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# The Italian policy for Seismic Microzonation

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ABSTRACT: After the first pioneering Seismic Microzonation (SM) studies carried out in the aftermath of the strongest Italian earthquakes in 1976, 1980, 1997, 1998 and 2002, to support the relevant reconstruction processes, the "Guidelines for Seismic Microzonation" (GSM08 2015) were released in 2008 by the Civil Protection Department (CPD) and the Conference of Italian Regions. The Guidelines not only inform on how SM studies aimed at identifying and characterize the different microzones should be carried out, but also on how SM outcomes should be used for territory management, emergency planning, post-earthquake reconstruction and structural design. According to GSM08, SM studies may be carried out at various levels of growing complexity and commitment, from level 1 to level 3. After the 2009 Abruzzo (L'Aquila) earthquake, almost one billion euro in seven years were allocated for a National Plan for Seismic Prevention to be set up by CPD in the Italian territory with seismic hazard characterized by ag≥ 0.125g. The plan has invested about 10% of the total fund in the SM of municipalities and in the evaluation of the seismic resilience of their urban emergency systems (Emergency Limit Condition – ELC). This investment enables about half of Italian municipalities to be endowed with SM - at least level 1 - and ELC. Finally, in order to assist the reconstruction process in the areas damaged by the 2016-17 Central Italy seismic sequence, the Italian Government allocated the funds needed for the level 3 SM studies complying with GSM08 of the 138 municipalities affected by the earthquake. The present paper describes the main challenges and achievements of SM in Italy.

## 1 INTRODUCTION

In Italy, pioneering seismic microzonation (SM) studies started in the 70s, after the Ancona 1972 and Friuli 1976 earthquakes, and then after the Irpinia 1980 earthquake, while more modern quantitative approaches were implemented after the Umbria-Marche 1997, Pollino 1998 and Molise 2002 earthquakes. In all these cases the aim was to provide local hazard information for the reconstruction process.

A radical change was introduced in 2008, with the release of the "Guidelines for Seismic Microzonation" (GSM08 2015), by the Civil Protection Department (CPD) and the Conference of Italian Regions. The Guidelines not only inform on how to carry out studies aimed at identifying and characterize stable areas, stable areas susceptible to local amplifications and areas subject to instability, but also on the use of SM outcomes for territory management, emergency planning, post-earthquake reconstruction and structural design. According to GSM08, SM studies may be carried out at various levels of growing complexity and commitment, from level 1 to level 3.

The first important test of the Guidelines was made in Abruzzo, soon after the 2009 earthquake, where a level 3 SM was carried out in the most damaged municipalities, involving about 150 researchers and experts (Working Group MS–AQ 2010). In the meanwhile, Law 77/2009, concerning the reconstruction of the affected areas, allocated almost one billion euro in seven years for seismic prevention on the Italian territory. The National Plan for Seismic Prevention set up by CPD was aimed to primarily reduce human losses and to improve emergency management where higher intensities are expected. For this reason, the Plan is limited to the territories with seismic hazard characterized by ag≥ 0.125g. The plan has been implemented by investing not only in the seismic upgrading of buildings and infrastructures, but also in the SM of municipalities and on the evaluation of the seismic resilience of their urban emergency systems (Emergency Limit Condition – ELC), according to an integrated and prospective strategy for seismic risk mitigation. This investment allows about half of Italian municipalities, i.e. the most seismically dangerous ones, to be endowed with SM - at least level 1 - and ELC.

The 2016-17 Central Italy seismic sequence occurred when the level 1 SM activities were completed or still in progress in many affected municipalities. In order to accelerate the process and assist the reconstruction process, the Italian government allocated the funds needed for the level 3 SM studies complying with GSM08 of the 138 municipalities affected by the earthquake to be carried out in few months by professionals, with the technical-scientific assistance and advice of the concerned scientific community, through the Seismic Microzonation Centre, and of CPD.

The 50 years' history of seismic microzonation in Italy is then characterized by an evolutionary continuity, in which the scientific advancements have been developed in parallel with practical applications, for which strong coordination efforts of the national and local stakeholders, and of the scientific and the technical communities have been made. The most important and qualifying aspects of this complex process are described in the present paper, along with the results achieved so far.

## 2 PIONEERING EXPERIENCES

*"Spectators who found themselves above the eminent places, saw the peaks, and the planes of the mountains moving like the melting of the ice in the cold countries, and the waves of the sea, regurgitating in the Messina Canal, took away the petty inhabitants from the beaches and threw the fish into it"* (Torcia 1783).

This is one of the best-known descriptions of the effects on the territory of the 1783 earthquake in Calabria (Italy), a "descriptive seismic microzonation" which, however, makes the gravity of the problem very well.

