Seismic Microzoning in Italy: A Brief History and Recent Experiences

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SUMMARY – *In an attempt to develop a diffuse culture of prevention against earthquakes, the Italian government has issued an Act (June 24 2009 n. 77) and subsequent ordinances which regulate the distribution of resources to those regions that promote studies of seismic microzoning (SM). As a result, during the last years the number of Italian SM studies has been increasing and posing many new problems and challenges to administrators and scientists. The aim of this paper is to illustrate, through some salient examples of recent SM cases in Italy, the emerging philosophy of a new current of SM studies that can be called ordinary, namely projects devoted to seismic risk reduction through the usual preventive activities that can be carried out by local governments with the contribution of local officials and professionals, to the maximum extent possible. While the SM studies are generally elaborate, slow and costly, the logic of ordinary SM projects is that they have to be performed smoothly, rather quickly and cheaply. The aim is not to obtain the best SM product at any price but the best SM project consistent with efficient administrators who really want to reduce seismic risk in their regions.*

In order to reach this objective and to guarantee the quality of the products, local governments (regions, provinces and municipalities) now have new duties; that is, they must undertake, in conjunction with scientists and researchers, positive actions to improve the state of knowledge and of practice in seismic risk reduction in the region, to increase the number and technical capacities of local professionals and public officials, to reduce time and investigation costs through drawing up basic geological maps also in digital format at an appropriate scale for SM, issuing specific valuable SM guidelines, implementing digital models of the territory, creating regional seismological, geological and geotechnical data banks, controlling the accuracy of the obtained SM maps and so on.

The paper focuses on unprecedented problems posed by the new legislation also to scientists and researchers, who are now called by administrators and public officials to play different scientific roles than in the past in order to contribute to advancing the frontiers of knowledge as well as the state of practice through experience transfer and applications.

Keywords: Seismic microzoning, Site effects, Soil amplification, Landslide hazard, Soil liquefaction.

1. Introduction

As is well known, during an earthquake, because of local conditions, the values of peak ground acceleration recorded at the various sites in a given territory are generally different from those recorded in a flat rocky site of reference. But it is possible also to observe that in some areas these values do not differ much from each other. Therefore it is possible to identify within that territory some homogeneous zones. As Figure 1 shows, the ratio H/V between horizontal and vertical accelerations on rock has a flat trend while on alluvial soils it has a peak of amplitude which corresponds to the fundamental frequency $f_0 = V_S / 4H$ (V_S being the shear wave velocity and H the thickness of the deposit) and depends on impedance contrast between deposit and bedrock.

Notoriously, seismic microzoning (SM) is the scientific operation which has as its objective the identification of homogeneous zones in terms of local response to a reference earthquake, taking into account the interactions between seismic waves and the local geological, topographical and geotechnical conditions that modify the basic hazard (i.e., the hazard evaluated on a flat hard ground). In the seismic language hazard is generally expressed in terms of maximum acceleration in a given interval of time.

The identification of these areas demands that complex scientific studies are made. But SM is not only a scientific operation. SM has a social dimension, because the knowledge of the responses of the various sites is a prerequisite for decision making in a given seismic territory. The results of a study of SM are of great importance in regional and urban planning: to guide the choice of new settlements and infrastructures, to establish eligibility and priorities of interventions, to identify scenarios of hazard to a larger scale than that of the single building, to plan emergency and finally, in post-earthquake reconstruction.

In Italy, SM studies have a long history. The problem of the influence of the site on the damage caused by an earthquake was identified after the Messina earthquake in 1908. On that occasion, it was officially stated that it was not possible to rebuild buildings lying *'on sites located above or near fractures, landslides or potentially sliding slopes'*. But also during many other Italian

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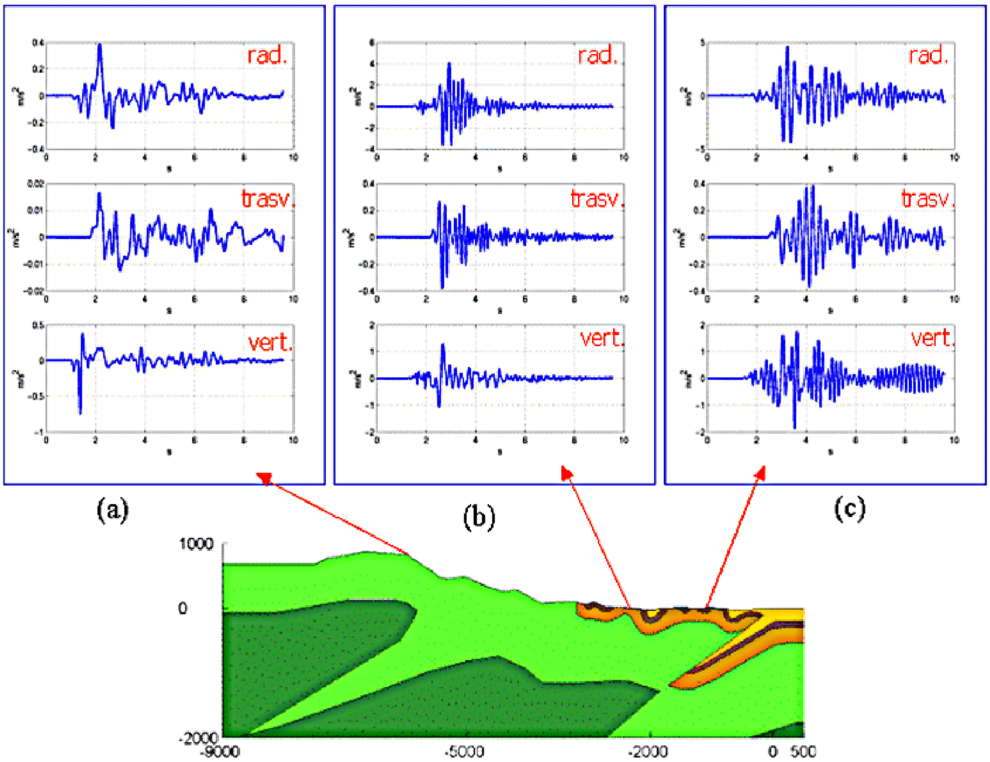


Fig. 1. *Different seismic responses obtained in various sites of Cagli, Italy (from Priolo and Laurenzano, 2004).*
Differenti risposte sismiche ottenute in alcuni siti di Cagli, Italia (da Priolo e Laurenzano, 1004).

earthquakes (Friuli, 1976; Irpinia, 1980; Umbria Marche, 1997; L'Aquila, 2009; Emilia-Romagna, 2012) it has been observed that a main cause of damage was unfavourable site conditions. Due to its complex morphology and geology the whole country is prone to 1-D or 2-3 D or topographic effects. Each region has its own problems of seismic and non-seismic hazards (landslides, rock falls, liquefaction, subsidence, etc). Moreover, Italy has very high density of habitants, of ancient villages, monuments, very often situated on dangerous sites, that are exposed to severe earthquakes (Figure 2). Therefore, SM is an essential measure of prevention.

However, although for over 40 years SM has been considered by scientists and researchers to be one of the most effective preventive measure against earthquakes and many advanced studies have been conducted on this topic, only recently has this issue become the subject of ~~a~~ public debate on a national scale which involves not only researchers but also public administrators and professionals.

2. The Italian governmental legislation for SM studies

One of the main reasons why discussion on SM studies has arisen is the issue of a government Act (June 24 2009 n. 77, art. 11) that provides for a multi-annual programming through specific ordinances (OPCM n. 3907/2010, OPCM n. 4007/2012, OCDPC n. 52/2013) to regulate the distribution of resources to those regions which promote SM studies for seismic risk reduction.

With this important legislative initiative the Italian government has invested politically in the consideration of site effects and SM receives official recognition and even specific funds (although exiguous).

Thus, on this topic there has arisen a lot of reflections and proposals not only about how to allocate resources, but also on how to increase a culture of prevention based on SM, to check standards and uniform criteria, to increase the number and technical capacity of professionals and technicians of public administrations, to identify measures for reducing investigation costs through seismological, geological and geotechnical data banks, and quick, in situ, geophysical measures, etc.

But it must be noted that, even if, with some exceptions, it is now quite clear, at lexical level, that SM is a scientific procedure for assessing local seismic hazards, the scientific substance of the SM (that is, techniques and procedures) is really poorly known and its scientific complexities are generally misunderstood and underestimated by public officials and professionals. Thus, the dialogue between administrators, professionals and scientists is often rather problematical.

Moreover, given the great variety of morphological and geotechnical soil conditions in Italy, the process of identifying standardized procedures valid for the national territory is very complex. Because any study of SM presents specific questions related to the particular characteristics of the territory, national guidelines must, on the one hand, give standards for producing homogeneous and comparable products, but on the other hand

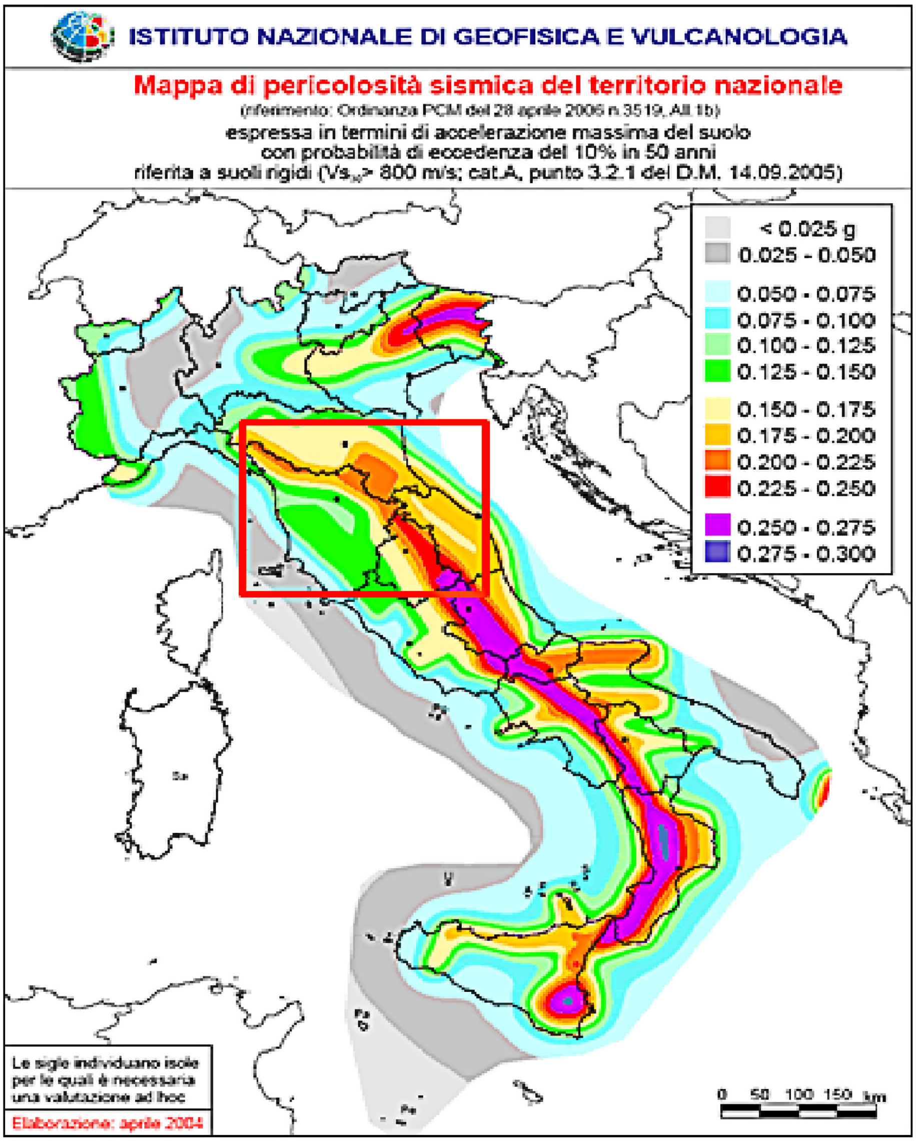


Fig. 2. *The Italian map of seismic hazard (INGV, 2004, mod.) with indication of the area in which the case histories presented in the paper fall. The coordinates of extreme points of the rectangle are: latitude 45° 3'23.59"N and longitude 9°12'22.48"E; latitude 41°38'50.51"N and longitude 14°48'22.74"E.*
Mappa della pericolosità sismica dell'Italia (INGV, 2014, mod.) con indicazione dell'area in cui ricadono i casi presentati. Le coordinate dei punti estremi del rettangolo sono: latitudine 45° 3'23.59»N e longitudine 9°12'22.48»E; latitudine 41°38'50.51»N and longitudine 14°48'22.74»E.

must also give space to specific regional guidelines, that in turn must consider the different zones within the same region.

In this paper some recent, salient Italian cases of SM will be presented. But one observation is opportune in order to understand their relevance in the Italian context. It is about the different roles of researchers and scientists. Most of the SM cases presented may be defined as ordinary, because their distinctive character is that they are locally conceived and designed exclusively for the purpose of prevention. Although experts and even university departments are involved, the promoters, the protagonists, the users of these SM are the regional administrators, local technicians and professionals. From this point of view, these SM studies can be considered a third generation.

3. **Three Generations Of SM studies In Italy**

In fact, looking at the evolution of Italian seismic codes of the last 40 years, three generations of SM studies can be distinguished.

The first generation includes essentially the two main studies conducted in Tarcento (Brambati et al. 1980) and Ancona (VV. AA., 1981). They were performed respectively after the earthquakes of Friuli (1976) and Ancona (1972) by Italian researchers with typically scientific objectives, in order to test computation procedures, investigation techniques, etc. Especial relevance was given to SM final results, in order to offer useful elements for structural design (Figure 3 and Figure 4). Therefore, the scientists came to the decision that the results must be given in terms of design acceleration spectra that modified the spectra of the national building code. It must be outlined that in that period the

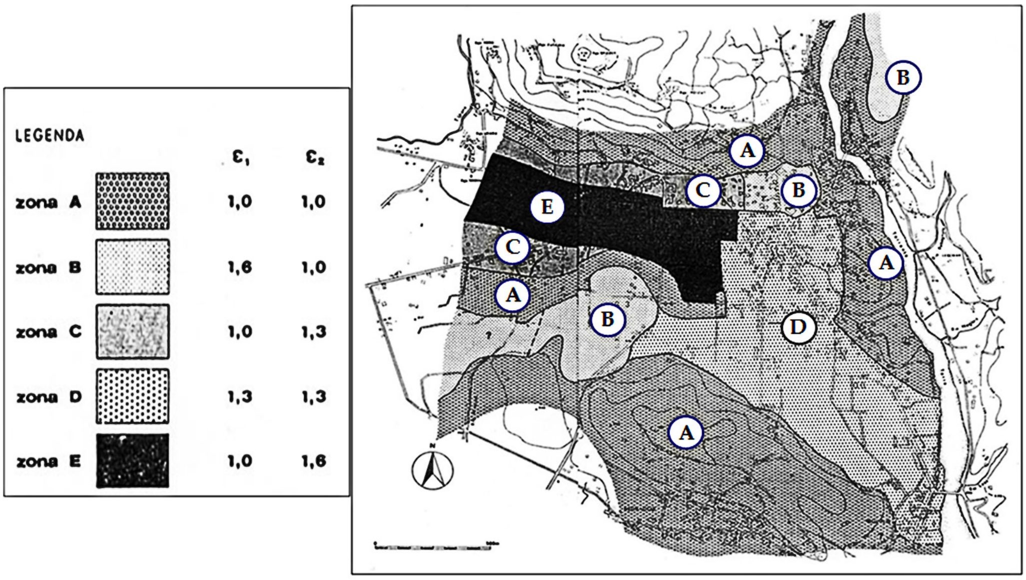


Fig. 3. *Microzoning map of Tarcento (Friuli) (from Brambati et al., 1980, mod).*
Carta di microzonazione di Tarcento (Friuli) (da Brambati et al., 1980, mod.).

