L'AQUILA EARTHQUAKE 2009: A WASTED OPPORTUNITY TO IMPROVE THE SEISMIC RISK MANAGEMENT FROM ITALIAN STRONG EARTHQUAKES

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ABSTRACT

This contribution is devoted to highlight some drawbacks in current practices for predicting seismic hazard in Italy where strong seismic events are commonly characterized by near-field conditions and high spotlight PGA measurements. The highlighted critical points are: (1) the use of Cornell's method for defining the reference national hazard and (2) the need of multidisciplinary approaches to seismic characterization of surface geology. Some best practices from worldwide as well as past Italian experiences are reported to suggest future strategies for managing the seismic hazard at national scale. Accordingly, some results from VEL (Local Seismic Effect Evaluation) project, developed in Tuscan Region since 1998, will be briefly illustrated.

KEYWORDS

Seismic characterization, VEL project, seismic hazard, microzoning studies.

INTRODUCTION

The recent "strong motion" earthquake sequences recorded along the Italian territory since 2009, showed common characters: (1) surficial hypocentre (lower then 12km depth); (2) relevant shaking suffered within a radius of 30km from the epicentre and (3) differentiated damages on structures mainly due to local seismic amplification of surficial sediments. Consequently, an intensive microzoning activity has been developed in the last four years in those territories, such as L'Aquila crater and Ferrara province, placed in the epicentral areas of the "unexpected earthquakes" of April 6th, 2009 and

May 20th and 29th, 2012. Plural scientific approaches have been testing on Italian territory to address microzoning studies for urban planning. These activities must be focused on (1) near field conditions and (2) on several seismic records from the last strong motion events. Moreover, they shall be compliant with the maps of maximum expected seismic intensities based on the Italian historical earthquake catalogues and databases that are sound and complete enough to support the prediction of earthquakes with a return period higher than 475 years. In this paper, some critical aspects of microzoning strategies commonly used in Italy have been pointed out and new proposals are provided to be discussed.

RECENT EVOLUTIONS OF ITALIAN SEISMIC MICROZONATION RULES

The need to identify seismic homogeneous zones in urban areas was born after the 1997 Umbria-Marche and 2002 San Giuliano di Puglia earthquakes. These events caused differentiated damages, casualties and disruptions, that enforced the evidence that local seismic effects play a relevant role also in near field conditions. The fruitful debate developed within the Italian scientific community on the best practices and most meaningful parameters for the seismic Italian territory classification and zonation, gave birth in 2006 [1] to the seismic Italian hazard map for different return periods. Moreover, the National Office for Civil protection was commissioned by the government to develop and issue novel guidelines and best practices for microzoning studies. The international guidelines from Technical Committee for earthquake geotechnical Engineering, TC4, [2] were taken as a reference. Then, the Italian microzoning guidelines and criteria were published in 2008 [3] based on three subsequent levels of detail in microzoning studies: level 1, mapping homogeneous geological units with respect to seismic behaviour by means of surface geological relieves; level 2, mapping numerical indexes for homogeneous susceptible areas by means of simplified approaches according to standard procedure prescribed by DPC; level 3, mapping homogeneous seismic responses drawn from site specific experimental surveys and one, two- and even three-dimensional numerical analyses when needed. Meanwhile the scientific community was discussing how these guidelines and criteria can be applied over the whole national territory for decreasing the seismic risk, the first “unexpected” main shock of L’Aquila earthquake occurred on April 6th, 2009 at 3:32 local time, causing 306 fatalities, more than 60,000 people displaced and heavy damages to civil structures and buildings: the old town of L’Aquila was strongly damaged and Onna city was completely destroyed under the near field 5.8 Ml (Local Magnitude) earthquake with 9km hypocentre depth.

