THE SEISMIC ZONATION OF LATIUM REGION BASED ON NEW CRITERIA

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ABSTRACT :

In 2007 Latium Regional Administration and ENEA signed an Agreement of Research in order to define a new approach for the regional seismic zonation accordingly to the new criteria and laws recently approved in Italy for the building code in seismic areas. The resulting study was based on two methodologies: an historical and seismological analysis of the regional seismicity and a statistical and spatial analysis of uniform hazard response spectra related to sites included into the Latium boundary. The historical analysis produced an evaluation of the maximum historical intensity in every Municipality, together with the information on magnitude and epicentral distance of the related events: these data were used in querying international strong-motion databases in order to select a set of real ground-motion recordings. The statistical analysis outlined by a cluster technique six groups of spectra which characterise the regional seismic hazard and can be used to allocate each Municipality into the proper Seismic Zone. The selected time-histories, scaled to the spectral shape of each group, represent a useful tool for the structural design of buildings in seismic areas. The same clustering procedure was applied also to the site elastic spectra furnished by the new Italian legislation and the discrepancies between the resulting spectral shapes were discussed. Through this research, Regional Geological Survey produced two different scenarios of seismic zonation.

KEYWORDS: Historical seismicity, uniform hazard spectra, local elastic spectra, statistical clustering, ground-motion time histories, Seismic zonation scenarios.

1. INTRODUCTION

Since 1998 the Italian legislation has given to Regional Administrations the competence of seismic zonation. For this reason the Latium Regional Administration carried out a seismic zonation based on the new national criteria defined in the Act of Law OPCM 3519/06, so as to replace the previous zonation issued in August 2003 [D.G.R. Lazio 766 August 1, 2003]. Within this legislative context, an Agreement of Research between Latium Regional Administration and ENEA was signed in 2007 for the analysis of regional seismicity, aiming at the identification of groups of Municipalities with homogeneous characteristics of local shaking [Rinaldis et al., 2008]. The adopted approach jointed an historical and a statistical analysis of seismic data, response spectra and ground-motion recordings.

The seismic historical compilations considered in this study are the new data sets recently made available by the INGV-DPC Project S1 (2005), particularly the Parametric Catalogue of Italian Earthquakes CPTI04 [CPTI Working Group, 2004] and the related database of macroseismic intensity observations BDMI04 [DBMI Working Group, 2007]. For the seismotectonic characterization of the Latium area, the ZS9 Seismogenetic Zonation of the national territory was adopted [Meletti et al., 2008]. The same INGV-DPC S1-Project diffused Uniform Hazard Spectra (S1-UHS) with a return-period of 475 years, calculated on a 5 km wide mesh covering the whole Italian territory; these spectra were statistically analysed together with the Local Elastic Spectra defined by the shape-parameters annexed in the new Italian seismic regulation [DM January 14, 2008].

2. HISTORICAL ANALYSIS

In order to evaluate the maximum local intensity felt in each Municipality and the seismological parameters of the related earthquakes, the historical seismicity of Latium Region was studied. The resulting data were used as query-keys in the selection of ground-motion recordings from international accelerometric databases. As first step the earthquake intensity fields were analysed so as to identify events with intensity observations higher than the damage threshold, defined by the VI degree of the MCS scale, within the Regional territory. In this way 103 events were selected; the spatial analysis of their epicentres overlapped to the ZS9 zones (Fig. 1) highlights clusters of earthquakes that, for their level of magnitude and distribution of intensities, can be considered representative of seismotectonically homogeneous areas, here named Seismic Centres (SC).