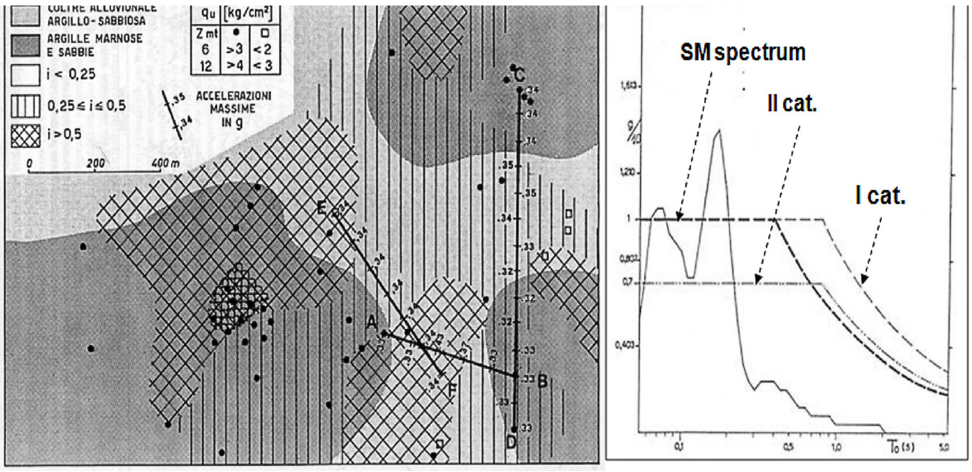


Fig. 4. *a) Microzoning map of Ancona with comparison between earthquake damage; b) new proposed spectrum, intermediate between I and II Category spectra of national building code (from VV. AA., 1981).*
a) Carta di microzonazione di Ancona e confronto con la carta del danno b) nuovo spettro proposto (da VV. AA., 1981).

codes for a seismic design were very simple with respect to soil and site effects, and the only parameter for taking into account soil conditions was the coefficient of foundation ε.

Thus, the final results of SM studies of Tarcento were in terms of design acceleration spectra modified on the basis of the ε-values attributed to each zone identified for low and high frequencies. Even if the results of SM of Tarcento have been utilized for reconstruction, the first generation SM studies can be considered typically scientific products and for a long time they have constituted leading examples and reference points.

After the Irpinia earthquake in 1980, some geological maps were immediately drawn up in the perspective of reconstruction in 39 urban centres destroyed by the earthquake, also by considering the effects of geology on the damage. This work was carried out under the control of scientists from the National Geodinamica Project of the National Research Council (CNR, 1983) and constitutes a first example of quick studies of SM.

But it was later that some universities and research institutes, such as the National Group for the Defence from Earthquakes (GNDT), the Institute for Seismic Risk Reduction (IRRS), in collaboration with a number of enlightened local authorities (regional and municipal) gave rise to a number of SM projects, which involved many Italian researchers from different disciplines: seismologists, geologists, engineers. In this context a first guide for SM studies was written with the contribution of many authors (Faccioli, ed., 1986). The SM studies were conducted either after earthquakes in the perspective of reconstruction or for advancing preventive pilot experiments. Some of these experiments were promoted by GNDT in the town of Gubbio (Augusti et al., 1985; Crespellani, 1985; Benedetti et al., 1988; Augusti et al., 1988; Crespellani and Garzonio, 1988; Augusti et al.,

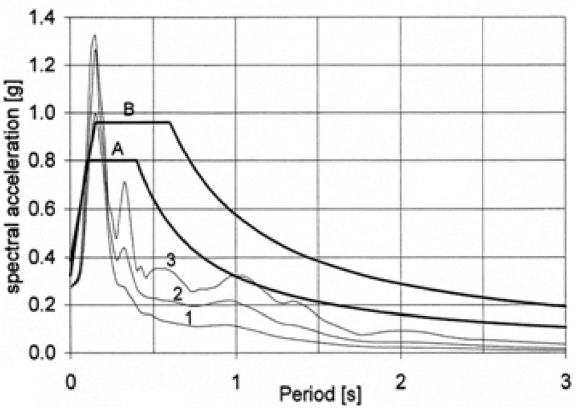


Fig. 5. *SM results in the historical centre of Città di Castello, Umbria, in terms of acceleration spectra compared with Eurocode 8 spectra for class A (rock or stiff deposits)and class B (deep deposits of medium stiff soils):*
(1) average acceleration spectra
(2) average acceleration spectrum plus a standard deviation
(3) envelope spectrum
(from Crespellani et al., 1997).
Risultati dello studio di SM del centro storico di Città di Castello, Umbria, in termini di spettri di pseudoaccelerazione, messi a confronto con gli analoghi spettri dell'EC8 per le classi di terreno A (roccia o terreni rigidi) e B (depositi profondi di media rigidezza):
(1) spettri medi in accelerazione
(2) spettro medio in accelerazione più una deviazione standard
(3) spettro inviluppo
(da Crespellani et al., 1997).

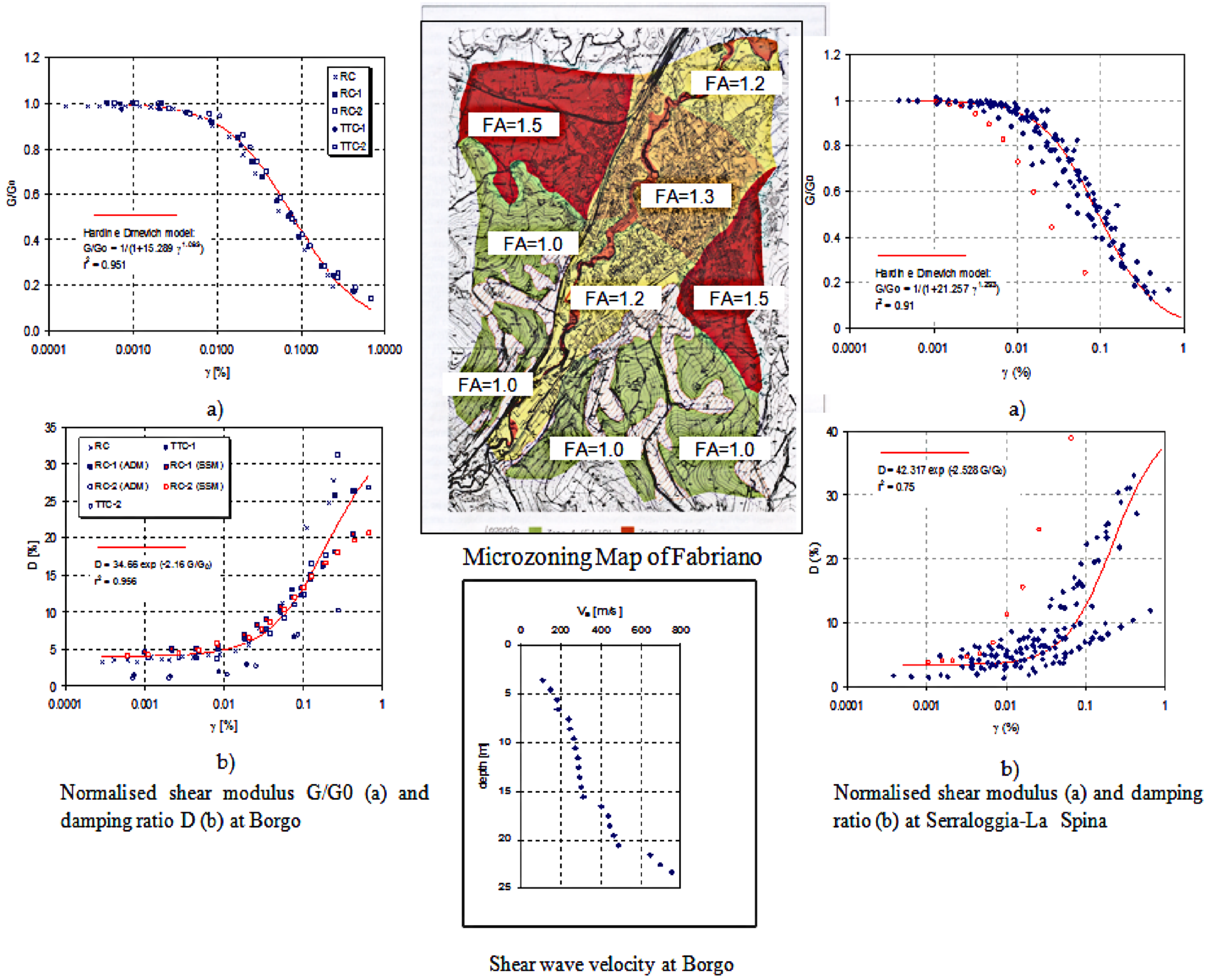


Fig. 6. *SM map of Fabriano (at centre) and some geotechnical results of in situ and laboratory dynamic tests (resonant column) (from Crespellani et al., 2001; Marcellini and Tiberi, 2000).*
Carta di MS di Fabriano (al centro) e alcuni risultati di prove geotecniche in sito e in laboratorio con l'apparecchio di colonna risonante (da Crespellani et al., 2001; Marcellini and Tiberi, 2000).

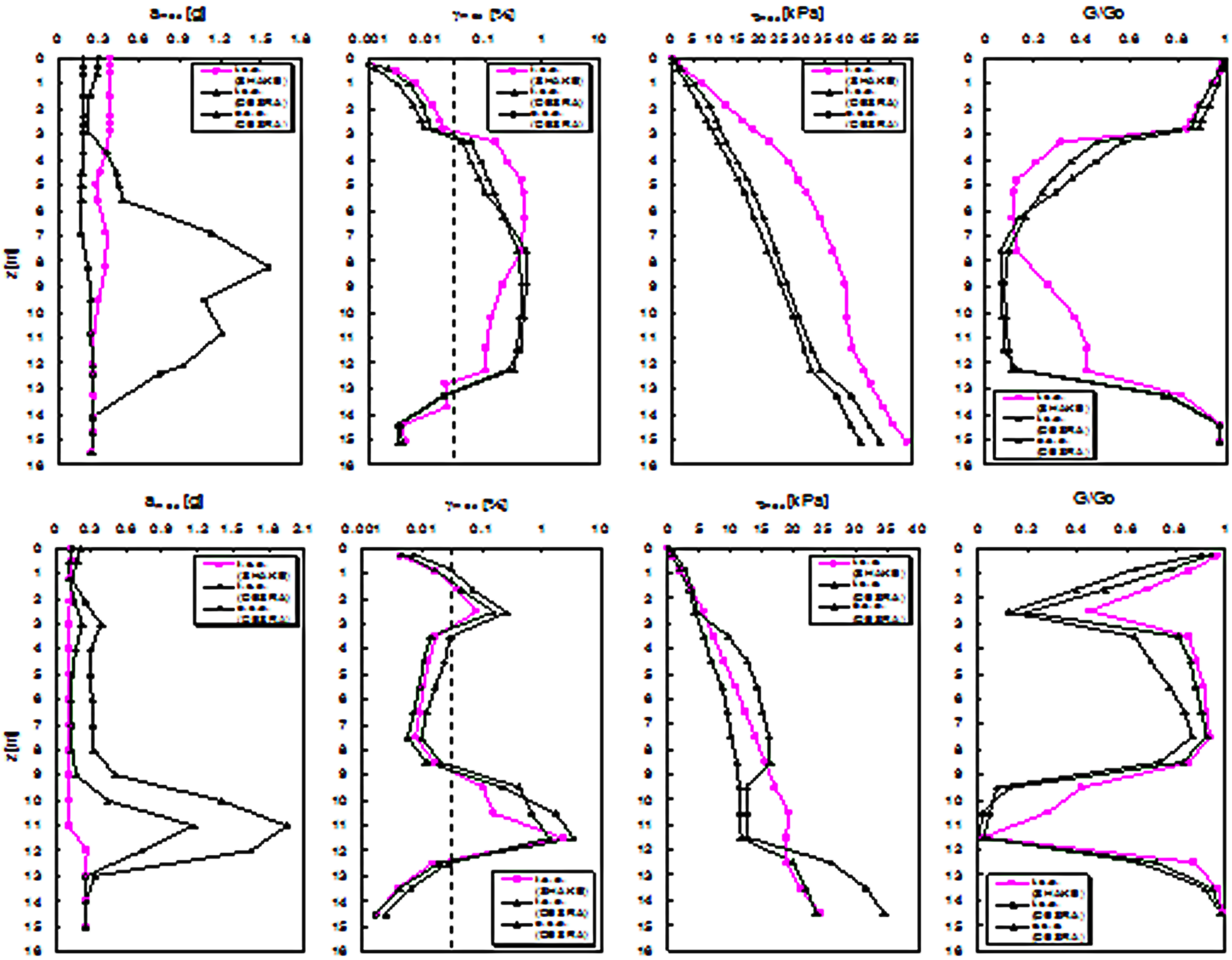


Fig. 7. *Liquefaction testing and analyses at Nocera Scalo. Results of the seismic response analyses in terms of total (t.s.a.) and effective (e.s.a.) stresses at site DH and CH obtained by means of SHAKE and DRESDA (from Crespellani and Madiai, 2002).*
Prove e analisi per lo studio del rischio di liquefazione a Nocera Scalo. Risultati delle analisi di risposta sismica in termini di tensioni totali (t.s.a.) ed efficace (e.s.a.) nel sito DH e CH ottenute con i codici SHAKE e DRESDA (da Crespellani and Madiai, 2002).

1989;), in Naples (Vinale, 1988a e b), in a site near Florence (Vannucchi, ed., 1991), in Città di Castello (Crespellani et al., 1997), Calabritto (Maugeri and Carrubba, 1997), in Emilia-Romagna (Marcellini et al., 1998), and in Catania (Faccioli and Pessina, 2000). Figure 5 shows the main results of the SM in the historical centre of Città di Castello, Umbria, compared with EC8 horizontal acceleration spectra for soils of class A and B.