The report of the Italian seismologist Mario Baratta following the great 1908 earthquake of Calabria and Sicily (Baratta 1910) marks the first (and perhaps also the only one until 1970) study of SM in Italy. The key element of the approach is the detailed reconstruction of damage to buildings in relation to morphological and geological features of the territory. The aim of that seismic microzonation is in fact the understanding of the phenomenon, from which general indications emerge for the planning of the reconstruction, that will be integrated in the later technical rules for the reconstruction (Royal Decree 18 April 1909, No. 183). One of the technical documents supporting the rules reports as follows:

"*It is forbidden to construct buildings on marshy lands, landslides, and on the boundary between soils of different stiffness, or above a steep slope, except when it is a compact rock; in which case it is essential to prepare one or more horizontal support surfaces for the building, carrying out the necessary excavations*".

Curiously, in the technical reconstruction commission, a geologist is missing.

Although in the world (USA, Japan) studies on the subject have been ongoing since the 50s, in Italy between 1970 and 1980 only "experimental" SM studies not related to seismic events had been carried out, which had no impact on the current legislation. Following the two earthquakes of Ancona (1972) and Friuli (1976), two SM studies were carried out in the post-event phase (even if on relatively small areas such as those of Ancona and Tarcento respectively). However, the use of intensive and advanced techniques (extensive data collection of *ad-hoc* surveys produced, 1D and 2D modeling of the local seismic response) would have laid the methodological foundation for future studies (Faccioli 1986).

The possibility of extensively applying what emerged from the experiences of Ancona and Tarcento was offered by the activities promoted by the CNR's (National Research Council) Finalized Geodynamic Project (PFG) to support the reconstruction of the areas affected by the 1980 Southern Italy (Irpino-Lucano) earthquake. PFG involved, in addition to CNR, several Universities, with the active support of regional experts of the Emilia-Romagna and Tuscany Regions (CNR-PFG 1983). This is a turning point in quantitative terms: 39 inhabited centers of Campania and Basilicata were microzoned, with all the implications in terms of coordination, management and expenses. The large area extension implied the wide use of essentially rapid qualitative methods (geological and geomorphological elements together with observed damage data). The geomorphological surveys that focus on the delimitation of areas with unstable land were of particular importance.

Another important experience was made after the earthquake that hit Umbria and Marche in 1997. It concerned again an extended area (there were 60 towns involved). Also in this case, the local public administrations (Marche and Umbria) largely contributed to the investigation and construction of seismic microzonation maps, together with the National Seismic Service (now incorporated in the Civil Protection Department) and CNR.

After 1986, until the Molise earthquake (2002), the approach to seismic microzonation did not change substantially, even if new low cost geophysical techniques were introduced (i.e. H/V method after Mt. Pollino earthquake, 1998) and were widely applied on subsequent occasions. In reality, with the seismic microzonation of San Giuliano di Puglia (Molise), the SM studies changed significantly under two essential aspects:

- a new and more complex seismic design code was introduced, that required studies of local seismic response at the scale of building (at least under certain conditions) and in any case provided a new possible "language" to SM (i.e. classes of foundation soil).
- for the first time, the Regions and their technical offices began to develop their own SM projects, giving rise to a long-term vision, which considers SM as a tool for reducing seismic risk in the territorial planning phase and not only an emergency management tool.

## 3 GUIDELINES FOR SEISMIC MICROZONATION (GSM08)

The progress of the different experiences carried out by the various Regions (the list progressively included Umbria, Molise, Lazio, Basilicata, Lombardia, Emilia Romagna) and the growing heterogeneity of the proposed approaches led the Conference of Regions and Autonomous Provinces to define updated addresses for future SM activities.

After one year of elaboration and drafting work, in 2008, the "Guidelines for Seismic Microzonation" (GSM08), were released jointly by the Civil Protection Department (CPD) and the Conference of Italian Regions (GSM08 2015). The document was designed and implemented with the help of regional experts, who have been working on the topic for years, and of numerous researchers from universities and national scientific institutions, coordinated by the Civil Protection Department. These guidelines not only inform on how to carry out studies, but also on the use of their outcomes for territory management, emergency planning, post-earthquake reconstruction and structural design. There are also described, in attached documents, some procedures for SM studies, which represent, on their own, operational tools for the application of the criteria: mode of preparation of investigations, drafting of the maps, composition of the abaci for amplification evaluation and simplified procedures.

