligrafico e Zecca dello Stato, Roma (in Italian), available online at the website www.cslp.it.

Peruzzi G., Albarello D., Baglione M., D'Intinosante V., Fabbroni P. and Pileggi D.; 2016: *Assessing 1D seismic response in microzoning studies in Italy*. Bull. Earthq. Eng., **14**, 373–389, doi: 10.1007/s10518-015-9841-z

TC4 (Technical Committee for Earthquake Geotechnical Engineering); 1999: *Manual for Zonation on Seismic Geotechnical Hazard. Revised edition,* Technical Committee for Earthquake Geotechnical Engineering (TC4) of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), 209 pp.

Various Authors; 2011: *Contributi per l'aggiornamento degli "Indirizzi e criteri per la microzonazione sismica",* Ingegneria sismica, 28, 2, Patron editore Bologna, Italy, (in Italian) available on line at the website http://www.protezionecivile.gov.it/resources/cms/documents/aggiornamento_indirizzi_microzonazione_sismica.pdf.

WGSM (Working Group on Seismic Microzoing); 2008: *Indirizzi e criteri per la microzonazione sismica*. Conferenza delle Regioni e delle Province autonome – Dipartimento della Protezione Civile, Roma, 3 vol. e DVD, (in Italian) available online at the website http://www.protezionecivile.gov.it/jcms/it/view_pub.wp?contentId=PUB1137, English version at http://www.protezionecivile.gov.it/httpdocs/cms/attach_extra/GuidelinesForSeismicMicrozonation.pdf?.

WGSMLA (Working Group on Seismic Microzoning the L'Aquila Area); 2010: *Microzonazione sismica per la ricostruzione dell'area aquilana*. Regione Abruzzo, Dipartimento della Protezione Civile, 3 vols and dvd, 796 pp. (in Italian), available online at the website http://www.protezionecivile.gov.it/jcms/it/view_pub.wp?contentId=PUB25330.

Corresponding author: Dario Albarello
Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università degli Studi di Siena
Via Laterina 8, 53100, Siena
Phone: +39 0577 233725; e-mail: dario.albarello@unisi.it