But it was especially after the seismic sequence of September and October 1997 in Umbria and the Marche that the urgent need to introduce the effects of local conditions into the regional codes was felt. In some towns, the damage was clearly due to the geomorphological conditions of the site and the geotechnical characteristics of foundation soils, and it was therefore necessary in view of reconstruction, to undertake studies of SM to determine the amendments to be made to seismic actions indicated by the national seismic code (DM 16.01.1996).

Leading SM studies of the second generation were those carried out at Nocera, Umbra and Fabriano (Marcellini and Tiberi, eds. 2000; Cattaneo and Marcellini, 2000; Marcellini and Maugeri, ed. 2001). They were carried out by a team of researchers of GNDT and some Italian universities. They marked a qualitative leap, because, for the first time, they were based on a large number of instrumental seismological and geological surveys as well as geotechnical dynamic testing and in-depth analyses (Figure 6 and 7). In the perspective of reconstruction, expeditious SM projects were also carried out in about 80 villages in Umbria (Pergalani et al., 2000).

Successively, some regions have given greater impetus to the works already undertaken or have initiated new studies of SM, involving researchers from various disciplines and assigning an important role to geotechnical, dynamic, in situ and laboratory testing. It is worth mentioning in particular the research promoted by the Regione Emilia Romagna in some areas of the Adriatic coast (Marcellini et al., 1998), the Regione Umbria in the Val Tiberina (Boscherini et al., 2002), the Regione Marche in some minor historical centres (Mucciarelli and Tiberi, 2004) and at Senigallia (Mucciarelli and Tiberi, 2007), the Regione Toscana in

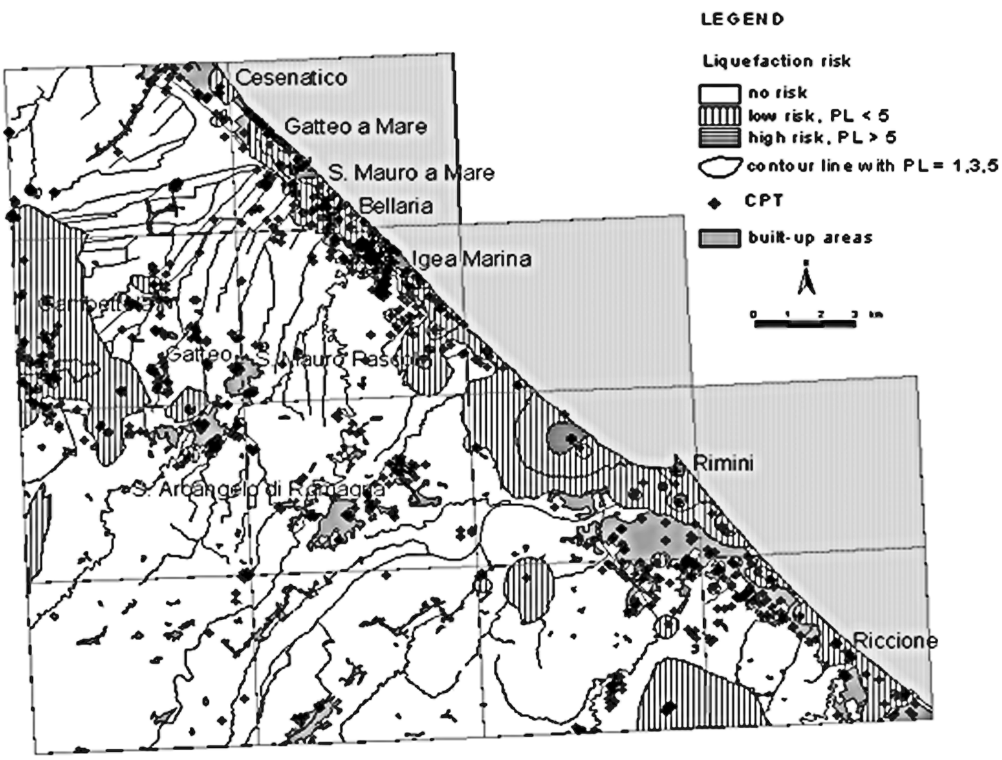


Fig. 8. *Map of liquefaction risk on the Adriatic coast (from Crespellani et al., 1999).*
Carta del rischio di liquefazione sulla costa Adriatica (da Crespellani et al., 1999).

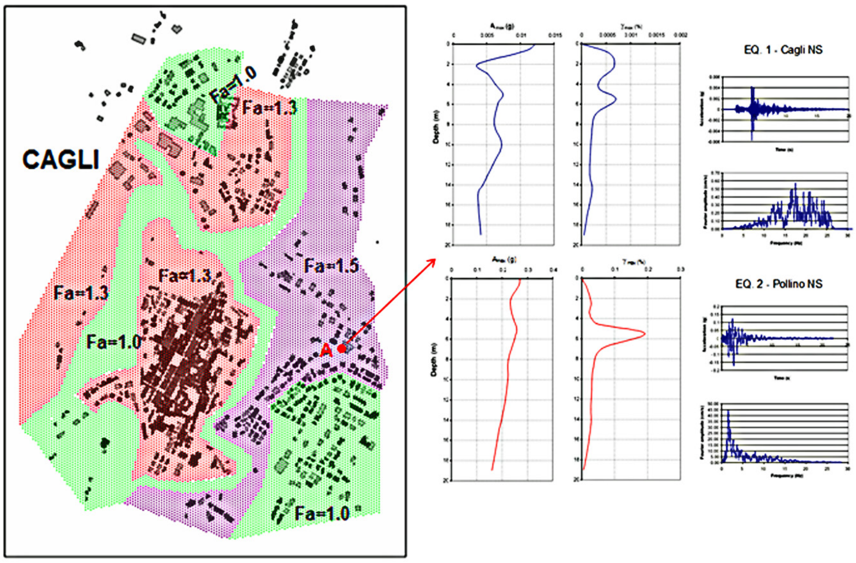


Fig. 9. *SM map of Cagli (left) and values of maximum peak acceleration and shear deformation amplitudeversus depth in four sites of Cagli by considering two different inputs (right) (from Mucciarelli and Tiberi, 2004, mod; Crespellani et al., 2004a).*
Carta di MS di Cagli (a sinistra) e valori del picco massimo di accelerazione e della deformazione di taglio in funzione della profondità in quattro siti di Cagli ottenuti considerando due differenti input (a destra) (da Mucciarelli and Tiberi, 2004, mod; Crespellani et al., 2004a).

Garfagnana (Ferrini, 1999). Figures 8, 9 and 10 show some results of the SM studies performed on the Adriatic coast, at Cagli and Senigallia. A description of the geotechnical aspects of the studies can be found in some papers of geotechnical researchers at Florence University (Crespellani et al., 1999a; Crespellani et al., 1999b; Crespellani e Uzielli, 2001; Crespellani et al., 2001; Crespellani and Madiai, 2002; Crespellani et al., 2002a; Crespellani et al., 2002b; Crespellani et al., 2002c; Crespellani et al., 2002d; Bardotti et al., 2004; Crespellani et al., 2004a; Crespellani et al., 2004b; Madiai and Simoni, 2004a; Madiai and Simoni, 2004b; Madiai et al., 2006; Crespellani et al., 2007; Simoni and Madiai, 2007; Facciorusso and Madiai, 2007).

Compared to the first generation studies of SM, the second generation of SM studies has two distinguishing

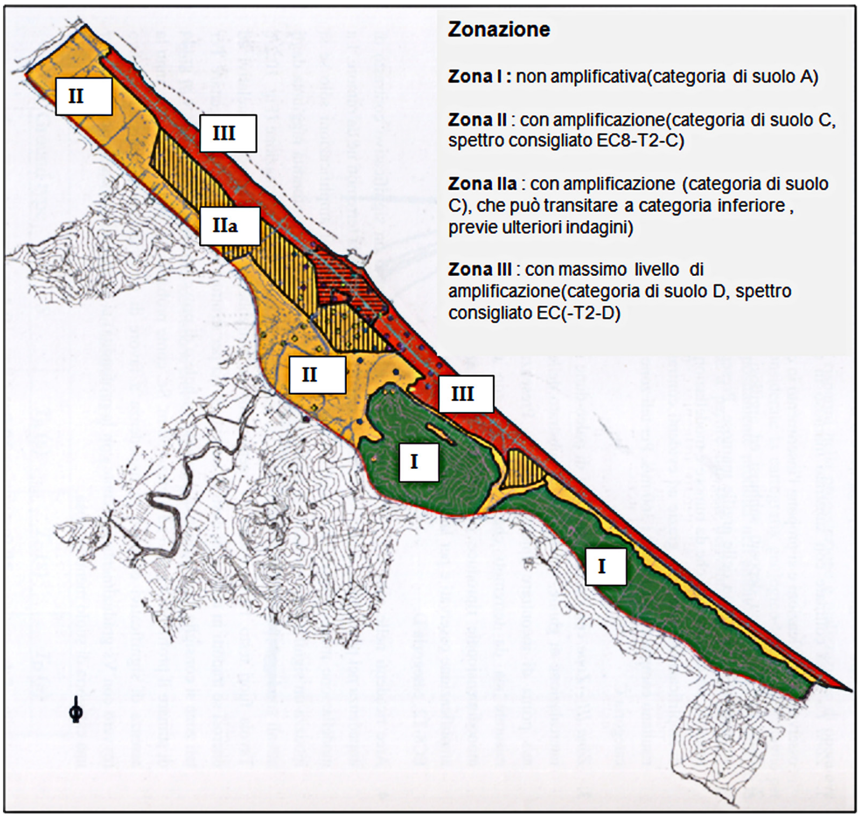


Fig. 10. *SM map at Senigallia and dynamic properties of soils (from Marcellini and Tiberi, 2007, mod).*
Carta di MS di Senigallia (from Marcellini and Tiberi, 2007, mod.).

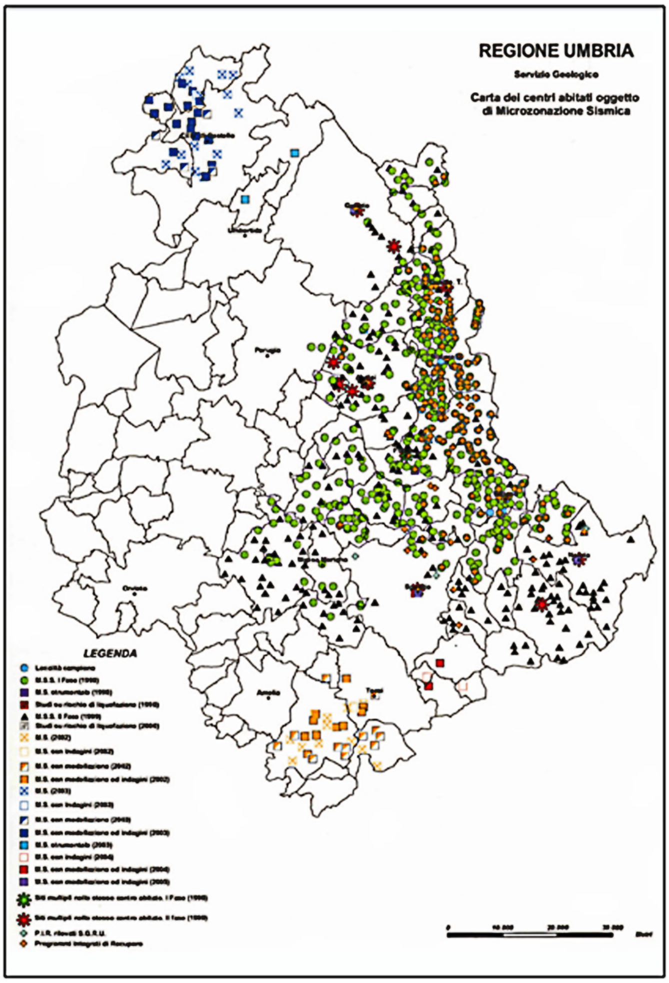


Fig. 11. *Programme of SM studies in the Umbria region (from Boscherini and Motti, 2011).*
Programma di studi di MS nella regione Umbria (da Boscherini e Motti, 2011).

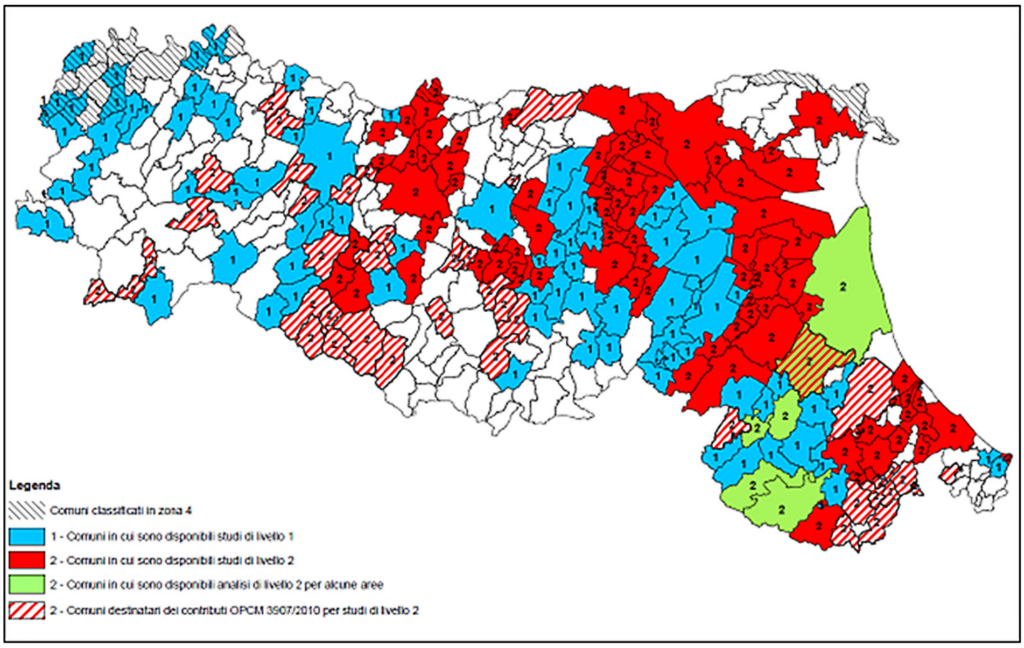


Fig. 12. *Programme of SM in Emilia Romagna with the municipalities of category IV(in which SM studies are not necessary), the municipalities that have carried out Grade 1-SM (blue), Grade 2- SM (red), Grade 2-SM partial, and the municipalities where Grade 2-SM studies are in progress with funds of the new Act OPCM 3907/2010 (from Martelli and Romani, 2012).*
Programma di studi di MS in Emilia Romagna, con indicazione dei comuni in cui gli studi MS non sono necessary (zone di IV categoria), dei comuni che hanno già condotto studi di Grado 1, Grado 2, e dove sono in corso o previsti studi di Grado 2 con i finanziamenti della dell' OPCM 3907/2010 (da Martelli and Romani, 2012).

characteristics. The first is that they have been generally planned on a regional scale, choosing some test sites, that is, some urban centres of particular relevance from seismic and social points of view. The second is that in all these studies the campaign of geotechnical investigations, in addition to geophysical surveys and the collection of existing geological and geotechnical information, has been a central characteristic of SM, as can be inferred from the large number of surveys and in situ and laboratory geotechnical tests, most of which were devoted to establishing the dynamic parameters indispensable for the construction of models as realistic as possible and defined with maximum detail for simulations with different seismic inputs so as to obtain the envelopes of the peak acceleration and response spectra valid for the site.