The results of the SM studies are summarized and represented on thematic maps of the territory, maps of Homogeneous Microzones in Seismic Perspective (HMSP, Figure 1) and SM maps, distinguishing (according to Guidelines for seismic microzonation, GSM08 2015):

- stable zones, in which the seismic motion is not modified with respect to that expected in ideal conditions of rigid rock (a stone rock not pervaded by fractures and not affected by significant phenomena of alteration) with flat horizontal surface;
- stable zones with amplifications, in which the seismic motion is modified, compared to that expected in ideal conditions of rigid and flat rock, due to the geological/geophysical/geotechnical and/or morphological characteristics of the territory;

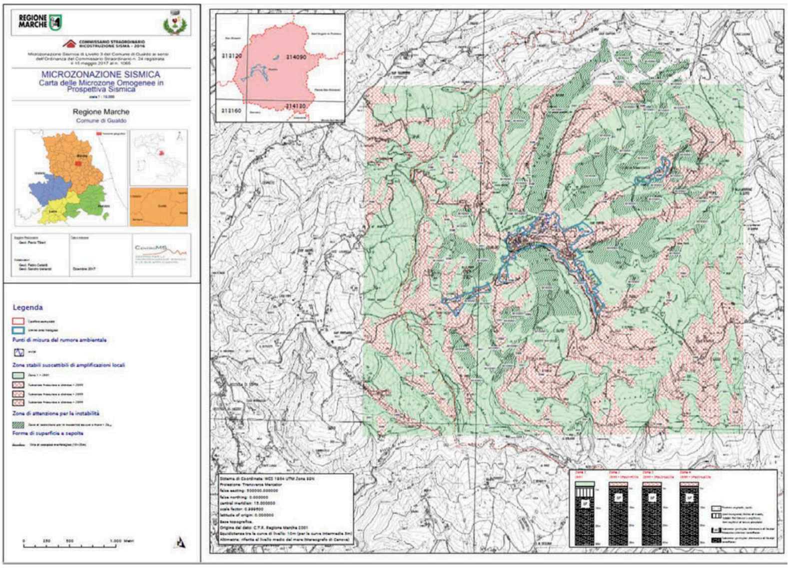


Figure 1. Map of Homogeneous Microzones in Seismic Perspective (HMSP) (example).

- unstable zones, where earthquake deformation phenomena can be activated (triggered by the earthquake), such as landslides, soil liquefaction, superficial faulting and differential ground subsidence that can create morphological steps.

According to the different scales and the different levels of intervention (see below), SM studies are conducted on the areas in which the land use regulations foresee their use, or their potential transformation, for building or infrastructures purposes, or their use for civil protection purpose.

The SM studies for this scope are important in order to:

- guide the choice of areas for new settlements;
- define the eligible interventions in a given area;
- plan surveys and levels of detail;
- establish guidelines and methods of intervention in urban areas;
- define intervention priorities.

According to GSM08, the SM studies are divided into three levels of detail. Level 1 of SM consists of a collection of pre-existing data (inventories) or results from specific rapid survey campaigns (in particular environmental seismic noise measurements), elaborated in order to divide the territory in qualitatively homogeneous zones with respect to the phenomenology described above (amplifications and permanent instabilities). Level 1 is aimed also at the creation of the geological model of the subsoil (in seismic perspective) of the studied area, as well as the identification of the different types of zones as defined above. Level 2 (when geological and morphological conditions allow for the use of simplified methods) and level 3 of SM associate values of amplification factors (AF) (both levels) and response spectra (only level 3) to the stable zones subject to amplification as defined in level 1. Both levels, with the acquisition of new data, can lead to the revision of the HMSP maps (level 1) and characterize permanent instabilities through specific parameters. Level 1 and 2 can only be applied to land planning, while level 3 can also support the seismic design of constructions.

The final maps of the level 2 and 3 studies, according to national and regional guidelines (GSM08 2015), provide the distribution on the territory of the Amplification Factors (AF), defined as:

$$AF = \frac{\int_{Ta}^{Tb} Sa\, dT}{\int_{Tb}^{Ta} Sb\, dT}$$

Where: *Sa* is the elastic response spectrum at the study site (usually at the surface), *Sb* is the elastic response spectrum at the reference site (nearby site where the bedrock, i.e. type A ground, outcrops); $T_a$ and $T_b$ represent the extremes of the interval of vibration periods T of interest.

The amplification factors (AF) provide quantitative information on the modifications of the response spectrum due to the peculiar geological, geophysical and geotechnical characteristics of the considered microzone, with respect to the reference spectrum derived from the basic hazard, for the different intervals of vibration period taken into consideration.

In conclusion, GSM08 is a national reference for studies aimed at the seismic characterization of the territory. The GSM08 have been later updated (Technical Commission for Seismic Microzonation 2017a; 2017b) and integrated by specific guidelines for the management of the territory in areas affected by seismic instability (superficial faulting, liquefaction, landslides). The urban and territorial planning in these areas has been regulated by referring to the urban categories and to the conditions of greater or lesser danger (ZA, zone of attention, ZS, zone of susceptibility, ZR, zone of respect).

The discipline of land use and transformation provisions in areas of instability has been divided into two types of indications:

- urban planning indications, which define possible regulations by the urban planning instrument also in terms of intervention categories and designated use and implementation methods;
- building indications, which define, with reference to the seismic technical regulations, which categories of intervention are possible for existing and new buildings and on which classes of use.