After that, the Italian microzoning guidelines and criteria were applied by the Working group MS–AQ [4] to those portions of L’Aquila crater where the macroseismic intensity map (Fig. 1a) reported values higher than V MCS and within the epicenter area where it pointed out relevant differentiated amplification effects [5]. These differentiated responses were also recorded by accelerometer stations (Fig. 2c). Meanwhile discussion on these topics were on, other three “unexpected” main shocks of Emilia Romagna earthquake hit the provinces of Ferrara and at a lesser extent of Modena: May 20th at 4:03 local time with Ml^{INGV} 5.9 and 6.3km depth and May 29th at 9:00 with Ml^{INGV} 5.8 and 10.2km depth, and Ml^{INGV} 5.3 and 6.8km depth at 12:55 local time events [6].

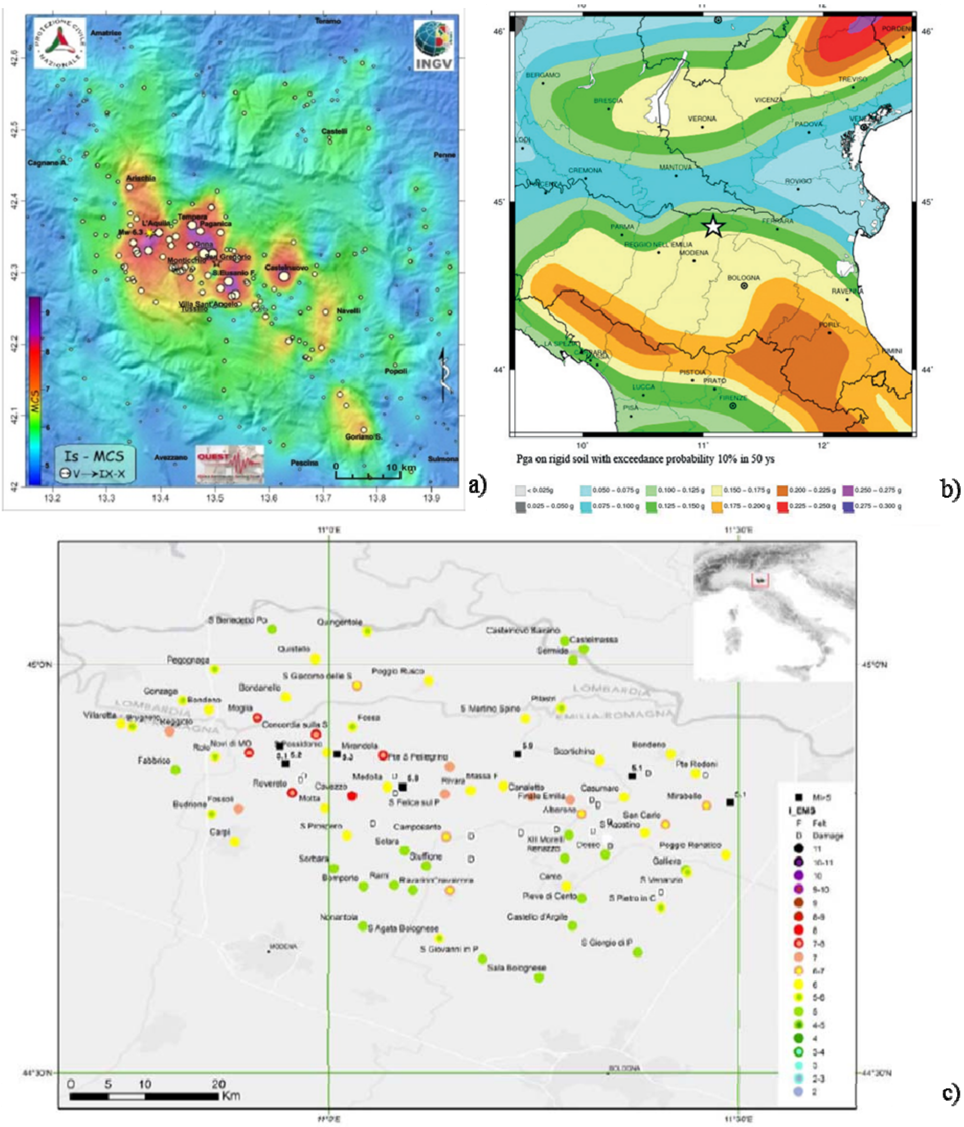

Figure 1 - a) Intensity Map of 2009 L'Aquila earthquake on April 6th at 3:32 local time; b) Seismic hazard map for microzoning studies issued by OPCM N. 3519 (2006); c) Intensity map of the 2012 Emilia Romagna earthquakes after all shocks up to June 3rd (After Quest Working Group 2012).