In synthesis, the second generation of SM studies was the result of a dialogue between public officials and researchers who, working side by side, have made a great contribution to advance the frontiers of scientific knowledge of SM in Italy and to bring into focus a lot of scientific and practical problems. The most recent case of this type of study is that of L'Aquila (Gruppo di lavoro MS-AQ, 2008).

As said above, the third generation of SM studies is of a different nature, because its goal is not of a scientific nature but is exclusively the seismic protection of citizens. These studies are the result of a close collaboration between local governments (regions, provinces and municipalities) and the local professionals (engineers and geologists), and are ordinary tools of prevention against earthquakes. While the SM studies of first and second generation are generally elaborate, slow and costly, the logic of ordinary SM projects is that they have to be performed smoothly, quickly and cheaply. The aim is not to obtain the best SM product at any price but the best SM project consistent with efficient administrators who really want to reduce seismic risk in their region. As an example, Figures 11 and 12 show the diffusion of these studies in the Umbria region (Boscherini and Motti, 2011) and in Emilia Romagna (Martelli and Romani, 2012). In Figure 12 are also shown the municipalities in which Grade-1 or Grade-2 SM maps are available and those municipalities that will benefit from funds on the basis of the new legislation.

In the national strategies of seismic risk reduction, these studies represent a point of arrival and a starting point: a point of arrival because the long march undertaken for making SM studies an ordinary tool of prevention against earthquake reaches finally its objective, but also a starting point because the extension of this prevention tool in the country needs time and funds. In fact, the state of seismic knowledge and of the practice is very different in the various parts of the country. In some places the state of the art is rather advanced, while in other regions many of those conditions necessary for SM to become an ordinary strategy for seismic prevention are totally lacking.

4. The National Guidelines for SM Studies (Gruppo Di Lavoro MS, 2008)

As known, at international level, the technical procedures for carrying out the different operations and drawing up SM maps are defined by the TC4 Manual

Tabella 3.3-1 - FA per profilo di Vs costante (argilla)

		Vs											
		100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**700**
	5	2.23	2.19	1.75	1.47	1.21	1.11	1.06	1.03	1.01	1.00	1.00	0.99
	10		2.06	2.02	1.92	1.67	1.47	1.30	1.18	1.12	1.10	1.04	0.99
	15		1.59	1.83	1.83	1.72	1.66	1.54	1.38	1.24	1.18	1.10	1.02
	20		1.21	1.54	$\boxed{1.65}$	1.66	1.57	1.51	1.42	1.33	1.26	1.17	1.05
H	**25**		1.14	1.26	1.45	1.51	1.50	1.45	1.39	1.34	1.27	1.19	1.07
	30		1.08	1.14	1.25	1.38	1.40	1.39	1.36	1.28	1.24	1.19	1.08
	35		1.00	1.12	1.15	1.21	1.30	1.30	1.29	1.26	1.20	1.15	1.09
	40		0.94	1.08	1.12	1.14	1.17	1.23	1.22	1.21	1.18	1.13	1.06
	50		0.79	0.99	1.07	1.09	1.09	1.08	1.09	1.08	1.10	1.08	1.02

FA = amplification factor of the response spectrum at low periods

Fig. 13. *An example of abacus valid for clayey soils for estimating the amplification factor FA on the basis of the average shear wave velocity Vs and the thickness H of the deposit (from Gruppo di Lavoro MS, 2008).*
Esempio di abaco per la stima del fattore di amplificazione FA dei terreni argillosi in base della velocità media delle onde di Vs e allo spessore H del deposito (da Gruppo di Lavoro MS, 2008).

(1993, 1998). In Italy, on 2008, in order to diffuse a knowledge on this topic and provide guidelines for SM, the Italian Civil Protection coordinated a team of about a hundred of Italian researchers and technical representatives of the Italian regional government authorities who made a first advanced proposal for establishing SM objectives, scales, grades of analysis, investigation techniques, geotechnical testing, procedures, maps and final products. These proposals have been passed by the competent authorities (Department of Civil Protection and Conference of Regions and autonomous Provinces) and are now effective (Gruppo di Lavoro MS, 2008).

The main purposes of the SM national guidelines were:

1) to ensure a correct path (procedural, scientific and implementation) for the reduction of seismic risk in a given territory by proposing shared procedures of SM at different levels of detail able to provide solutions to the many difficult problems that the application involves by drawing lessons from previous studies of SM;

2) to establish a common language that allows for comparisons and constructive dialogue between researchers, professionals and public officials, also in accordance with the indications given in the international field.

Due to the complexity of a study of SM and the costs of the investigation, three grades of analysis have been considered:

• Grade 1 preparatory to the actual studies of SM, is based on geological maps and the collection of existing data processed to divide the territory into microzones qualitatively homogeneous from a seismic perspective.

• Grade 2 gives a map that assigns to the homogeneous areas some quantitative parameters or spectra of engineering interest which indicate the level of local hazard.

• Grade 3 gives, for important public works or in zones at high levels of risk, a detailed map of seismic microzonation with emphasis on particular issues (landslides, liquefaction, etc).

As regards the methods of assessment of the local seismic response, they are related to the level of detail required.

At Grade-1 level the assessment of the amplification effects is made on exclusively geological bases by using proper coefficients and knowledge of the seismic input is not necessary.

At Grade-2 the estimate of amplification may be carried out by means of simplified procedures or tables that define the amplification factors at the surface, associated with individual lithostratigraphic situations (Figure 13).

At Grade-3 for the quantitative assessment of site effects, it is necessary to refer to specific, more complex procedures, which are different for each type of problem: local seismic response analysis, liquefaction, slope stability, etc. Evaluation of site effects is carried out by using special, advanced software that requires complex input data of high quality.

As shown by Madiai and Simoni (2010), one of the most intriguing problems in a study of SM is the choice of engineering parameters for expressing the amplification effects in stable areas where amplification of seismic motion is possible. In general, there are two basic types of coefficients, which refer respectively to the peak values of the acceleration and to the response spectra (acceleration or velocity). In the present version (Gruppo di Lavoro MS, 2008) the coefficients of amplification (FA) can be expressed in terms either of maximum horizontal acceleration ratio (PGA/PGA_0) or Housner Intensity ratio (SI/SI_0) for given period intervals ($0{,}1s < T_0 \leq 0{,}5s$; $0{,}5s < T_0 \leq 1{,}0s$), being PGA_0 and SI_0 respectively the maximum horizontal acceleration and Housner Intensity at the bedrock and being PGA and SI the same quantities at the surface of the deposit. To facilitate this task the national guidelines provide tables for Grade-2, which give directly the amplification coefficient FA = (SI/SI_0) as a function of S-wave velocity and thickness of the deposit.

After the latest legislation and in order to promote SM studies, the national guidelines are now being revised to take into account the variety of Italian seismic problems that have emerged from the more recent earthquakes. Especially after the seismic events that struck the Emilia region in 2012, the opportunity was assessed of a revision in order to give more importance to some local hazards, such as liquefaction, generally considered less important in the previous national classification maps and codes.

5. New tasks for local governments and researchers

National guidelines give formal support for SM studies, but for local ordinary SM projects, more detailed guidelines, referring to the specific seismic, environmental, economic and social context under examination, are required. This observation leads directly to the root of the matter: the new duties of local governments and the different roles of scientists.

It is well known that seismic protection is inextricably conditioned by the current state of scientific and technological knowledge, concerning the nature, causes, manifestations and characteristics of the seismic events expected in the region as well as the vulnerability and exposure of the urban context.

The premise of any preventive action of a local government is therefore this knowledge. In this context, the relationship between local governments and scientists plays a central role, but the social nature of ordinary SM projects gives to these relations a special character. In fact, it is not a question of applied knowledge, but knowledge aimed at achieving specific social purposes of safety, with limited funds and time..

The relationship between local governments and scientific research in the field of SM ordinary projects can therefore be characterized in three different ways, namely as:

1. A contribution to the accumulation of knowledge on the seismic hazards, vulnerability and exposition of local context.
2. The selection of knowledge from the existing seismic heritage, aimed at drawing up SM maps or a diffusion of knowledge.
3. The formulation of new research programmes aimed at providing responses to specific questions.
4. The elaboration of regional abacuses or tables for a quick estimate of seismic response more representative of the local hazard than those elaborated at national scale (Gruppo di Lavoro MS, 2008).

As an example, among the actions of local governments that involve of scientists and researchers and must precede or accompany ordinary SM projects, there are:

- the transfer of knowledge to local professionals and technicians of public administrations on the subject of SM;
- the implementation of seismological, geological and geotechnical regional databanks, through the collection, digitization, archiving, and updating of existing geological and geotechnical data;
- the drawing up of basic geological maps also in digital format at a proper scale for studies of SM (1:5000 or 1:10000);
- the control of SM projects carried out on a local scale in the early stages of setting up work and final products, etc;
- the issue of detailed technical guidelines dealing with the evaluation of the local seismic response, liquefaction estimates, landslide and slope stability evaluations, etc., indicating appropriate procedures proportioned to the SM grades, to seismic and site conditions, to the state of knowledge and the state of practice.

It must be emphasized that the involvement of scientists is essentially cultural and educational in order to ensure high quality of the final products and to guarantee best practices consistent with the average level of professional local culture. Nevertheless, Italian experience shows that specific research is sometimes also required, typically for determining regional attenuation laws, local correlations between shear wave velocities and CPT- point resistance (Madiai and Simoni, 2004b), for drawing up tables for rapid estimates of coefficients of amplification in the site (Marcellini et al., 2006), etc.

In the present phase of change, scientists and researchers are also required to work hand in hand with local administrations and professionals in order to realize and propose exemplary models of Grade-3 SM projects.

6. Some SM Studies in Emilia Romagna

In Italy, most of the cases of ordinary SM studies have been performed in the Regione Emilia-Romagna. This is not casual, but is the result of the long way undertaken a long time ago in this region. Since the 1970-80s, many regional acts demonstrate an attention to the problem of prevention and mitigation of seismic risk and many efforts were made by the regional government authority to create a culture of SM. But it was especially since the end of the 1990s that the Regione has undertaken specific programmes and actions for promoting SM studies, performing research that involved scientists of the National Research Council, the Polytechnic of Milan and the University of Florence, and preparing the conditions necessary to include SM among the ordinary strategies of seismic safety, that is: regional guidelines, a geological and geotechnical data bank, training courses for public technicians and professionals, basic geological maps at scale 1:10.000 in all towns and villages of the region mainly exposed to hazards, etc. (Facciorusso, 2012). The promoted research covered a large variety of seismological, geological and geotechnical problems, aimed at giving

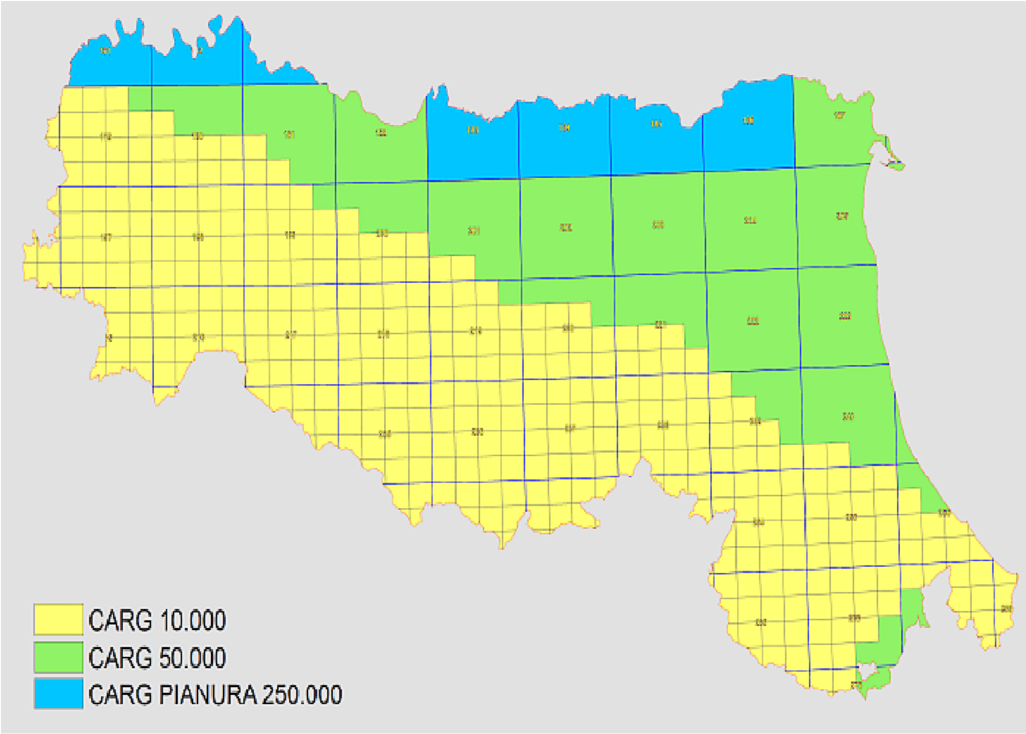


Fig. 14. *Municipalities having basic geological maps at scale 1:10.000 (yellow) and in other scales (green and blu), available in the Emilia-Romagna region (from Martelli and Romani, 2012).*
Comuni dell'Emilia Romagna già dotati di carte geologiche di base a varie scale (da Martelli and Romani, 2012).

every urban centre some reference acceleration spectra, to evaluate seismic response analyses in test sites with more complex software, to prepare tables for a quick evaluation of site amplification effects, to estimate the seismic vulnerability of the embankments of tributary streams of the Po River (Pergalani et al., 2013), etc.

Figure 14 shows the index of the geological maps available, also in digital form, for the Emilia Romagna region. At present, the Emilia-Romagna Geological and Geotechnical Data Bank has more than 60.000 soil profiles (from soundings, CPT, etc.) and geotechnical data of about 3000 soil samples. They can be downloaded freely from the website of the Regione.