## 4 THE POST-EARTHQUALE SEISMIC MICROZONATION IN ABRUZZO IN 2009

On 6 April 2009 at 3.32 (local time) a Mw 6.3 (according to INGV-CPTI15, https://emidius.mi.ingv.it/CPTI15-DBMI15/) earthquake destroyed the historic city of L'Aquila (Abruzzo, Italy) and dozens of villages along the Aterno River Valley. In order to support the reconstruction process, a microzonation study of the most damaged areas was immediately started (Working Group MS–AQ 2010).

The L'Aquila earthquake provided the opportunity to make an important test of the methodologies given in the "Guidelines for Seismic Microzonation". For the first time, with the contribution of about 150 researchers and experts from various universities, research institutes, technical offices of the Italian Regions, a high quality seismic microzonation at level 3 of GSM08 was achieved; these studies made it possible to characterize homogeneous areas with numerical parameters of ground shaking. The SM studies were promoted and coordinated by the Civil Protection Department and the Abruzzo Region. They met the needs of the reconstruction process of the municipalities that had undergone a macroseismic intensity equal to or higher than the VII MCS degree. 44 localities were studied. The activity was organized into 10 thematic tasks, as follows.

- Task 1: Previous data retrieval and archiving.

Approximately 300 stratigraphical logs were collected, organized and computerized together with *in situ* geognostic data (SPT, CPT, etc.). An information system was built, which was made available through a WebGis tool, for uses related to the future management of the territory.

- Task 2: Definition of the geological-technical model of the subsoil and the coseismic phenomena.

For each area interested in seismic microzonation, a technical geological survey was carried out, 1:5000 scale maps and a series of representative geological sections were produced. In these maps the main seismic deformations (active and capable faults, seismic landslides, differential subsidence) are also reported.

- Task 3: Geotechnical subsoil characterization.

Approximately 100 litostratigraphic boreholes were drilled in which *in situ* geognostic analyses were carried out and undisturbed samples were taken for laboratory tests (physical and dynamic characteristics).

- Task 4: Geophysical subsoil characterization.

In all drilled boreholes, a seismic analysis (Down Hole) was conducted. In all the sites seismic refraction analysis, MASW surveys, Re.Mi. surveys and geoelectrical acquisitions were conducted.

- Task 5: Instrumental analysis of aftershocks and microtremors.

In all the sites, immediately after the main event, arrays of accelerometric stations were positioned and seismic noise analyses were performed with portable digital instruments.

- Task 6: Determination of the input earthquake for numerical simulations.

Based on seismotectonic data, historical seismicity and accelerometric data, seismic inputs for the numerical simulations were determined.

- Task 7: Numerical simulations.

On the basis of the geological, geotechnical and geophysical data collected, a series of 1D and 2D lithotechnical sections were prepared and were analyzed: numerical simulations were performed using different numerical codes chosen according to the geological-technical data represented in the sections.

- Task 8: Damage analysis

In some areas (Onna and San Gregorio, Castenuovo, other villages in the L'Aquila surroundings) a damage analysis was conducted, accompanied by a detailed analysis of the vulnerability of the buildings.

- Task 9: Relationships with urban planning and seismic code.

The areas surveyed for the microzonation seismic studies was defined in agreement with the municipal administrators and experts, identifying the local planning problems. All the regulatory plans were collected and computerized; the main tables of the regulatory plans were superimposed on the seismic microzonation maps. Both the inputs and the spectra obtained at the ground surface with the numerical simulations were compared with those proposed in the seismic code.

- Task 10: Production of reports, cartography and data dissemination.

Basic data and results were reported in a monograph with plenty of data and maps and on a DVD (Working Group MS–AQ 2010).

## 5 THE NATIONAL SEISMIC PREVENTION PROGRAM

After the L'Aquila earthquake in 2009, Decree n. 39 of 28/4/09 (Art. 11) allocated a budget of 965 M€, distributed in the years 2010-2016, for activities of seismic risk reduction in Italy.

This amount is just a small fraction of what is actually needed, nevertheless a wide-spectrum national plan for seismic risk mitigation has been implemented by the Italian Civil Protection Department. The primary objective of the plan is to reduce human losses, so that the action is especially addressed to high hazard and high risk areas. It is implemented not only through the seismic upgrading of structures, to produce the immediate reduction of the seismic risk of the retrofitted constructions, but also through the evaluation of the local seismic hazard and the seismic resilience of urban systems, according to a more integrated and prospective strategy for seismic risk mitigation (Dolce 2012).

The following lines of action have been implemented:

- Seismic microzonation studies and analyses of the emergency limit condition;
- Vulnerability reduction of strategic public buildings and bridges/viaducts and of private buildings;
- Urgent intervention.