These seismic events occurred in an area where the hazard map [1] (Fig. 1b) predicted low hazard level although the intensity maps did not (Fig. 1a). Furthermore, a differentiated damaged level was plotted by Quest Working Group [6] (Fig. 1c) within 20km from the epicentre. Finally, 21/06/2013 at 10:33:57 UTC a seismic event of Ml^{INGV} 5.2 was recorded in Lunigiana at a 5.1km depth. In field surveys performed by Quest Working Group [7] by the end of June 2013 showed maximum intensity degree of 5-6 and 6 MCS within epicentral area. Although this last earthquake was not as severe as the others two, uncommonly, this earthquake was “expected” and such reduced effects on building structures can also be attributed to the last ten year policy of prevention and vulnerability reduction performed on the most hazardous portions of Tuscan territory. To this end, Tuscany Region Office for Seismic protection has been financing a project for estimating local seismic effects, called VEL project since 1998. It was a pioneering project accomplished by some good working strategies for microzoning studies that are still up to date and showed their efficiency where applied. Hereafter, some good practices for Italian seismic zonation are briefly reported from the writing authors’ experience in VEL projects as far as from international microzoning activities, according to the following points: (1) maximum intensity maps to be used for a preliminary zonation of the most hazardous areas; (b) integrating multidisciplinary experimental techniques to seismic characterization of sites.

POINT HISTORICAL APPROACH VERSUS CONTINUOUS ATTENUATION LAWS

Since 1976 after Friuli earthquake, when the first microzoning studies were performed, it was quite evident that, based on historical catalogues of the seismic events, the strong earthquakes occur where they occurred in the past. Although different Magnitudes can be felt at different return periods, [8] showed that the seismic local amplification can increase the felt intensity up to 2-3 intensity degrees of MCS. After more than ten years, Signanini et al. [9], Midorikawa [10] and lately, after the 2012 Emilia Romagna earthquake, Paolini et al. [11] focused on the maximum felt intensity maps derived by complete historical seismic catalogues as the key tool for guiding the choice of microzoning studies within the most hazardous areas in urbanized territories. Such a selection is needed because, especially in Italian territory, money is limited whereas the whole national territory is affected by earthquakes.

Thus, microzoning surveys in near field areas shall be performed in those territories that suffered repeated destructions and fatalities in the past, according to the maximum intensity maps, such as the one from Boschi et al.[12] (Fig. 2a, black circles). This latter was drawn based on thorough analysis of historical documents on past earthquakes from the years 1 BC to 1992 and it shows the expected intensity higher than VI degree in Mercalli Cancani Sieberg (MCS) scale. This choice on the intensity degree is commonly used to highlight the areas where seismic events caused from severe damages to collapse of urbanized environment (from IX to XI). As can be noted, this map shows limited areas irregularly shaped that suffered partial or complete destructions. Based on such a map, the recent “unexpected” strong events of L’Aquila and Emilia Romagna earthquakes could have been predicted (compare Fig. 1a, c with Fig. 2a). The reason of the misleading information from Italian seismic hazard map is related to the prediction of the ground motion amplitude at a site through the peak ground acceleration (PGA) attenuation laws. The estimation of these ground motion prediction equations (GMPE), whether or not truly representative of seismic shaking, is affected by too much uncertainties related to (1) the models used for seismogenic zonation of the national territory and (2) the interpolation of mean trend in PGAs databases from national and worldwide records. These uncertainties dramatically increase when the PGA estimation is referred to near field areas. This is evident from recent studies by Faccioli [13] shown in Fig. 2b: here, the uncertainty in predicting the GMPE based only on Italian Strong motion database (ITACA) [14], recorded on stiff soil V_{S30}=900m/s. As can be noted, in near field areas (up to 20km far from the fault Rf), the high scatter in recorded PGA values suggest: (1) not to rely on attenuation laws and (2) that V_{S30} does not identify the “seismic soil types” with respect to local amplification in PGA values. Recently, Faccioli [15] back-analyzed his GMPE by the Emilia Romagna recorded PGAs. He stated the validity of GMPEs derived only from local seismic event databases especially for hypocentral distance higher than 20km. Thus, is it realistic to consider that PGA values continuously decrease, in the first 10-20km far from the seismic source? The records tell us a different story ([5], [16], [17], [18]): PGAs are distributed spot-like nearby the seismic source increasing abruptly where soft sediments lie on stiff bedrock and subsurface geometries as basin shapes are filled by soft sediments (Fig. 2c).