By using the geological and geotechnical data of this bank, in a large zone of the Adriatic coast, where liquefaction occurred during some historical earthquakes, an in-depth study was made in order to evaluate the liquefaction risk and to draw a liquefaction map. The research performed has been illustrated in many papers (Marcellini et al., 1998, Crespellani et al., 2003). Recently new updated studies have been performed on the basis of new geotechnical data collected in the area by Facciorusso (2009), Facciorusso et al., (2012), Facciorusso et al., (2012) .

In the last ten years the number of SM studies is largely growing, because approximately three quarters of the region comprises areas susceptible to seismic local site effects (Martelli and Romani, 2012). In 2007 the Regione issued guidelines for seismic microzonation studies in Emilia Romagna to support territorial and urban planning (DAL, 2007). These guidelines provide general criteria and practical instructions for the identification of the areas subject to site effects and for drawing up the SM maps at three grades of detail.

The philosophy of the recent SM studies, performed by following these guidelines, is that they must be carried out at local level by local governments (municipalities) and local professionals, with the supervision and control of regional officials and technicians in conjunction with some experts in the field of SM. In general, scientists and researchers are involved only for special problems that can emerge from ordinary SM of Grade -1 or Grade- 2, for performing Grade-3 SM and conducting in-depth research in order also to present exemplary models (Martelli et al., 2013a; Martelli et al., 2013b). One of these examples is the Grade-3 SM at Spinello.

6.1. *A Grade-3 SM at Spinello*

According to regional guidelines (DAL, 2007), a SM of grade-3 is required for the areas where major public works are planned and particular local risks are identified in a Grade-1 microzoning. In this case Grade-2 may be omitted.

The area of the urban centre of Spinello is characterized by considerable landslide susceptibility even in non-seismic conditions as evidenced by the geological map (Figure 15). Quiescent and active landslide areas with ground movements involving the shallowest layers of the soil deposit have been detected in SM Grade-1. Given the relatively high seismicity of the region, a detailed study of Grade-3, promoted by the regional government, was carried out with the scientific contribution of researchers of the Civil and Environmental

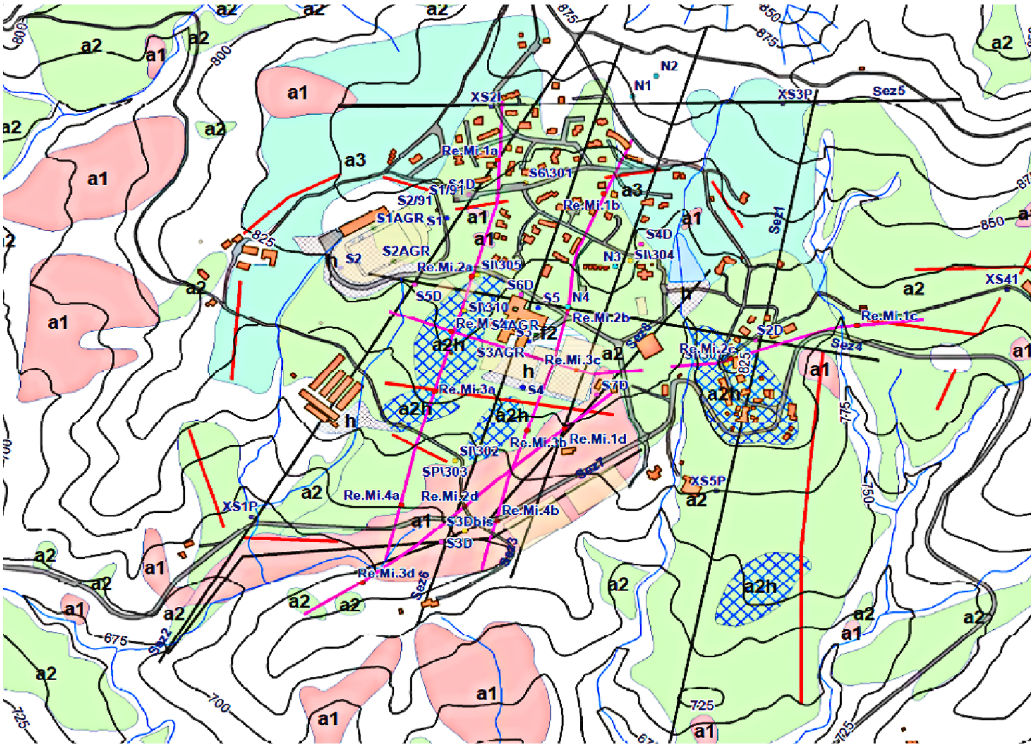


Fig. 15. *Geological map of Spinello area and location of boreholes, seismic lines and selected subsoil profiles (from Facciorusso et al., 2012a). White areas: marly-arenaceous formation; a1: active landslides; a2: quiescent landslides; a3: other slope deposits (da Facciorusso et al., 2012a).*
Carta geologica di Spinello e localizzazione dei sondaggi, delle linee sismiche, e di alcuni profili selezionati (da Facciorusso et al., 2012a).

Main parameters of the input signals M1, M2, M3, 4, M5: *N= number of points; Dt = temporal interval; PGA = maximum peak acceleration; Ia = Arias Intensity; RSI = Housner Intensity; T0 = fundamental period; DB = bracketed duration*

Nome	*N. Punti*	*Δt (s)*	*PGA (g)*	I_a *(cm/s)*	*RSI (cm)*	T_0 *(s)*	D_B *(s)*
M1	3963	0.005	0.02	0.44	2.598	0.402	19.81
M2	4517	0.005	0.04	1.04	4.964	0.269	22.58
M3	3998	0.005	0.48	70.74	65.445	0.436	7.41
M4	6576	0.005	0.11	13.70	21.747	0.758	6.42
M5	8935	0.005	0.05	1.20	8.614	0.910	44.67

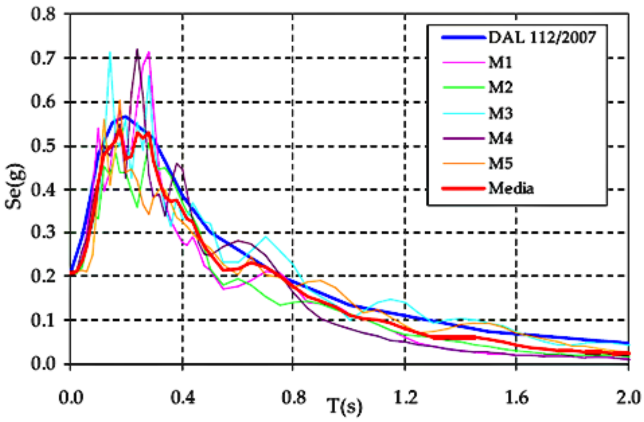


Fig. 16. *Elastic response spectrum of the expected ground motion (return period 475 years, 5% damping) from regional regulations (DAL, 112/ 2007) and spectra of the input signals used in the analysis of local seismic response (from Madiai et al., 2012).*
Spettro di risposta elastico del moto atteso (con periodo di ritorno di 475 anni, con smorzamento del 5%) suggerito dalle norme regionali (DAL, 112/ 2007) e spettri dei segnali di input usati nelle analisi di risposta sismica locale (da Madiai et al., 2012).

Department of Civil Engineering of the University of Florence, Italy. A detailed description of these studies can be found in Facciorusso et al., (2012a) and Madiai et al., (2012).

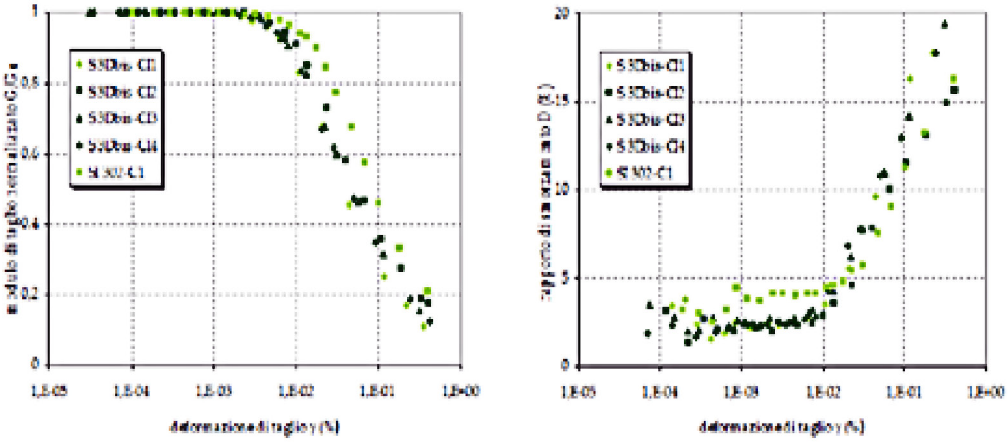


Fig. 17. *Decay of normalized shear modulus from resonant column tests and damping ratio variation with shear deformation amplitude (from Madiai et al., 2012).*
Curva di decadimento del modulo di taglio normalizzato e variazione del coefficiente di smorzamento con l'ampiezza della deformazione di taglio ottenuti in prove di colonna risonante (da Madiai et al., 2012).

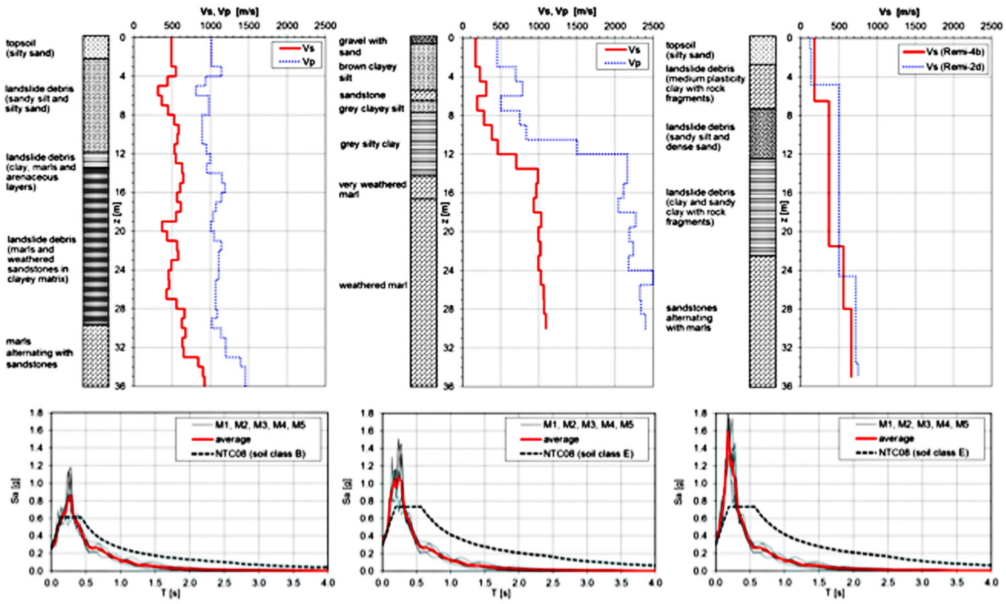


Figure 18. Results of down hole testing and response spectra calculated by PROSHAKE in three different sections compared with the spectra proposed by the national building code (NTC 2008) (from Madiai et al., 2012, mod.).

Fig. 18. *Results of down hole testing and response spectra calculated by PROSHAKE in three different sections compared with the spectra proposed by the national building code (NTC 2008) (from Madiai et al., 2012).*
Risultati di prove downhole e spettri di risposta calcolati con il codice PROSHAKE in tre differenti sezioni e confronto con gli spettri proposti dalle normative nazionali (NTC 2008) (da Madiai et al., 2012).

The research consists of the following main steps:

(1) identification of a number of seismic inputs for the numerical analyses;

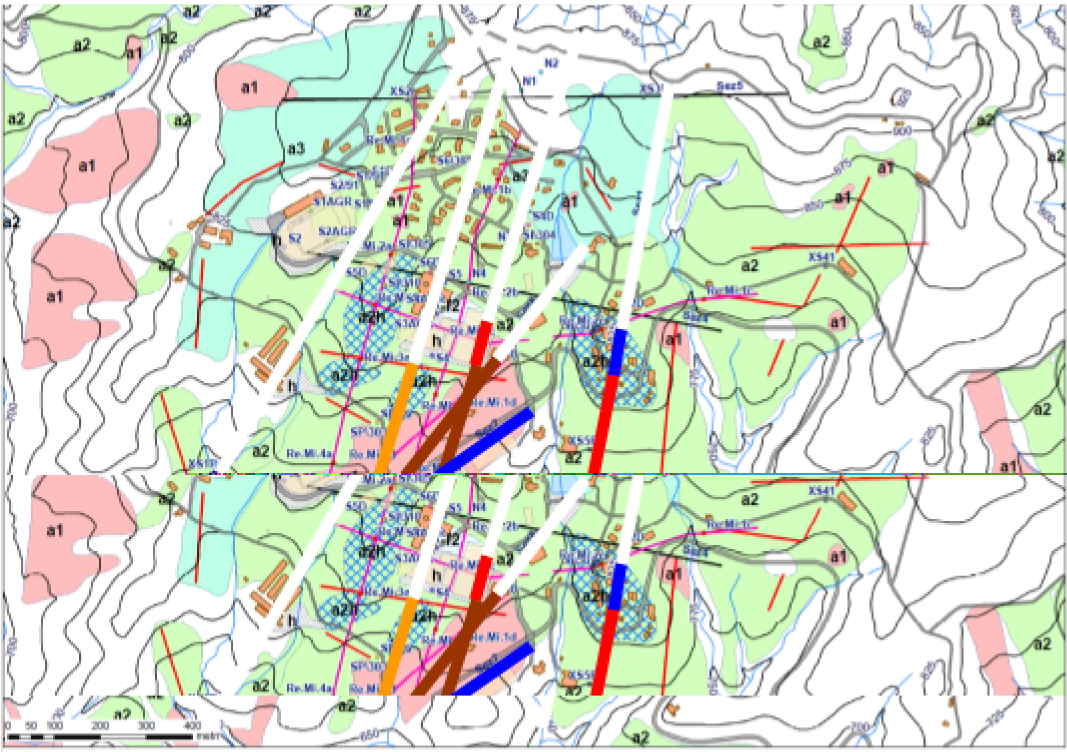
(2) the construction of a model of the subsoil and determination of soil geotechnical properties through static and dynamic testing;

(3) numerical analyses to evaluate the amplification of ground shaking and to assess potential for slope failure;

(4) mapping of homogeneous areas with respect to expected site amplifications and landslide risk.

As concerns step 1, in conformity with regional guidelines, five accelerograms, having spectra similar to the reference spectrum for the site but different characteristics, have been selected. Figure 16 shows their spectra scaled to the peak acceleration value expected in 475 years (ag = 0.209) according to the national code (D.M. 14 GENNAIO 2008).