Funds were distributed among different Italian regions based on a seismic risk index drawn from the probability of building collapses in the various regions, as derived from the seismic risk assessment maps available in 2010 produced by the Civil Protection Department and by its centres of competence. Moreover, only the municipalities with a seismic hazard characterised by peak ground acceleration on stiff soil with horizontal surface, as given by the Italian 475 years return period hazard map MPS04 (Stucchi et al. 2004), higher than 0.125 g were allowed to access the contribution (Dolce 2012).

To summarise, the philosophy of the national prevention program is essentially based on:

- Pointing towards the reduction of the risk of human losses, rather than economic losses;
- Dealing with a wide spectrum of problems, then stimulating the attention of private owners and administrators towards the different problems of seismic risk (vulnerability of buildings, importance of local amplification and coseismic effects and use of microzonation studies to improve urban and emergency planning, correct implementation of civil protection plans considering the vulnerability of the strategic elements and of the interconnection routes);
- Asking for co-funding by local public administration and by private owners, in order to multiply the actual effects of the fund allocated by the State.

The different actions are implemented through programs of the Regions and the Autonomous Provinces. The regional programs are defined according to the regional priorities and the fund available, considering the requests of municipalities. As said above, the plan was addressed not only to structural prevention, but also to non-structural prevention, through the seismic microzonation (SM) of municipalities and the evaluation of the seismic resilience of their urban emergency systems, through the Emergency Limit Condition (ELC) analysis, a new concept explained below, purposely introduced in the National Prevention Program. This investment allows about half of Italian municipalities, i.e. the most seismically dangerous ones ($ag \geq 0{,}125g$), to be endowed with SM - at least level 1 - and ELC analyses.

The state of advancement of the national Plan for Seismic Prevention can be found in: http://www.protezionecivile.gov.it/jcms/it/piano_nazionale_art_11.wp

### 5.1 *The Emergency limit condition*

Seismic risk evaluations in an urban context presuppose the definition of urban planning objectives, expressed in terms of the performance of a settlement or the diverse systems of which it is made, to be ensured in the case of an earthquake. The same objectives should orient further investigations and necessary interventions of prevention. In the absence of these indications it is very difficult to successfully identify focused actions and priorities of intervention; on the contrary, there is a risk of defining a framework of measures that is unsuitable to, or, worse yet, over dimensioned and thus impossible to implement.

With this aim, diverse possible limit conditions for urban settlements have been defined (see Bramerini et al. 2013). Limit conditions are defined as thresholds of physical and functional damage that, when exceeded due to an earthquake, a settlement – due to the damage suffered by the diverse systems of which it is made – is subject to significant modifications of its ability to function, whose progressive worsening compromises its very existence.

Analogous to the limit states in building codes (though referred to the structural performances of a single construction), various limit conditions can be defined for a settlement, corresponding to increasing losses in the ability of its component systems to function. It is possible to identify diverse limit conditions:

- the limit condition of operations (the settlement is not affected by significant modifications);
- the limit condition of damage (a reduction in functions that are partial or limited in time);
- the limit condition for safeguarding the existence of the settlement (damage that is significant or prolonged in time, though not sufficient to compromise the general characteristics of the settlement);
- the limit condition of collapse (when only a few primary urban functions resist, while many other functions, including housing, are compromised on the whole in the medium term).

Each limit condition presupposes the maintenance of some systems and some urban functions and the progressive loss of other functions, ending in a state of total crisis.

At the limit condition of collapse, the settlement, even if damaged, preserves the possibility to be recovered; in other words, it is possible to maintain or restore its general characteristics and the functionality of its component systems necessary for the restoration of ordinary urban, economic-social and relational activities. Having exceeded the damage corresponding with the limit condition of collapse, the restoration of the settlement is no longer ensured; the only urban functions that can be guaranteed are those indispensable to the management of an emergency.

This is a further limit condition that can be defined as the Emergency Limit Condition (ELC): a situation when, following an earthquake, an urban settlement taken in its entirety suffers physical and functional damage sufficient to produce the interruption of almost all of its urban functions, including housing. In any case, the settlement conserves the functionality of the majority of its strategic functions for an emergency and their connection and accessibility with its surroundings. In correspondence with the emergency limit condition, only the system of emergency management (comprised of Strategic Buildings, Emergency Areas, Infrastructures of Accessibility and Connection) remain active. Having surpassed this condition, the level of damage and loss of functionality is sufficient to compromise the effective and timely performance of assistance and first response, besides the restoration of the settlement.

The analysis of the ELC of an urban settlement needs:

a. the identification of buildings and areas that guarantee strategic emergency functions;
b. the identification of infrastructures of accessibility and connection with the rest of the territory, buildings and areas listed under point a) and possible critical elements;
c. the identification of Structural Aggregates and individual Structural Units that may interfere with the Infrastructures of Accessibility and Connection with the rest of the territory.