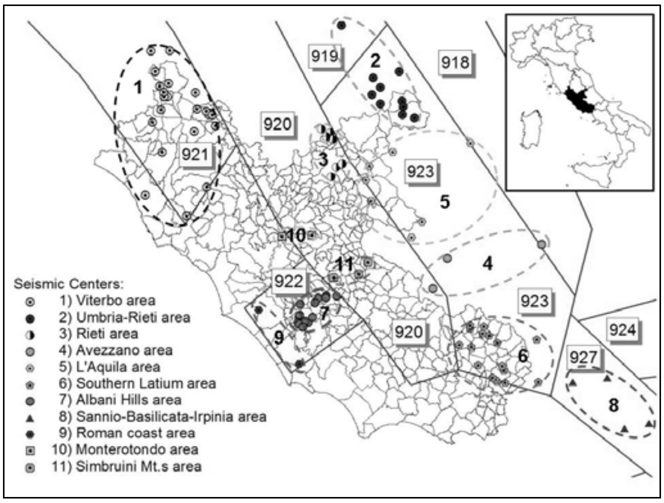


Figure 1 Distribution of the selected earthquakes

The ZS9 n. 923 (the zone with the greatest release of seismic energy in Central-Southern Apennine, wide extensional seismogenetic structures and high magnitude earthquakes) includes SC4 “Avezzano area” and SC5 “L’Aquila area” with 6.5-7.0M events and maximum epicentral intensities (I_{0Max}) between IX-X and XI MCS; SC2 “Umbria-Rieti area” (6.0-6.5M and I_{0Max} between X and XI MCS); SC6 “Southern Latium” (6.0-6.5M and I_{0Max} between IX-X and X MCS). The ZS9 n. 927 (the zone is located outward the Regional boundary, but affects the levels of Latium local shaking; it is characterized by an extensive tectonics and represents the area of maximum release of seismic energy in Southern Apennine) includes SC8 “Sannio-Basilicata-Irpinia area” (6.5-7.0M and I_{0Max} between X and XI MCS). The ZS9 n. 920 (the zone is coincident with the Tyrrhenian sector of Apennine with extensive tectonics; it is characterized by a low energy seismicity and few events with relatively elevated magnitude) includes SC3 ”Rieti area” (5.5-6.0M and I_{0Max} between VII-VIII and VIII-IX MCS) and two minor Seismic Centres: SC10 “Monterotondo area” and SC11 “Simbruini Mt.s area”. Though characterized by a local seismicity (5.0M and I_{0Max} between VI and VII), the latter SCs furnish a non negligible contribution in the definition of the local seismicity. The ZS9s n. 921 and 922 (related to the volcanic districts of northern Latium and Albani Hills respectively) include the areas of the Tyrrhenian Central Italy side with an elevated heat-flow and characterized by a diffused seismicity with a moderate energy release and very few medium-high magnitude events. The ZS9 n. 921 includes SC1 “Viterbo area” (5.0-5.5M and I_{0Max} between VII and VIII MCS), while into ZS9 n. 922, SC7 “Albani Hills area” (5.0-5.5M and I_{0Max} between VI-VII and VII-VIII MCS) and SC9 “Roman coast area” are located. This last SC is characterized by predominantly local events (5.0-5.5M and I_{0Max} between VI and VII MCS).

To obtain a reliable evaluation of the spatial intensity distribution, minimizing the influence of site geological and morphogical characteristics on each local intensity level, the application of intensity-epicentral distance decay models was attempted. In particular were taken into account the Blake’s classical relationship with the parameters esteemed for Central Italy [Marcelli and Spadea, 1981] and some new formulations adopted by the INGV-DPC Project-S1 [Gómez Capera et al., 2007], i.e. a model that hypothesizes an intensity decay proportional to the cubic root of the epicentral distance [Gómez Capera, 2006] and a log-linear model scaled on a specific definition of epicentral intensity [Pasolini et al., 2007a–b]. Tests performed by some of the selected events furnished unsatisfactory results, since the distribution of residuals between observed and theoretical intensities appeared widely variable in terms of both epicentral distance and azimuth. This result can be ascribed to the fact that all the applied attenuation models are based on the hypothesis of an isotropic intensity decay, whereas the macroseismic fields, particularly for the events in the Apennine area, show a strong anisotropy, with an intensity decay lower in NW-SE direction, i.e. parallelly to the Central Apennine chain direction, than in the orthogonal one. For this reason the spatial distribution of intensities was modelled by manually traced isoseismal maps. Each SC was separately analysed, starting from the earthquakes characterized by the higher level of Io and the more homogeneous distribution of local intensity data points. As a result, 29 out of the 103 considered earthquakes were selected as the most representative in the assessment of local historical seismic hazard within Latium Region area.