The construction of a subsoil model was made referring firstly to a large number of geological studies, geophysical surveys and geotechnical testing of the regional geological and geotechnical data bank; later,



CLASS	FS	Landslide hazard
	FS ≤ 1.05	Very high
	1.05 < FS ≤ .25	High
	1.25 < FS ≤ .45	Medium-to-high
	1.45 < FS ≤ .75	Low-to-medium
	1.75 < FS ≤ .05	Low
	2.05 < FS ≤ .00	Very low
	FS > 3.00	Absent

Fig. 19. *Landslide hazard in static conditions for the different sections of the slope (from Facciorusso et al., 2012a).*
Franosità in condizioni statiche in differenti sezioni del pendio (da Facciorusso et al., 2012a).

three new integrative campaigns of investigation (Figure 15), including 19 boreholes, 27 SPT, 2 DH, 56 seismic refraction profiles, 15 refraction microtremors have been carried out. The laboratory tests performed in the Geotechnical Laboratory of the University of Florence included, beside the usual tests for classification, edometric tests, CIU tests and resonant column tests. In Figure 17 the shear modulus decay and damping ratio with shear deformation amplitude obtained on some samples, are shown.

Numerical analyses to evaluate the amplification of ground shaking and to assess potential for slope failure have been performed in three verticals selected in representative sites having different stratigraphic profiles, in which the thickness of detritus is respectively 30 m, 12 m, 18 m and corresponding to class of soil C), E) and E). For the analysis of local seismic response, the code PROSHAKE was used. The results obtained are shown in Figure 18. The comparison between the elastic response spectra from numerical modelling and the spectrum suggested by the national building code (D.M. 14 GENNAIO 2008) shows that the last is not conservative at periods T < 0.3 sec. while it is too conservative for periods T > 0.5 sec.

As far as slope stability analyses are concerned, they have been performed by considering the conditions of the most representative sloping profiles before, during and after the expected earthquakes. Limit equilibrium methods were implemented and numerically solved. Quiescent and active landslide zones were thus identified with greater accuracy together with the most probable sliding surfaces. Figure 19 shows the landslide hazard assessed in static conditions for the different analysed sections of the slope. Stability analyses under seismic conditions were conducted using the pseudostatic method of Carter and the rigid block method of Newmark under various hypotheses of absence and presence of a water table at various depths.

As an increase of pore pressures during earthquake does not seem possible, pre-seismic and post-seismic conditions do not differ between them.

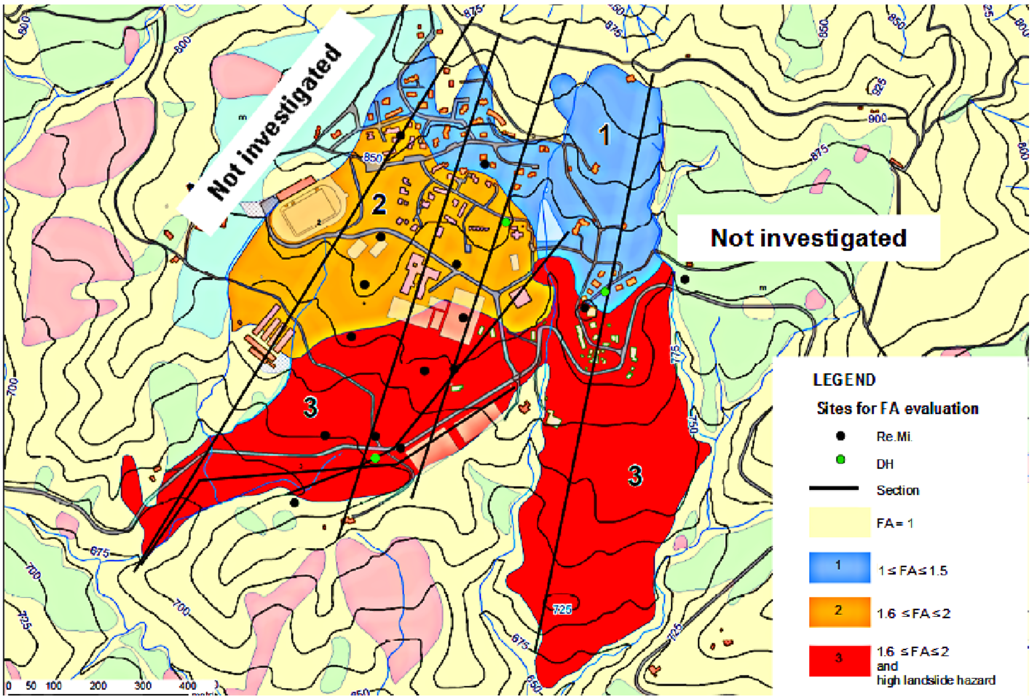


Fig. 20. *Seismic microzoning map of Spinello (from Facciorusso et al., 2012a).*
Carta di MS di Spinello (da Facciorusso et al., 2012a).

The study allowed the mapping of four zones (Figure 20) which are expected to be homogeneous in terms of both amplification factor (FA) and landslide safety factor (FS).

Significant and widespread liquefaction phenomena were observed during the main seismic events of Emilia-Romagna earthquake of May 20th and 29th, 2012. They were a big surprise for inhabitants and scientists. Indeed, during the earthquake of 1570 in Ferrara, that had a great impact on the ancient buildings of the town (Figure 21), some modest liquefaction phenomena were observed. But because the seismicity of the area is quite low, the risk of liquefaction in the area was never considered a real hazard. Therefore, the extended liquefaction phenomena (Figure 22) which occurred during the recent seismic sequence were the object of in-depth studies by Italian researchers and officials of the Emilia-Romagna Regione. Observation covered a wide area of about 1,200 km^2, but the most significant and widespread effects took place in the smaller area of San Carlo and Mirabello villages (Vannucchi et al., 2012, Fioravante et al., 2013). They were induced by the 20th May main shock. This main event occurred at 02:03:53 (UTC) and it was followed at 02:06:30 by an aftershock of ML = 4.8, immediately followed by another shock of ML = 5.1 at 02:07:31.

6.2. *Grade-3 SM at San Carlo and Mirabello*

A considerable number of surveys were performed at the sites where the most severe liquefaction-induced effects and damages were recorded. The assessment was based on the results from 86 cone penetration tests, 9 down-hole tests, 14 boreholes and a great number of size-grain distribution and plasticity tests performed on the extracted samples were acquired and used in the subsequent liquefaction analyses.

In some papers of Facciorusso (2009), Facciorusso et al., (2012b), Martelli et al., (2013a), Martelli et al., (2013b), Facciorusso et al., (2014), liquefaction potential and corresponding risk classes were determined using CPT-based simplified procedures (Robertson and Wride, 1998). As a result, the analyses showed that the simplified methods underestimate the observed effects, that is, the obtained results are not consistent with the observed liquefaction.

The reason for this underestimation has been investigated and attributed to the peculiar characteristics of triggering motion. During the earthquake of the May 2012 very high values of the vertical acceleration on ground surface (PGAV) were recorded in the struck area and the main shock (magnitude Mw =5.9) was followed, in a few minutes, by two other strong shocks with comparable duration and magnitudes of 4.8 and 5.1 respectively. This led to a "multi impulse" seismic action with a global duration and an energy content that were much greater than those of the main shock. This can be considered as representative of a certain Italian local seismicity but, since vertical components of seismic actions are not included in the evaluation of the cyclic stress ratio (CSR), the liquefaction risk could be underestimated when simplified methods are applied. For the purpose of liquefaction risk assessment, an empirical method that takes account of this characteristic of the seismic action has been proposed. On this basis, in view of reconstruction, the SM map for liquefaction shown in Figure 23 was drawn up.

Fig. 21. *Ancient prints of the Ferrara earthquake (1570).*
Antiche stampe del terremoto di Ferrara (1570).

Fig. 22. *Liquefaction phenomena at S.Carlo (from Vannucchi et al., 2012).*
Manifestazioni di liquefazione a S. Carlo (da Vannucchi et al., 2012).

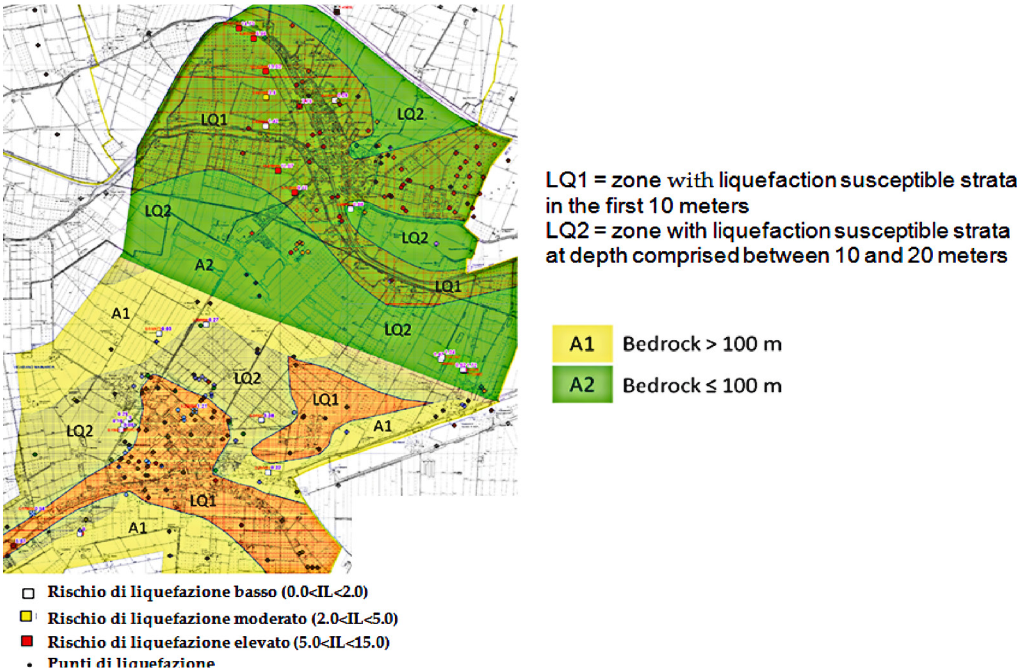


Fig. 23. *Liquefaction map at S. Carlo (da Martelli et al., 2013b).*
Carta del rischio di liquefazione. (da Martelli et al., 2013b).

7. Some SM cases in Tuscany

Since the 1980s, the Regione Toscana has initiated an extensive and intensive research programme for the reduction of seismic risk in the most exposed areas of the region, namely in the Garfagnana and in the Mugello, involving many scientists and researchers from specialized scientific institutes of the National Research Council (GNDT and IRRS) and some Italian universities (Politecnico di Milano, University of Pisa, University of Florence). In the Garfagnana a special project (named Progetto Terremoto Garfagnana) was promoted. Basic geological maps and landslide maps at 1:10.000 scale in almost all villages of the Garfagnana and Lunigiana (Nardi, 1985-1992) have been drawn up and many other specific investigations have been carried out for a revision of seismicity (Patacca et al. 1986), estimating the expected shaking (Marcellini and Tento, 1987a; Marcellini and Tento, 1987b), determining regional attenuation laws (Grandori et al., 1987), and drawing vulnerability maps, etc. On In 1998, a new research programme, named VEL (acronym of 'Valutazione degli Effetti Locali') was launched with the specific aim of carrying out studies on the local effects of earthquakes in the most prone urban areas. To this end, the following actions were carried out: a digitized geological and geotechnical database accessible on-line, numerous campaigns of geophysical surveys and geotechnical in situ and laboratory testing, and the implementation of a regional accelerometric network. Some pilot studies have been conducted at Castelnuovo Garfagnana, San Romano, Pieve Fosciana, Piazza al Serchio (Crespellani et al., 2002). Successively, studies of SM are planned in 207 urban centres, where the basic geological and geomorphological cartography at scale 1:2.000 has been completed. At the same time a lot of seismic refraction lines in the P and SH waves (about 91 km of land surveyed), boreholes and geotechnical in situ dynamic tests (down-hole) have been conducted for a total of over 10 km of perforations.

Over the past five years, a great impetus was given to the ordinary SM studies. The reference for these new studies of SM are the guidelines and national standards (Gruppo di Lavoro MS, 2008) while for studies of Grade -1 a handbook of criteria commensurate with the regional context has been specifically formulated.

A study of Grade-3 was recently conducted in Barberino di Mugello. It is worth listing briefly the salient points thereof.

7.1. *Grade-3 SM at Barberino di Mugello*

The study was developed assessing local seismic effects in an area that extends for about 2.5 square kilometres and includes some villages, industrial and commercial settlements near Barberino di Mugello, the most important urban centre of the western Mugello (Facciorusso et al., 2012c; Facciorusso et al., 2013; Madiai et al., 2014).

The area under study is one of the most seismically active areas of the northern Apennine chain and was affected in the past by two main earthquakes in 1542 and 1919 with moment magnitudes of 5.9 and 6.3 respectively. From a tectonic point of view the Mugello valley is a tectonic basin ("*graben*") oriented approximately in the northern Apennines direction (NW-SE) and filled by Plio-Pleistocene lacustrine deposits; the area under study lies on a sub-basin located at the NW side of the valley.

The following main steps were included in the study.

1. Definition of the main geological and geomorphologic features with identification of the most significant structures and geo-lithologic units at scale 1:2000;

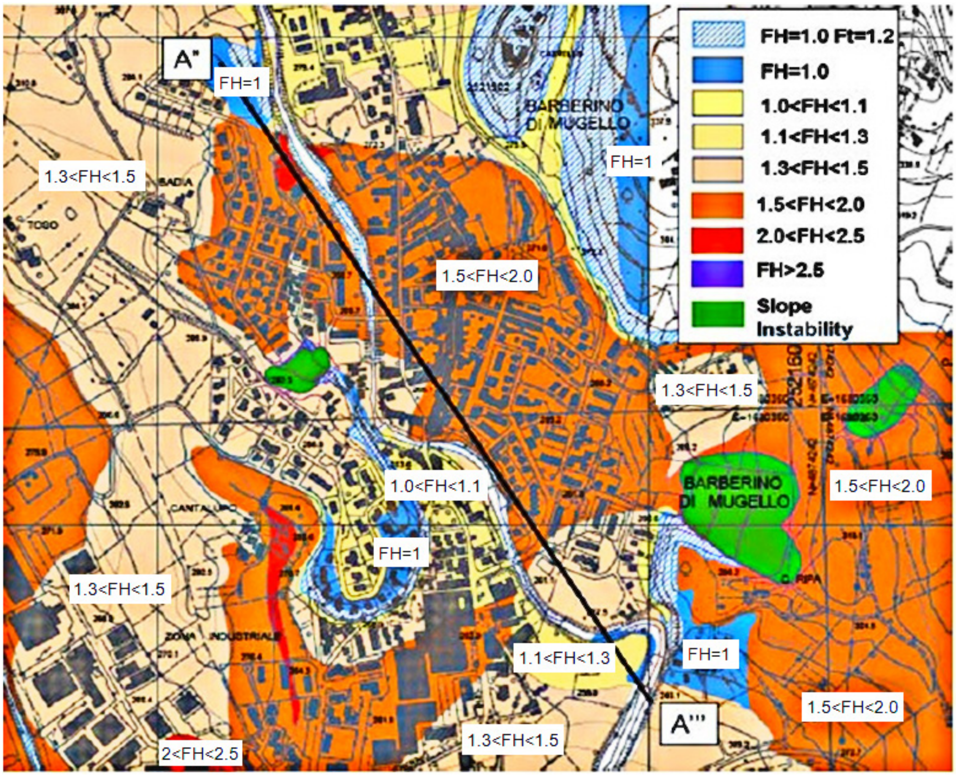


Fig. 24. *Grade-3 Microzoning map of Barberino (from Madiai et al., 2014, mod.).*
Carta di MS di Grado-3 di Barberino (da Madiai et al., 2014, mod.).