To this end, a set of Data Archiving Standards have been produced, based on the use of 5 typical forms and represented on a series of maps (in the format of shapefiles, Figure 2): SB Strategic Buildings (light blue), EA Emergency Areas (light green), AC Accessibility/Connection infrastructures (red and yellow lines), SA Structural Aggregates (orange striped), SU Structural Units (orange).

### 5.2 *Monitoring of SM and ELC activities*

The support and monitoring, at national level, of the SM studies and analysis of ELC are guaranteed by a National Technical Commission established in 2011, according to Article 5,

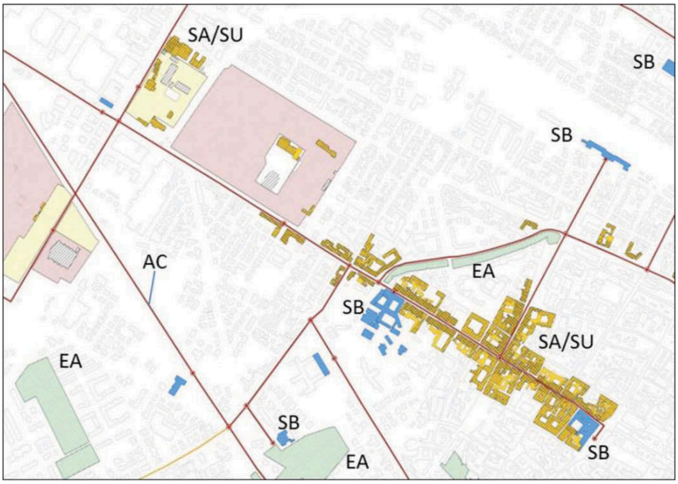


Figure 2. Map of Elements for ELC Analysis (detail).

OPCM 13 November 2010, No. 3907, whose membership includes representatives of the Regions and Autonomous Provinces, of the municipality association and of the professional chambers. This commission is also the body that formally approve the study of each municipality.

The state of implementation of the SM and ELC activities carried out with the funds of Law 77/2009 (around 100 million euros) is quite advanced, although the process to set up and approve the Civil Protection ordinances for each yearly fund and to set up regional programs, as well as to carry out the SM and ELC studies and deliver them in the correct shape, is quite long-lasting. To date (January 2019) a total of 3595 SM studies are planned, representing about 92% of the municipalities eligible for funding (3896 municipalities with ag≥0.125g). 1995 SM studies have been delivered (55%) and 1536 resulted to be compliant (77% of the delivered ones). As for ELC analyses, 3205 are planned, of which 1404 were delivered (44%) and 1013 were judged compliant by the above said Commission (72% of the delivered ones).

The maps in Figure 3 shows the municipalities for which the SM studies and the ELC analyses have been planned with the funds allocated by Law 77/2009.

Over 80% of the SM studies are level 1 studies (basic knowledge level). This was inevitable because few Regions had already started a seismic microzonation program before law 77/2009, and then it was not possible, as a first step, to proceed with the upper levels.

The high level of quality, standardization and homogeneity at the national level have been guaranteed by the general adoption of the standards for SM studies and for analyses of ELC prepared by the above said Technical Commission (Technical Commission for Seismic Microzonation, 2016) and, above all, of the "Guidelines for seismic microzonation" (GSM08 2015).

The availability of all the SM studies and ELC analyses in a standardized format allows statistical elaborations to be carried out and relevant general considerations to be made.

The preliminary statistical elaborations performed on the compliant studies show that only 9% of the studied territory falls into stable areas with no amplification effects, while about 21% are in areas prone to instability and the remaining 70% in areas susceptible to amplification. The analysis of the number and size of the areas highlights:

- the stable areas that can amplify are numerically the most represented and, on average, the most extensive ones;
- even the unstable areas are numerically significant, but they are the least extensive (average size per municipality less than 0.40 $km^2$);
- the stable not amplifying areas are numerically the least represented ones, with an average extension ranging between 0.03 $km^2$ in Calabria and Friuli and 0.95 $Km^2$ in Puglia.