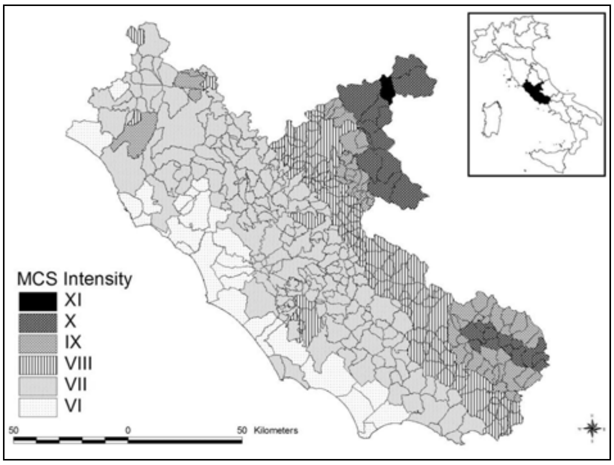


Figure 2 Maximum historical intensity distribution in Latium Region

The isoseismal maps of the selected events were geographically referred and analysed by ArchGIS® in order to identify, for each Municipality, the maximum value of local intensity caused by the combined effect of all the SCs. In case of identical maximum local intensities owing to several earthquakes, the ones related to events with the closest epicentre were chosen. Finally, the seismic parameters of the events which historically produced the maximum felt intensities, in terms of Io, Magnitude and epicentral distance, were selected for each Municipality. The geographical distribution of intensities values is shown in Fig. 2. In accord with the structural and seismotectonic features of Central Italy, these values form a series of bands parallel to the Apennine chain axis. The higher intensities are located close to Rieti area and Southern Latium SCs; an ample band with intermediate intensities, between VI-VII and VII MCS, occupies the central section of the Latium Region, including the SCs of Viterbo and Albani Hills, as well as the smallest SCs located near Monterotondo and Simbruini Mt.s areas. Finally, the lowest intensity values are located near by the Tyrrhenian coast.

Table 1 Total number of selected strong-motion records

Classes of epicentral distance	Classes of magnitude				
	50-55	**55-60**	**60-65**	**65-70**	Total
< 10 km	38	4	2	0	44
10-30 km	127	26	15	8	176
30-60 km	38	50	23	16	127
60-100 km	11	7	26	22	66
> 100 Km	0	4	6	6	16
Total	214	91	72	52	429

Summarizing these information, all the Municipalities were classified in seismically homogeneous groups characterized by seismic Severity Indexes (SI) which describe the values of Io, Magnitude and epicentral distance by the use of classes defined according to discrete scales (Io: V-VI/VI, VI-VII/VII, etc; Magnitude: 5.0-5.5, 5.5-6.0, etc.; epicentral distance: 0-10km, 11-30km, 31-60km, 61-100km, >100km). Considering that the maximum historical intensity in each Municipality can derive from the contribution of several SCs, the historical analysis highlights 10 Municipalities affected by 4 SCs (and consequently related to 4 different SIs); 33 Municipalities affected by 3 SCs; 144 affected by 2 SCs and 239 affected by only one SC. To verify the real influence of the different SCs on the hazard level of each Municipality connected with more than one SI, the probable level of local ground shaking expressed in terms of Predicted Spectrum of Acceleration (PSA) was obtained by the Sabetta and Pugliese (1996) attenuation model: in this case the PSAs were calculated at the seismic bedrock and with the upper-bound values of magnitude and epicentral distance of the previously defined Classes. As final result the triplets of Io, magnitude and epicentral distance values were obtained and used as search-keys in querying the international accelerometric data-bases. Table 1 shows the number of the selected strong-motion recordings.