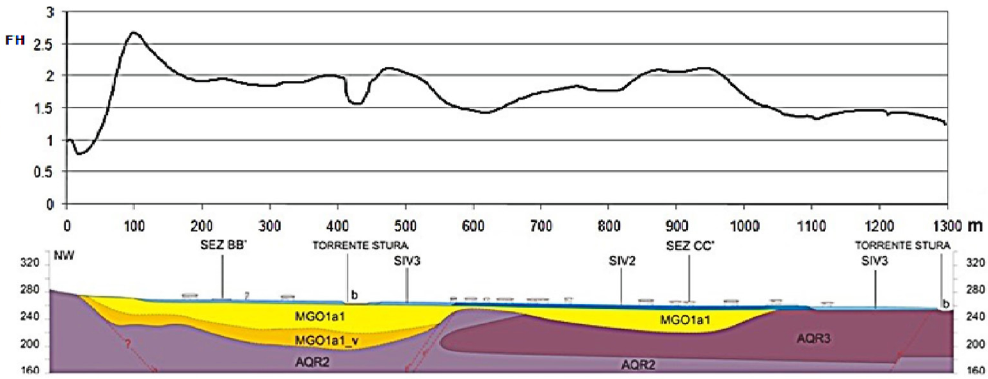


Fig. 25. *Average amplification factor FH (named FHa (0,1-0,5) in Figure) at short periods along the section A" – A''' (see Figure 24). FH = amplification factor: ratio between Acceleration Spectral Intensity (area under the acceleration response spectrum between period of 0.1s and 0.5s) of the deposit and reference rock site (from Madiai et al., 2014).*
Fattore di amplificazione medio FH a bassi periodi (nominato FHa (0,1-0,5) nella Figura) lungo la sezione A" – A''' (vedi Figure 24) (da Madiai et al., 2014). FH = rapporto tra l'intensità spettrale in accelerazione (area al di sotto dello spettro di accelerazione compresa tra i periodi di 0.1s e 0.5s) del deposito e del sito roccioso di riferimento (da Madiai et al., 2014).

2. In situ testing in the most representative sites and laboratory testing aimed at geological subsoil modelling and geotechnical characterization;

3. Drawing up of a preliminary (Grade-1) map aimed at identifying areas involved in different kinds of geotechnical phenomena (amplification, slope-instability, liquefaction, etc.);

4. Identification of relevant and representative cross sections to be analysed by means of 2D ground response model and definition of an appropriate geotechnical model for each section;

5. Identification of a number of acceleration recordings on outcropping rock to be assumed as input motion;

6. Implementation of numerical 2D analyses on selected sections and assessment of a suitable amplification factor profile along each section (Figure 24);

7. Zoning in terms of the selected amplification factor and drawing of an advanced (Grade-3) level map according to the procedure recommended by the Italian guidelines for microzoning (Figure 25).

Another recent in-depth study for seismic risk reduction was conducted in San Gimignano by some researchers of the University of Florence. The results are illustrated in the papers of Madiai et al., (2013) and Renzi et al., (2013).

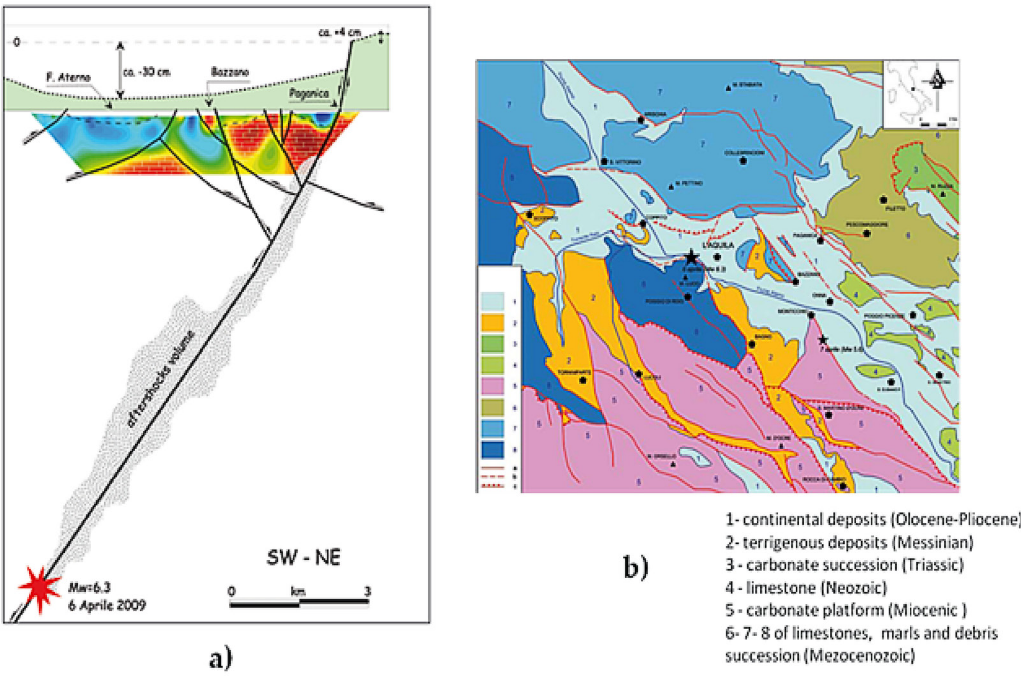


Fig. 26. *a) Localization of the Earthquake of April, 6, 2009 (from Galli et al., 2010) and b) geology of the area (from Boncio e Tallini, 2010, mod.).*
a) Localizzazione del terremoto del 6 April, 2009 (da Galli et al., 2010) e b) geologia dell'area (da Boncio e Tallini, 2010, mod.).

8. **The SM of L'Aquila**

In comparison with the above cases, the SM carried out at L'Aquila and surroundings is of a different nature, because it is typically a "national scientific product", even if its results constitute an essential basis for reconstruction.

As well known, on April 6 2009 an earthquake of Mw = 6.3 (Figure 26) killed 309 people and destroyed the historical centre of L'Aquila and surrounding areas. In May 2009 the authority delegated for the emergency promoted a comprehensive SM project in the municipalities struck by the earthquake and where a macroseismic intensity superior or equal to grade-VII MCS had been observed. The SM studies were coordinated by the Department of Civil Protection and the Abruzzo Regione and realized in accordance with the indications of the national guidelines (Gruppo di Lavoro MS, 2008). Grade-1 and Grade-3 SM studies were performed by involving about 150 researchers and experts from 10 Italian Universities (L'Aquila, Chieti-Pescara, Genova, Politecnico di Torino, Politecnico di Milano, Firenze, Basilicata, Roma1, Roma3, Siena), 8 Research Institutes (CNR, INGV, AGI, ReLUIS, ISPRA, ENEA, OGS, GFZ-POSTDAM), and public technicians and officials from 4 Regioni e 1 autonomous Province (Abruzzo, Lazio, Emilia-Romagna, Toscana, Provincia di Trento) and professionals of the Geologist Association of Abruzzo region.

The survey area was divided into 12 macro-zones and the activity was organized by considering the following themes.

1. *Collection, storage, organization and digitalization of previous geological and geotechnical data*. About 300 lithostratigraphic profiles, associated to SPT, CPT, etc. were found. Through a WebGIS system, this information can be also used in the Abruzzo region for future land use plans of the area.

2. *Definition of the geological model of the subsoil*. For each area considered maps at a scale of 1:5000 were drawn up.

3. *Geotechnical characterization of soils*. Approximately 100 boreholes were drilled, in which dynamic testing (down hole) was carried out. Many laboratory tests were carried out on undisturbed samples to determine their static and dynamic properties.

4. *Geophysical characterization of soils*. In all sites analysis of seismic refraction, MASW and Re.Mi. surveys and geoelectric acquisitions were conducted.

5. *Instrumental analyses of the mainshock, the aftershock and microtremors*. In all the territory struck by the earthquake immediately after the main event an array of accelerometric stations were placed and extensive analyses were conducted with portable digital apparatus for noise recording.

6. *Determination of the earthquake of reference for the numerical simulations*. On the basis of seismotectonic data, historical seismicity and accelerometry some seismic input for the numerical simulations was determined.

7. *Numerical simulations*. On the basis of geological, geotechnical and geophysical data collected , for each macro a series of 1D and 2D sections were taken, which were analysed by numerical simulations made using different codes, selected on the basis of geological-technical structures represented in the sections.

8. *Analysis of damage*. In some areas (Onna and San Gregorio, fractions of L' Aquila), an analysis was

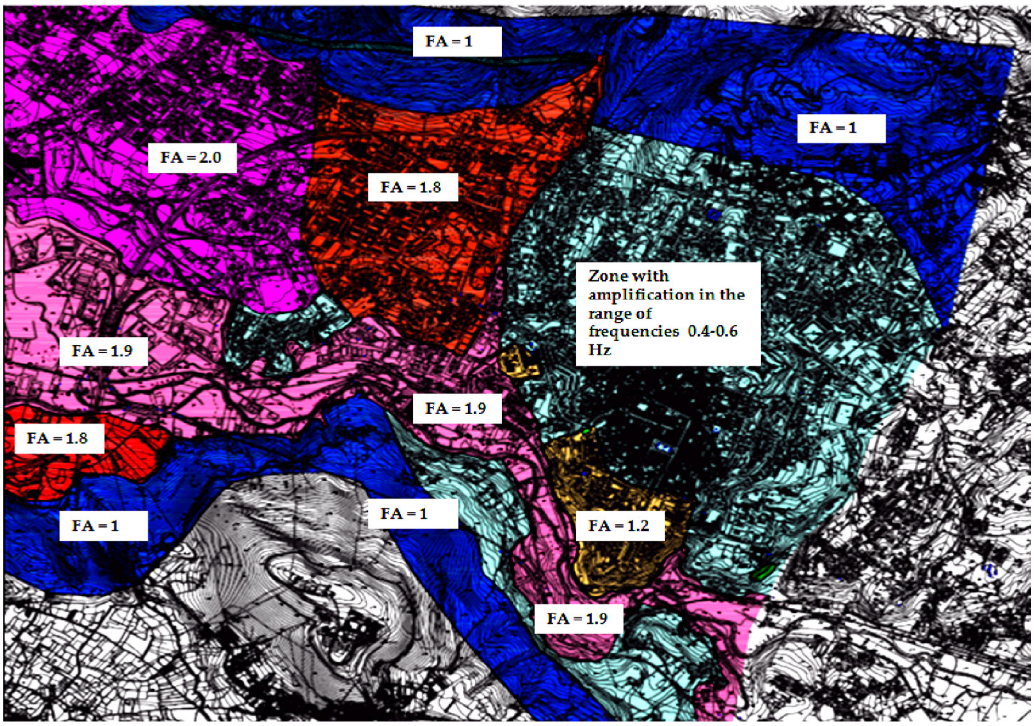


Fig. 27. *SM map of the historical centre of L'Aquila (from Gruppo di Lavoro MS-AQ, 2010, mod).*
Mappa di MS del centro storico de L'Aquila (da Gruppo di Lavoro MS-AQ, 2010, mod).

conducted of the damage, accompanied by a detailed analysis of the vulnerability of buildings.

9. *Connections of SM results with Urban Planning and Italian Building Code* (D.M. 14 GENNAIO 2008). The areas identified for studies of SM have been defined in accordance with municipal technicians, identifying local planning issues. All land use plans were collected and computerized; the main maps have been superimposed upon the Grade-1 SM maps. Both the inputs that the spectra obtained on the surface with numerical simulations were compared with those proposed by D.M. 14 GENNAIO 2008.

10. *Production of reports, maps and data diffusion*. The information on data collected, procedures used and results gradually obtained was continuously transmitted online.

The results of these studies are illustrated in detail in three volumes edited by the Gruppo di lavoro MS-AQ (2010). Many other scientific papers were written by the various scientists involved. Special issues of a few national and international reviews have been dedicated to this topic (Ingegneria Sismica, 2011; Italian Geotechnical Journal, 2013). A synthesis of the geotechnical analyses performed has been made by Monaco et al. (2012) and Santucci de Magistris et al. (2013). Results of the 2-D analysis of local response are given in Chamlagain et al. (2013) and Madiai and Simoni (2013), for two areas located in the upper and middle Aterno river valley respectively (NW and SE of L'Aquila town).

In Figure 27 the final map of SM of the city of L'Aquila is reported.

9. **Conclusions**

SM has a double-sided face: it is not only a scientific operation but also a political and cultural operation with social consequences which require key provisions for citizen safety. SM is one of the basic cognitive tools for seismic risk reduction, for reading and interpreting the territory in its specificity, hazards, vulnerability and exposition, and also in its potential resources, for a safer life and higher quality of life.

The case of L'Aquila shows clearly that SM involves so many scientific questions that the studies may be enlarged endlessly; in this sense each SM is always an unfinished work. But it is also evident that, even if they are fundamental for advancing the frontiers of knowledge, these types of studies are a rarity not compatible with the principle of a comprehensive diffusion of SM in each urban centre of our country.

But the growing demand for ordinary SM studies collides with a growing need for scientific correctness. From a technical and scientific point of view, in some Italian regions the state of the art in SM is now very advanced and it is possible to give adequate scientifically correct answers to the many questions that arise for the reduction of seismic risk on an urban scale.

But in other parts of the country the state of knowledge and practice are much behind. The risk is that it may spread the idea that a study of SM is a simple, routine operation that can be done at home, by using automatic software or other unknown procedures. Trash SM maps may be a high risk factor exactly like earthquakes. Any SM study, even if of Grade-1, requires specific competences to join together science and art. It needs science inasmuch as it is necessary to manage a variety of advanced and complex methods that are the result of shared and consolidated experiences on a global scale. It needs art because it requires a great capacity of reading and interpreting the territory in its specificity, in its hazards and constraints.

In the less advanced regions, governmental actions (ordinances, guidelines, economic incentives, etc.) have a fundamental role of cultural promotion in order to bring the state of the art to a higher level through the training of local experts. Also scientists have key functions in the transfer of knowledge and in the organization of those basic services for SM studies (cartography, GPS systems, digital data banks, etc.).