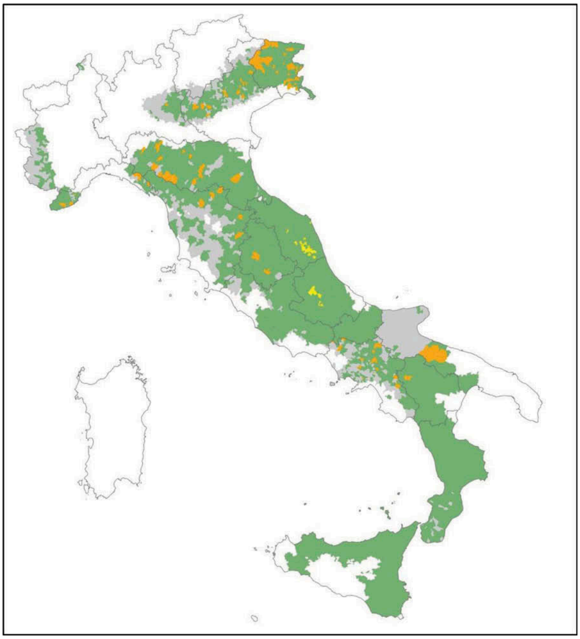

Figure 3. SM and ELC studies funded with the National Plan of contributions. Green: SM and CLE studies programmed or carried out. Orange: only SM studies programmed or carried out. Yellow: only CLE studies programmed. Grey: Municipalities that do not have yet programmed studies. White: Municipalities whose studies cannot be funded (ag≤0.125g).

Considering the intersection of ELC analyses with SM information, from the compliant studies received it comes out that 20,1% of the strategic buildings fall into unstable areas (Table1) and only 5,3% falls into stable areas with no or negligible local amplification. The remaining part of the strategic buildings (72.5%) falls into stable areas susceptible to amplification. Similar considerations apply to emergency areas and accessibility or connection infrastructures, as can be seen in Table 1.

Also interesting is the analysis of the distribution of the types of instability (Table 2): slope instability and liquefactions are the most represented, while only 4% of the territory examined and classified as unstable is due to presence of active and capable faults. These percentages refer only to the territory investigated and not to the whole Italian territory. The high value related to liquefactions is due to the relatively high number of SM studies of Regions affected by liquefaction potential (mainly in the Po Plan) that are included in these sample.

These general statistics emphasize the paramount importance of SM to identify safety problems to be tackled when planning future developments of a municipality as well as when planning future risk mitigation measures.

The entire activity has seen the full participation of the Regions, which have legislated to incorporate in the land planning the Seismic Microzonation and the analysis of the Emergency Limit Condition. They also defined the co-financing scheme envisaged by the implementing

Table 1. Strategic elements and location on the type of SM areas (percentage values)

| | Stable areas | Susc/Ampl areas | Unstable areas | Undefined |
|---|---|---|---|---|
| Strategic building | 5,3 | 72,5 | 20,1 | 2,1 |
| Emergency area | 6,5 | 70,9 | 19,6 | 3,0 |
| Accessibility/Connection infrastructures | 5,6 | 66,4 | 26,2 | 1,8 |

Table 2. Percentage distribution of types of instability

| Landslide | Liquefaction | Fault | Ground subsidence | Cavity |
|---|---|---|---|---|
| 39% | 47% | 4% | 7% | 3% |

ordinances, even in the well-known context of economic-financial difficulties. There has also been a broad involvement of Professional Bodies, primarily Geologists, who recognized in the initiative a moment of cultural growth and participation in a process of understanding risk improvement at the local level.

## 6 THE POST-EARTHQUAKE SM IN CENTRAL ITALY (2016-17)

The extension of the area affected by the seismic sequence of Central Italy, started on 24 August 2016 and continued with the shocks of 26 and 30 October 2016 and 18 January 2017, called for the decision of the Italian Government to promote a massive initiative to carry out SM level 3 studies in all 138 municipalities involved (Article 1 Decree Law 9 February 2017 No. 8), shown in Figure 4. The seismic sequence occurred when the level 1 SM activities funded by the National Plan were completed or in progress in many, though not in all, affected municipalities.

The Seismic Microzonation Center (SMC), established in the National Research Council but involving the entire concerned scientific community from universities and other national research institutions, was entrusted with the task of providing scientific support and coordination of the activities. On behalf of the Government Extraordinary Commissioner for the reconstruction, the SMC carried out technical-scientific support activities aimed at the preparation of criteria and the coordination of SM level 3 studies, that had to comply with the GSM08 and with all the relevant application documents set up by the National Technical Commission that monitors and supports the National Plan studies, as required by the above mentioned Decree Law n.8/2017.

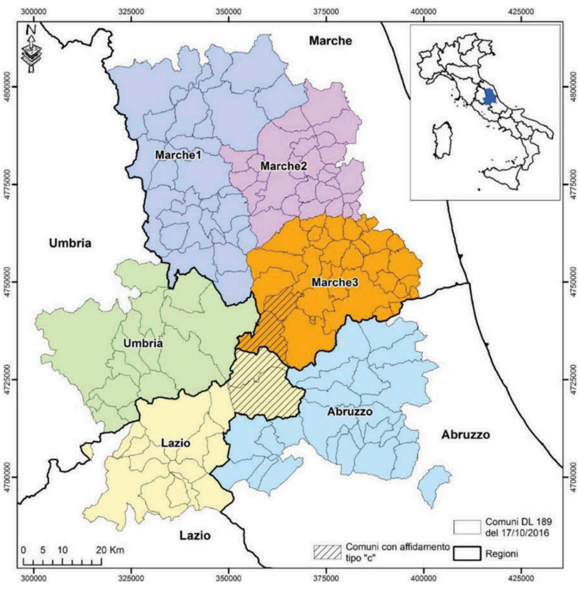


Figure 4. Territory of the 138 damaged municipalities of the four Regions Umbria, Marche, Lazio e Abruzzo, where the SM level 3 studies were carried out.