3. STATISTICAL ANALYSIS

Main goal of the cluster analysis was the achievement of an hazard zonation of Latium Region both statistically significant and consistent with the information on regional seismicity (*supervised clustering*). On this purpose, after a try-and-error procedure, a kernel density algorithm (*non parametric cluster*) was chosen. In a kernel density clustering, each group is defined as a region surrounding a local maximum of the probability density function, with no specific assumption on its shape. For a more effective spectra classification, incremental ratios of a particular interpolating function, instead of original absolute acceleration values, were used. In particular, for each Uniform Hazard Spectrum (S1-UHS) related to the grid defined by INGV-DPC S1-Project, a fitting operation on acceleration response (y) and period (x), by a non-linear Pearson IV equation, was performed, obtaining a good interpolation (mean R^2 near 0.99). After performing the kernel density clustering, an optimal number of 7 clusters was fixed. Subsequently, to constrain the grid-point classification into the Municipality administrative boundaries, an inductive process was applied, by both visual and statistical criteria such as the geographical contiguity to each grid-point. During this process one of the 7 clusters showed a slight areal influence and was therefore neglected, reducing to 6 the final number of clusters used to group the Latium Municipalities (Fig. 3).

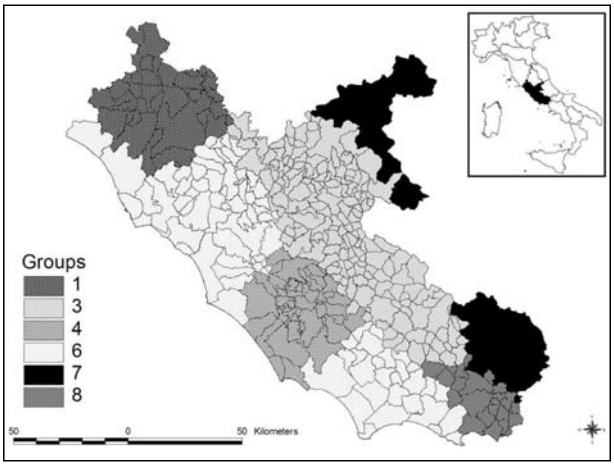
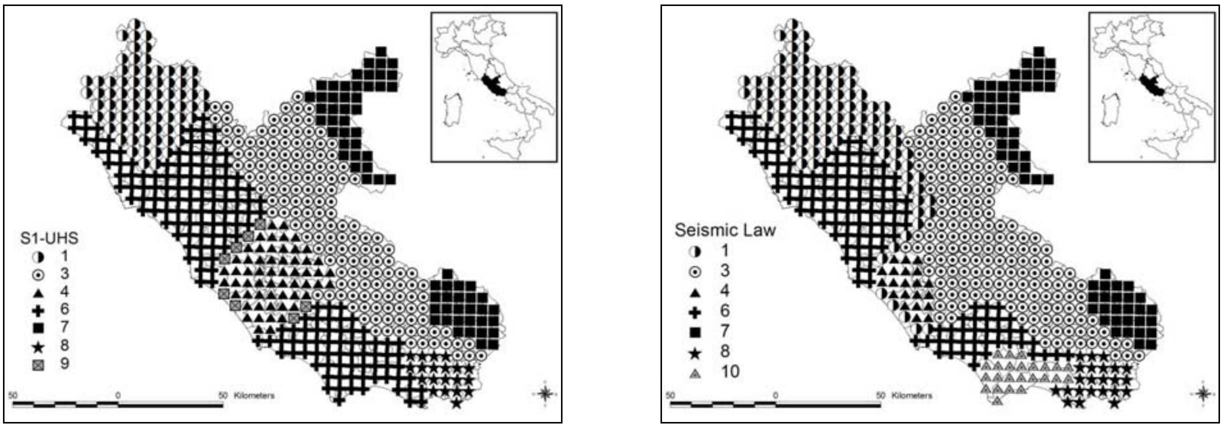


Figure 3 Groups of Municipalities from the statistical cluster analysis

Furthermore, as the new seismic Regulation [DM January 14, 2008] furnished formulae and parameters (a_g, T_C and F_0) to draw up the elastic response spectra in the same grid-points defined by INGV-DPC S1-Project, the relative spectral shapes were studied in comparison with S1-UHS. The analysis was performed by the same statistical technique used to elaborate S1-UHS. Figure 4(a-b) reports the result of these calculations: the maps clearly show some discrepancies nearby the regional NW and SE border and in Albani Hills area, while in Latium central area and nearby the Eastern border these difference are negligible.