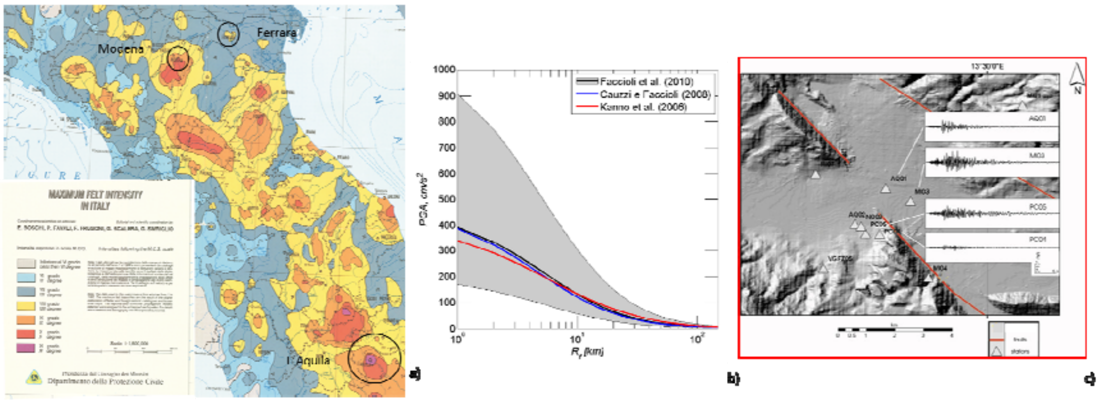

Figure 2 - a) Map of maximum felt Intensity in Italy (After [12] modified). b) Attenuation laws of peak ground acceleration (PGA) with the minimum distance to the fault (After [13], [20] and [21]): in grey the uncertainty bands of Faccioli’s attenuation law[19]]. c) Aterno Valley, Onna sector: the topography in grey tonality; the recordings of Ml 3.2 aftershock (EW component, origin time 2 May 2009, 2:21 UTC) are shown, normalized at the same scale (After [18] modified).

SURFACE AND SUBSURFACE GEOLOGY INVESTIGATED BY MULTIDISCIPLINARY APPROACHES

Concerning the level one in microzoning studies, it must be remembered that the knowledge of the subsurface successions with respect to lithologies, their dipping and buried geometries and dynamic parameters shall be a compulsory step towards the performance of local site response analyses. To get a realistic model of those portions of territory hurt by seismic wave propagation, in field investigations can be accomplished by means of integrating direct and indirect methods such as geophysical, geotechnical and geological approaches. The multidisciplinary approach allows to get twofold goals: (1) to increase the details on the sediment response to the shaking and (2) to calibrate those indirect investigation methods whose result quality relies on an adequate “dispersion curves” or “propagation curves” representing the subsurface geology.