With subsequent Commissioner Ordinance (No. 24 of 15 May 2017), funds were allocated to municipalities for assignments to professionals in charge of SM level 3 studies. The activity was coordinated by the SMC for the Territorial Groupings identified by the aforementioned Ordinance (Abruzzo, Lazio, Marche 1, Marche 2, Marche 3, Umbria), as shown in Figure 3.

The SM studies were all assigned to professionals within June 2017 and after their training, carried out by SM Center and completed in July 2017, the SM studies were started. Almost all the studies were delivered to the Municipalities within the end of 2017 for the subsequent evaluation and validation by the Technical Working Group established at the Commissioner's Office. All the activities, including validation of the studies, was completed by May 2018.

The SM level 3 studies were carried out using local 1-dimensional (1D) and two-dimensional (2D) local seismic response analyses performed on representative verticals, in an appropriate number to characterize all the microzone typologies identified in the map of "Homogeneous microzone in seismic perspective (HMSP)". The results of the numerical analyses were elaborated in terms of amplification factors of pseudoacceleration and pseudovelocity (AF), calculated for prefixed intervals of periods of vibration, as well as of elastic response spectra in acceleration (5% structural damping) with reference to 475 return period.

For the purposes of using the results of the SM level 3 studies for local amplifications, the interval classes of the periods of vibration of interest were defined as follows:

- 0.1-0.5 s
- 0.4-0.8 s
- 0.7-1.1 s

The results of the SM studies are represented in maps, with reference to these period intervals for the use of both AFs and response spectra. With regard to the areas affected by coseismic instability and landslides, the analyses of the behavior in dynamic conditions was postponed, in agreement with the Commissioner, to subsequent specific studies.

Finally, in order to make the studies operational for reconstruction planning as well as for seismic design of interventions on existing damaged buildings (strengthening or replacement), General Criteria for the use of the results of SM level 3 studies for the reconstruction were established (Ordinances of the Government Extraordinary Commissioner for the reconstruction No. 24, 12 May 2017, and No. 55, 24 April 2018). In particular, concerning seismic design issues, the General Criteria specify how response spectra derived by SM level 3 studies for the microzone of the building site under consideration can help the designer to decide whether the simplified approach according to the national building code NTC18 (DM 2018; Decree of the Ministry of Infrastructures, 17 January 2018), based on soil profiles A, B, C, D, E, can be adopted or a seismic local response analysis has to be carried out. If this is the case, criteria are also provided to decide the accuracy required, in particular on the use of 1D or 2D analyses.

## 7 CONCLUSION

Italy has a long lasting history in the field of seismic microzonation, with a continuous evolution since the early 1970s, both of the methods for the accomplishment of the relevant studies and of their application to the reconstruction process after strong earthquakes and to seismic prevention in peace time.

A fundamental turning point has been the issuing of the "Guidelines for Seismic Microzonation" (GSM08 2015) in 2008. They have created precise protocols at national level for the execution of SM studies and for their utilisation. Thus, a substantial harmonization of all the activities that were previously started by the Regions was established, finding a common way of operating.

New momentum to the application of SM at national level according to GSM08 was then given by the National seismic prevention program, funded with Law 77/2009, that has allowed the SM of almost half of the Italian (highest hazard) municipalities to be carried out at least at level 1. In the meanwhile, recent earthquakes, particularly the Central Italy seismic sequence of 2016-17, have further promoted SM studies as a fundamental tool for the reconstruction process.

All these advancements have been strongly promoted and supported by the National Department of Civil Protection and by the Italian Regions, with the full involvement of the entire scientific community focused on seismic microzonation and its application, including geologists, geophysicists, engineers and urban planners, as well as of the professional community, that has been engaged in the thousands of SM studies carried out so far.

The large involvement of the scientific and the professional communities, as well as of the stakeholders (national and local civil protection organizations, regional and municipal administrations) has determined a considerable cultural growth in the field, a common language and, what is more, a substantial increase of the seismic risk awareness and of the urgent need for rational strategies for risk reduction based on the SM and ELC outcomes.

Finally, what deserves consideration in all this process is that SM studies do not remain an academic or professional exercise, but their outcomes have become fundamental tools for seismic prevention activities, in particular for urban and emergency planning, with the introduction of the Emergency Limit Condition, but also for reconstruction activities after strong earthquakes.

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