The average spectral values for each cluster were also calculated and compared, pointing out the Groups for which the use of the Regulations parameters brings to underestimate the local seismicity, at least in some frequency intervals. For instance, in Group n. 6, within the 0.6–1.5 seconds range period, Regulations data tend to undervalue the acceleration, particularly for the 1 second period where the negative gap is more than 10% (Fig. 5). Moreover, exploring the difference in clusters distribution, an evidence of spatial autocorrelation was highlighted: this characteristic is not casual, but systematic and can be related to the peculiar features of the territory, since it appears positive in some clusters and negative in others.



(a) S1-UHS (b) Elastic response spectra

Figure 4 Comparison between cluster analyses on S1-UHS and spectra from seismic Regulation

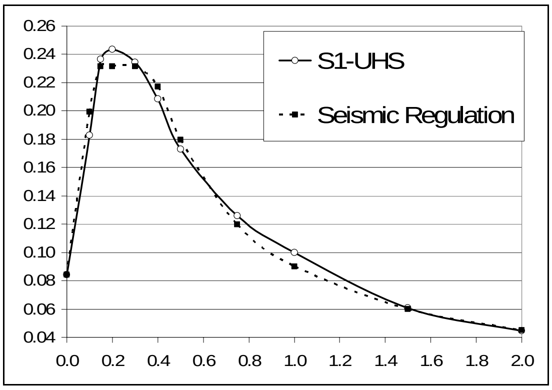


Figure 5 Comparison between seismic Regulation and S1-UHS data for cluster n. 6

4. THE TIME-HISTORIES

The new Italian seismic law [DM January 14, 2008] admits the use of recoded accelerograms, when their choice is representative of the site seismicity; besides it must be adequately justified by seismogenic characteristics of the source, site conditions, magnitude, distance from source and maximum horizontal acceleration. The recorded accelerograms must be selected and scaled in order to approximate the defined spectral response within the periods of interest.

For each Municipality, real ground-motion recordings were selected [Rinaldis et al., 2008] on the base of the relative SI parameters and scaled according to the spectral shape of the Group to which the Municipality belongs. The technique used to generate time-histories is a modified version of the methodology proposed by Silva [Silva, 1984]. The advantage of this method consists in a “natural” mode to incorporate non stationary trends, randomness and changes over time in the frequency content of the registered accelerograms. This feature is achieved by keeping constant the phase while changing the scale, as the phase determines how energy is distributed over time. The full frequency content is defined from the response spectrum by an iterative method. However, the spectra that characterize the 6 Groups of Municipalities (Fig. 6) were generated from a frequency distribution derived as an average among different types of events (in terms of magnitude and distance). To introduce the variability due to different magnitudes and distances, the low frequency cut off of the filter "butterworth" was applied, taking into account the "corner frequencies" characteristics of earthquakes of a certain magnitude. Changing in this way the spectral content at low frequency, it is possible to get different durations for earthquakes of varying magnitude and distance (for the choice of values "corner frequencies" and in consequence the duration see report on page 5.19. 24 in Silva, 1984; for use of the "corner frequency" as a parameter for selecting the low frequency cut-off see Rinaldis et al., 1994).

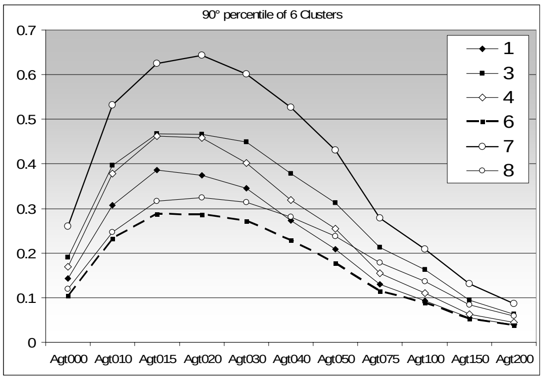


Figure 6 Spectral shapes of the 6 Municipalities groups

To select the final time-histories a degree of severity criterion, defined by Arias intensity, was applied. For each group, 9 time-histories were selected: three for the higher degree of severity, three for an intermediate degree of severity and three for a low degree of severity. Fig. 7 shows an example of the time-histories that have been generated applying this methodology to the Municipality Group no. 3 (see Fig. 3).