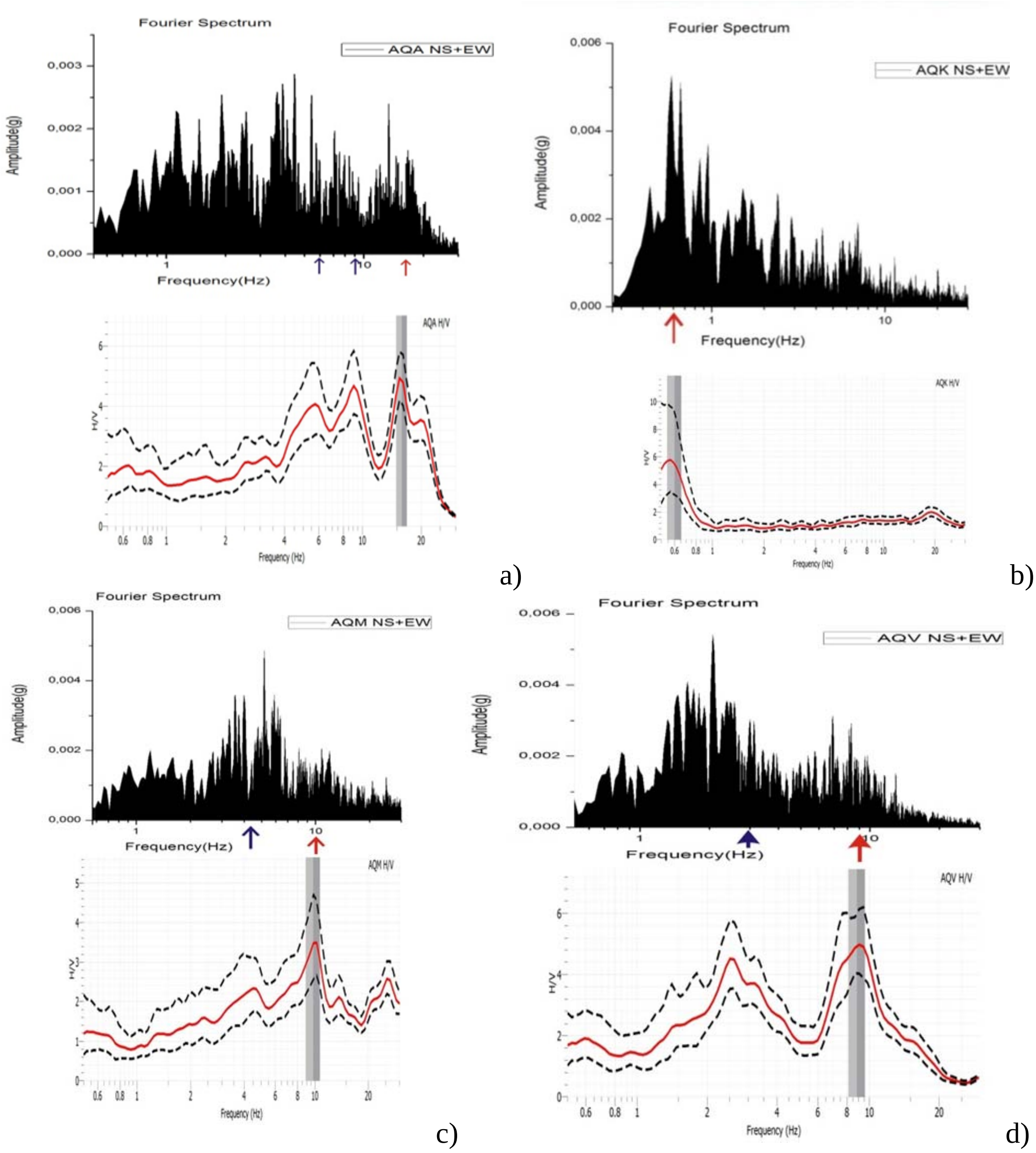

Figure 3. Pairs of Fourier spectrum and H/V ratios calculated by Nakamura's method, related to the main shock records on April 6, 2009 at four seismic stations: a) AQA, b) AQK, c) AQM, d) AQV. The Fourier spectra is calculated from the strong motion records and the H/V ratios are calculated from the tails of the records (weak motions).