In this context, the Act (June 24 2009 n. 77) and the following ordinances for regulating the distribution of resources to those regions that promote studies of seismic microzoning constitutes a real challenge for our country.

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Gli studi di microzonazione sismica in italia: una breve storia e alcune recenti esperienze

T. Crespellani

SOMMARIO – *Con l'obiettivo di diffondere e sostenere una cultura della prevenzione sismica, il governo italiano ha emanato una legge (24 Giugno 2009, n. 77, art. 11) che, attraverso una serie di susseguenti ordinanze, regola la distribuzione di risorse alle amministrazioni regionali che promuovono studi di microzonazione sismica (MS).*
Il numero degli studi di MS è andato perciò negli ultimi anni aumentando rapidamente, specialmente nell'Italia Centrale, ponendo nuovi problemi e nuove sfide sia agli amministratori che agli esperti in materia sismica, chiamati a garantire la correttezza scientifica delle nuove sperimentazioni.
Lo scopo del lavoro è illustrare, attraverso un breve esame di alcuni casi significativi recentemente condotti in Emilia Romagna (a Spinello e a San Carlo e Mirabello) e in Toscana (a Barberino di Mugello), la filosofia emergente del nuovo filone di studi di MS finalizzati alla riduzione del rischio e alla crescita di una cultura della prevenzione sismica a scala locale. A titolo di confronto, verrà anche illustrato l'esempio di MS della città de L'Aquila, che ha coinvolto esperti afferenti alle più importanti istituzioni italiane specializzate nella difesa dai terremoti.
Verranno in particolare esaminati i problemi che non trovano precedenti negli studi di MS finora condotti e i nuovi compiti degli esperti e degli studiosi in materia sismica, chiamati a contribuire, nel contesto creato dalla legge n. 77, all'avanzamento, a scala locale, delle frontiere della conoscenza e dello stato della pratica.

Parole chiave: Microzonazione sismica, Effetti di sito, Amplificazione della risposta sismica locale, Rischio di frana, Liquefazione del terreno

A seguito del terremoto distruttivo che ha colpito nel 2009 la città de L'Aquila, il governo italiano ha emanato una legge (legge 24 Giugno 2009, n. 77, art. 11) a cui hanno fatto seguito tre ordinanze (OPCM n. 3907/2010, OPCM n. 4007/2012, OCDPC n. 52/2013) aventi come oggetto la disciplina per la distribuzione di risorse alle amministrazioni regionali che promuovono studi di microzonazione sismica (MS). Si tratta di un evento molto rilevante nel panorama sismico italiano perché con questi atti legislativi il governo non solo ha dato prova di investire politicamente sulla prevenzione e sul tema degli effetti di sito – che in Italia per la sua configurazione orografica è di particolare rilievo (come gli effetti disastrosi dei terremoti continuamente dimostrano) –, ma anche perché ha conferito un riconoscimento ufficiale agli studi di MS fino ad ora ritenuti solo un prodotto di interesse scientifico (e talora persino un po' velleitario).

Ma, come ben noto, la MS sismica non è solo un'operazione scientifica. Ha anche una dimensione sociale. La MS è oggi uno degli strumenti di conoscenza indispensabili per la riduzione del rischio sismico, per leggere e interpretare il territorio nei suoi aspetti specifici di esposizione e vulnerabilità, per stabilire gerarchie di pericolosità a scala regionale e locale, per prendere le opportune misure di sicurezza nelle zone più esposte, per pianificare i nuovi interventi strutturali e infrastrutturali sul territorio, per identificare scenari di pericolosità a scala più vasta di quella della singola costruzione, per identificare le sue risorse potenziali. La conoscenza delle risposte dei vari siti è una condizione imprescindibile per prendere decisioni di governo del territorio. È perciò fondamentale nella pianificazione territoriale e urbanistica, nella progettazione sismica, nella pianificazione e gestione dell'emergenza nonché nella ricostruzione post-sisma. Insieme alle normative sismiche e alla classificazione del territorio, è una componente essenziale delle strategie di difesa dai terremoti.

Poiché a seguito soprattutto della legge n.77, il numero delle MS è andato crescendo, nel tentativo di capire le implicazioni di questa diffusione degli studi di MS sul territorio nazionale e le loro interrelazioni con le norme sismiche, si è aperto in Italia un ampio dibattito, che ha visto una larga partecipazione non soltanto di ricercatori ed esperti afferenti a istituzioni accademiche e specializzate in materia sismica, ma anche amministratori dello stato e dei governi locali, funzionari e tecnici del Dipartimento della Protezione Civile e professionisti.

Al centro della discussione c'è soprattutto l'idea della diversità dei nuovi studi di MS rispetto a quelli riportati nella letteratura specifica. A differenza degli studi precedenti, in genere molto elaborati, scientificamente complessi, di lenta conduzione e dai costi elevati, i nuovi studi devono essere portati avanti con metodi di semplice applicazione, celermente e con costi ridotti. Lo scopo non è infatti quello di ottenere il migliore prodotto possibile a qualunque prezzo ma il miglior documento finale compatibile con l'obiettivo di amministratori responsabili di ridurre realmente il rischio sismico nel territorio. Facendo perciò i conti con le risorse e i tempi a disposizione.

Si tratta di studi di MS che, per distinguerli dai prodotti precedenti, si possono definire *ordinari* o di terza generazione, nel senso che, a differenza degli studi tradizionali, di carattere tipicamente scientifico e di avanguardia (prima generazione) o frutto di sperimentazioni, legate a un dialogo estemporaneo tra alcuni studiosi e talune amministrazioni illuminate (seconda generazione), sono indirizzati esclusivamente alla riduzione del rischio sismico in un dato territorio. Sono cioè studi che devono rientrare nelle normali attività di prevenzione, con il coinvolgimento, nella misura più ampia possibile, di amministratori e professionisti locali. Come si potrà vedere dagli esempi di seguito presentati, anche se vengono talora coinvolti singoli esperti o dipartimenti universitari, i soggetti promotori, gli attori, gli utilizzatori sono i tecnici delle amministrazioni e i professionisti locali. Sono cioè uno strumento conoscitivo della pericolosità regionale che deve essere messo a punto *dalla* società e *per* la società.

Ma la crescente domanda di questo tipo di studi di MS collide con una crescente necessità di correttezza scientifica. In alcune regioni italiane lo stato dell'arte è oggi molto avanzato ed è possibile dare risposte scientificamente corrette alle tante questioni sollevate da uno studio di microzonazione ordinario. Ma in altre parti del paese lo stato delle conoscenze e della pratica è molto indietro. Il rischio è che si possa diffondere l'idea che gli studi di MS possano essere eseguiti in modo semplicistico, usando qualche software in commercio e procedure automatiche indecifrabili, producendo documenti '*trash*' altrettanto pericolosi quanto i terremoti. Ogni studio di MS, anche di Grado-1, richiede sempre competenze qualificate specifiche e deve unire insieme scienza e arte. Esige scienza in quanto si tratta di padroneggiare metodi avanzati e complessi anche nelle forme semplificate, metodi che sono il risultato di esperienze e ricerche condivise a scala internazionale e che devono essere usati con cautela e discernimento. Esige arte perché occorre una grande capacità di leggere e interpretare il territorio nelle sue specificità, rischi, risorse e vincoli. Perciò il problema di 'accompagnare' scientificamente le ricerche delle nuove microzonazioni è un problema reale e denso di implicazioni.

Lo scopo di questo lavoro è duplice. Il primo è illustrare la filosofia emergente del nuovo filone di studi di MS, attraverso l'esame di alcuni casi-studio significativi, recentemente condotti in Emilia Romagna (a Spinello e a San Carlo e Mirabello) e in Toscana (a Barberino di Mugello). Per meglio comprendere la logica dei nuovi studi viene presentato anche il caso della MS de L'Aquila, la cui filosofia è invece quella classica, che vede la MS come occasione per un ampliamento delle frontiere della conoscenza scientifica. Si colloca quindi nel contesto delle microzonazioni di tipo scientifico, in genere portate avanti con il coinvolgimento di molti esperti e scienziati dopo un terremoto distruttivo per trarne lezioni e ammaestramenti.

Lo studio di MS de L'Aquila, promosso dal Dipartimento della Protezione Civile Italiana con il contributo scientifico di 150 ricercatori e studiosi afferenti alle più importanti istituzioni accademiche e di ricerca del paese, mostra che se si vogliono approfondire le tante questioni scientifiche sollevate da un terremoto le ricerche possono essere dilatate senza limite; in questo senso ogni studio di MS è sempre un lavoro non finito che può proseguire indefinitamente. Ma è anche evidente che questo tipo di studi non può che costituire una rarità, ed è incompatibile con il principio di una diffusione di studi di MS in ogni centro abitato delle zone esposte al rischio sismico. Perciò la diffusione di nuove forme di MS trova forti motivazioni.

Il secondo obiettivo è indicare, nel contesto creato dalla legge n. 77, i nuovi compiti dei governi locali e il ruolo degli esperti in materia sismica.

Infatti, per garantire la qualità scientifica degli studi di MS ordinari, i governi locali (regioni, province, comuni) hanno ora nuovi doveri. Devono cioè impegnarsi, insieme a scienziati ed esperti, a promuovere azioni positive specificamente indirizzate a migliorare lo stato delle conoscenze e della pratica nel campo della riduzione del rischio sismico, ad accrescere il numero e le capacità tecniche degli amministratori e dei professionisti locali, a ridurre i tempi e i costi delle indagini geologiche, geofisiche, geotecniche, ecc. Occorre cioè che le amministrazioni locali (specialmente quelle regionali) forniscano agli operatori quegli strumenti di conoscenza di base indispensabili per leggere il territorio in prospettiva sismica in modo scientificamente corretto, educando una classe di funzionari tecnici e professionisti ad effettuare tale lettura.

Questo significa redigere carte geologiche (anche in forma digitale) in scala appropriata per gli studi di MS (1:10000 o 1:5000) coprendo tutto il territorio esposto al rischio sismico, comporta stendere specifici criteri e indirizzi per uniformare le metodologie e i prodotti degli studi di MS nella regione, creare banche dati regionali di tipo sismologico, geologico e geotecnico, controllare la correttezza scientifica degli studi e delle carte di MS, promuovere corsi di formazione per tecnici e professionisti, sostenere i professionisti locali nelle fasi di avviamento degli studi, controllare i documenti prodotti e così via.

Nelle regioni meno avanzate, le azioni positive dei governi regionali (ordinanze, raccomandazioni, banche dati, ecc.) rivestono un ruolo fondamentale ai fini di innalzare lo stato dell'arte portandolo a un livello più alto. Ma anche gli studiosi e gli esperti hanno delle funzioni chiave nella trasmissione del sapere e nella organizzazione di quei servizi di base per gli studi di MS (cartografia, sistemi GPS, banche dati digitali, stesura di indirizzi e raccomandazioni, ecc.). Perciò, in questo contesto, la legge del 24 giugno 2009, n. 77 e le successive ordinanze emanate dal governo italiano, costituiscono una grande sfida per il futuro del paese in materia di riduzione del rischio sismico.

In questo lavoro, dopo una breve rassegna dei più importanti casi storici di studi di MS in Italia, come già anticipato, vengono presentati in dettaglio quattro casi recenti, dei quali tre di tipo ordinario e uno tradizionale. Si tratta in tutti i casi di studi di Grado-3, perché, anche nei tre casi ordinari, la complessità delle situazioni ha richiesto il sostegno scientifico e l'esperienza di studiosi della materia – nel caso specifico afferenti all'Università di Firenze – seppure con il coinvolgimento di professionisti locali.

Il primo caso esaminato si riferisce a uno studio di microzonazione nel centro abitato di Spinello, un centro dell'Emilia Romagna, soggetto a fenomeni franosi oltre che ad effetti amplificativi della risposta sismica locale. La presenza di movimenti in atto ha richiesto perciò anche verifiche sulla stabilità dei pendii sia in condizioni sismiche sia non sismiche. Essendo molte le condizioni di incertezza, sono state esplorate le diverse risposte alle varie situazioni ipotizzate in modo da identificare la rosa delle situazioni più critiche. La carta finale di microzonazione tiene conto delle varie criticità identificando una gerarchia dei rischi.

Il secondo esempio è lo studio di MS condotto nelle località di San Carlo e Mirabello, dopo gli eventi sismici del 29 maggio 2012 che hanno provocato in tali località estesi e appariscenti fenomeni di liquefazione. In particolare dettaglio vengono esaminati i risultati delle numerose indagini in sito effettuate dopo il terremoto e le analisi condotte per ridurre in futuro i rischi legati alla liquefazione. Viene quindi riportato il documento finale dello studio di MS.

Il terzo caso illustrato riguarda Barberino di Mugello, un centro abitato della Toscana che ricade in un'area dove sono possibili fenomeni amplificativi e a terremoti severi. Vengono descritte le indagini e le analisi effettuate per l'analisi della risposta sismica locale e vengono riportati i risultati finali nella carta di MS.

Come già anticipato, il quarto caso riguarda la città de L'Aquila. Il caso viene esaminato in quanto la sua filosofia si contrappone a quella dei casi di MS ordinari. Ma non solo per questo. Il caso riveste infatti un grande interesse scientifico sia sotto il profilo metodologico che dei risultati conseguiti. Infatti, il Dipartimento della Protezione Civile Italiana, che ha promosso e finanziato l'impresa, ha chiamato a raccolta circa 150 studiosi afferenti alle principali istituzioni accademiche e di ricerca. Il caso è emblematico del fatto che gli studi di MS, specie dopo un terremoto, sono un'occasione ineguagliabile per l'unificazione delle conoscenze scientifiche sul territorio, per vagliare metodi e procedure, per identificare le frontiere che si stanno aprendo a scala mondiale per la MS in tema di strumentazione e di tecnologie avanzate.

In sintesi, i quattro casi dimostrano che la coesistenza tra studi di MS ordinari e studi di MS non solo è possibile ma anche auspicabile.

I casi ordinari di MS esaminati evidenziano che di fronte alle nuove sfide sociali di prevenzione e riduzione del rischio sismico, la predisposizione di strumenti di conoscenza e il trasferimento di sapere rappresentano un percorso obbligato per un salto di qualità degli studi di MS. Perciò amministratori e tecnici dei governi locali devono trovare, attraverso il dialogo con gli esperti in materia sismica, i modi per predisporre gli strumenti indispensabili per una conduzione scientificamente corretta degli studi di MS ordinari.

Ma è anche fondamentale che vengano promossi e valorizzate alcune occasioni di confronto scientifico a scala nazionale e internazionale che facciano avanzare lo stato dell'arte in materia di difesa dai terremoti, con ricadute che, anche a scala locale, si possono rivelare benefiche nel breve e nel lungo periodo.