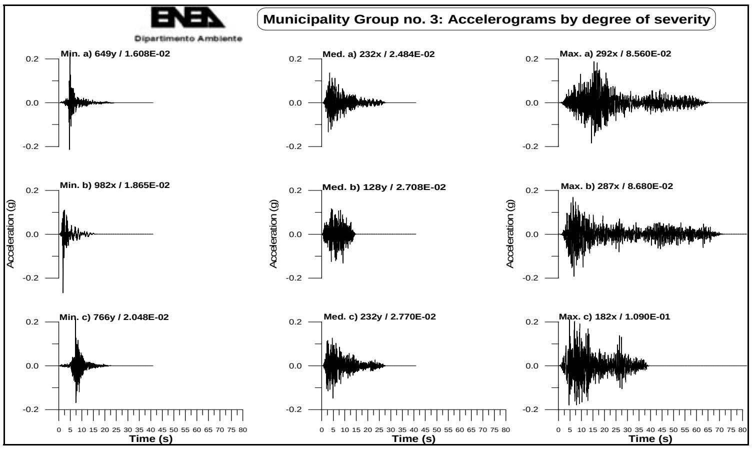


Figure 7 Time histories obtained for the Municipality group no. 3

5. SCENARIOS OF NEW SEISMIC ZONATION

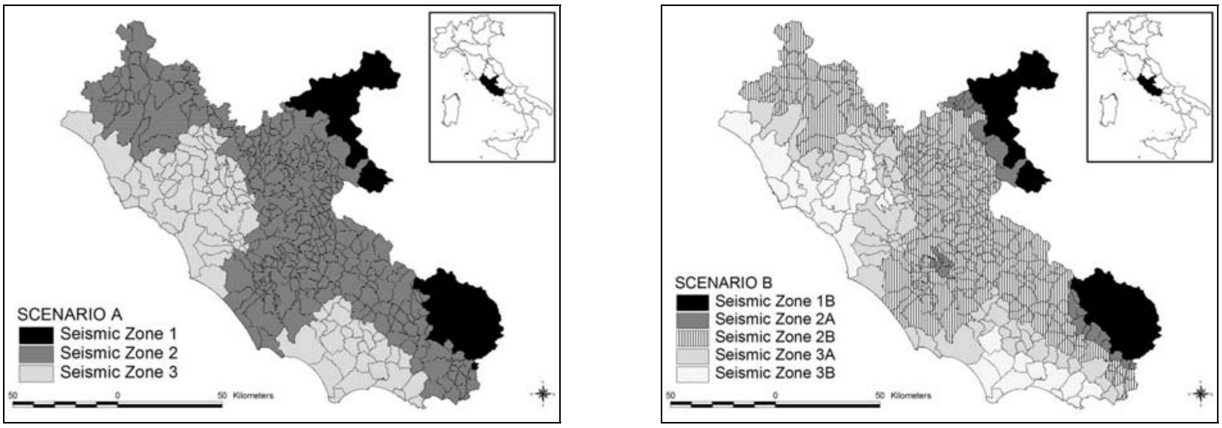
The Latium Regional Geological Survey elaborated two new scenarios of seismic zonation, adopting the INGV-DPC standard values of a_g at the 84th percentile [OPCM 3519 April 28, 2006]. This choice was justified by the necessity of maintaining the level of seismic security reached in the previous 2003 seismic zonation [DGR Lazio 766 August 1, 2003], i.e. not to move any Municipality to a Seismic Zone with an hazard level lower than the level of the Zone to which it was assigned by 2003 zonation. Moreover, the same ENEA research [Rinaldis et al., 2008] validated the level of seismic hazard in Latium Region. The two seismic scenarios are: Scenario A, a seismic zonation only based on data provided by ENEA research; Scenario B, a seismic zonation obtained merging both ENEA research data and INGV-DPC standard values of a_g at the 84th percentile.