Concerning the microtremor measurements, the level 1 microzonation map provides the homogeneous areas with respect to seismic behavior with the natural frequency of each area. These frequencies are measured by means of Nakamura's method [22] applied to ambient noise measures. The hypotheses underneath the procedure are the following:

- Microtremors are generated by local sources;
- Surficial sources of microtremors do not affect the deep sources;
- The vertical component of the motion is not affected by the local amplification of the surficial soft layer.

Thus, the Nakamura method assumes that microtremors are made up of Rayleigh waves that propagate in the soft half infinitive stratum of soil that is responsible of the local amplification. Nakamura's method is applied to four spectra in the frequency domain, that are two pairs of Horizontal (HS, HB) and Vertical (VS, VB) components related to the soft layer overlaying the rigid one according to the model in Fig. 4.

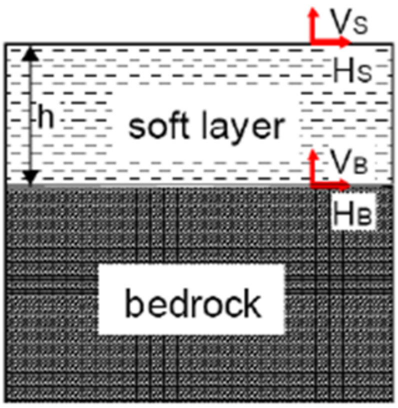

Figure 4. Reference model for Nakamura's method: VS and HS are the vertical and horizontal components of the motion on the surficial layer; VB and HB are the vertical and horizontal components of the motion on the bedrock.

For this reason it is also known as H/V method. The advantage of this method consists on separating the contribution of the source to path from the site in terms of frequency content of the signals through the ratio among recorded signal components avoiding the troublesome selection of a reference site. Among the empirical methods, the H/V spectral ratios on ambient vibrations (microtremors) is probably one of the most common approach and it is actually the recommended technique to derive the natural frequency of the site in microzoning studies in Italy.

Hence, an example of good practice to integrate indirect and direct characterization of dynamic response at a site, is represented by the calculation of the H/V ratio to both (1) ambient noise measurements and (2) the final portion of the records of the main shock on April 6, 2009 of L'Aquila earthquake. Four stations have been considered for this comparison, that are: AQA, AQK, AQM and AQV (Fig. 3).

As can be pointed out, none of the peaks measured by means of the Nakamura method correspond to the peak of the strong motion records but the one calculated at AQK station. This result cannot be predicted in advance. Moreover, the peaks from H/V correspond to higher natural frequencies in these four cases, than the ones from the weak motion records at AQK. According to the comparison undertaken it can be drawn that Nakamura's method: (1) often provides more than one peak corresponding to different natural frequencies; (2) the peaks are heavily affected by many factors especially in urban areas that are not easy to be disregarded by filtering the measurements; (3) the peaks in H/V ratios they are not commonly related to both weak and strong motion amplified frequencies. Thus, the use of noise measurements for microzoning activities should be discouraged especially when it is used alone and it is not validated by other geophysical testing.

CONCLUSIONS

In this paper, a working strategy for microzoning studies in near field areas, implemented by the writing authors during the VEL project and derived from recent seismic records can be drawn according to the following points: (1) the portions of the Italian territory where developing microzonation of level 3 shall be selected by means of maximum intensity maps as well as geologic, geomorphologic and geotechnical surveys; (2) the GMPEs shall be calibrated by local records and used for predicting the hazard level outside the near fault areas; (3) the multidisciplinary approach is the best way for seismic characterization of sites. Further studies on the several records from the recent strong seismic events are needed to improve the effectiveness of the good practices and to discard others.

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