SCENARIO A (Fig. 8a): each Municipality is associated to a seismic hazard value and to some characteristic ground motion time-histories defined by the level of historical seismicity. The six ENEA seismic hazard clusters [Rinaldis et al., 2008] are grouped in three different Seismic Zones, following a criterion of homogeneity in seismological data. The scenario joins the scientific approach with the need of an effective management of the seismic safety of the territory. Despite the different number of total Municipalities mainly due to the 19 Rome Suburbs with a medium-low risk, the comparison between scenario A and the 2003 seismic zonation highlights an increase of the security level due to the rise of Municipalities assigned to seismic Zone 1 (high risk). The Seismic Zone 4 (low risk) is not present at all.

Table 2: Comparison among Scenario A, Scenario B and 2003 seismic zonation (* include the 19 Rome Suburbs).

	Seismic Zone 1B	Seismic Zone 2 (2A+2B)	Seismic Zone 3 (3A+3B)	Seismic Zone 4	Municipalities
Scenario A	53	257	96	0	396*
Scenario B	45	252	99	0	396*
Classif. 2003	36	255	81	6	377

SCENARIO B (Fig. 8b)*:* The current National criteria for the seismic classification of the territory [OPCM 3519 April 28, 2006] admit the definition of seismic hazard by the values of peak acceleration (a_g); it is so possible to split the Seismic Zones in sub-zones with 0,025g of range. In the Latium Region, elaborating the INGV-DPC standard values of a_g at the 84th percentile, this division was operated by steps of 0,05g, obtaining 5 seismic sub-zones (1B is the higher and 3B is the lower in hazard). In this Scenario too, the Seismic Zone 4 (low risk) is not present at all. Most of the Latium Municipalities show a unique sub-zone value (fixed sub-zone). For the Municipalities belonging to different zones or sub-zones, the value of sub-zone affecting more than 80% of the territory was selected. If this condition is not satisfied (e.g. the sub-zone 2B at 60% and sub-zone 3A at 40%*)*, the ENEA clustering [Rinaldis et al., 2008] is adopted. Scenario B shows (Table 2) an increase of Municipalities assigned to Zone 1 respect to the 2003 seismic zonation; however it is less relevant then the increase defined by Scenario A.



(a) Scenario A (b) Scenario B

Figure 8: Seismic zonation of Latium Region

5. CONCLUSION AND DISCUSSION

An inductive-statistical methodology as well as an analysis of the historical seismicity were used to obtain a new hazard zonation of Latium Region. The statistical analysis of accelerometric data in form of Uniform Hazard Spectra allowed to define 6 Groups of Municipalities with homogeneous hazard. Real accelerometric records selected by the parameters coming from the historical analysis and scaled by the seismic hazard level of the Municipality Groups, provided a set of time-histories which can be used in structural design. Moreover, comparing the elastic response spectra annexed to the new seismic Regulation with the Uniform Hazard Spectra from INGV-DPC S1-Project, some discrepancies were highlighted. The differences concern both the areal distribution of clusters in some boundary areas and the comparison of the average spectra related to each Municipality Group, particularly within specific frequency intervals. The former difference could be justified with many hypotheses, such as an influence of neighbouring spectral values at distances greater than those considered, or a more conservative intent adopted in specific areas by the Civil Protection Department. The latter is much more interesting, but needs further analysis for a complete comprehension. Anyway, this result suggests that the common practise of a rough design of spectral shapes to be used in all seismic codes could cause an overestimation of hazard in certain frequency intervals as well as its underestimation in others. Finally, according to the new National seismic law and by the use of the aforementioned information, two different scenarios of seismic zonation were elaborated. The result is closer to the actual regional seismicity and improves the administrative tools of management of the territory in a seismic area.

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