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Seismic Hazard Mapping for Administrative Purposes

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Abstract. Local soil conditions, roughly summarised by considering a reference soil for each municipality of the Friuli – Venezia Giulia region in NE Italy, are introduced into probabilistic seismic hazard estimates: the subsequent improvement is checked by comparing these new results and the maximum observed intensities in each municipality to investigate if the major differences between probabilistic estimates and actually observed data can be explained by local site effects and/or by the geometry of the seismogenic zones used in the computation. In addition, a comparison between the new probabilistic hazard results, and the standard ones referred to rock is made for the present and the proposed Italian seismic zonation. The results underline the influence of the seismogenic model used, but are not determinant on the role of site effects.

Key words: seismic hazard, soil conditions, Friuli – Venezia Giulia, NE Italy

1. Introduction

Traditional hazard estimates refer to the hazard level, mainly expressed in terms of peak ground acceleration (PGA), in rocky soil conditions or, less frequently, in average soil. This is because soil conditions can abruptly change and the actual local shaking can be computed from the value expected on rock by modelling the increment due to soil effects. This is not valid when the ground motion is represented by quantities like the macroseismic intensity, because site effects are taken into account by the definition of the quantity itself. Consequently, seismic zonation, which is based on hazard estimates, classifies municipalities without taking into account soil conditions, that are considered only later, in the building design (e.g., by the design spectrum). These corrections can be important and may remarkably increase the expected shaking level.

The present Italian seismic zonation (Servizio Sismico del Consiglio Superiore dei Lavori Pubblici, 1986) was introduced between 1980 and 1984 and is based mainly on a probabilistic seismic hazard assessment (PSHA) of the national territory in terms of intensity (Gruppo di Lavoro Scuotibilità, 1979). The basic rule of the above zonation was to maintain the seismic category of municipalities already classified, and to add all the municipalities that exhibit similar hazard levels. About 1500 municipalities were already classified before 1980, according to the national

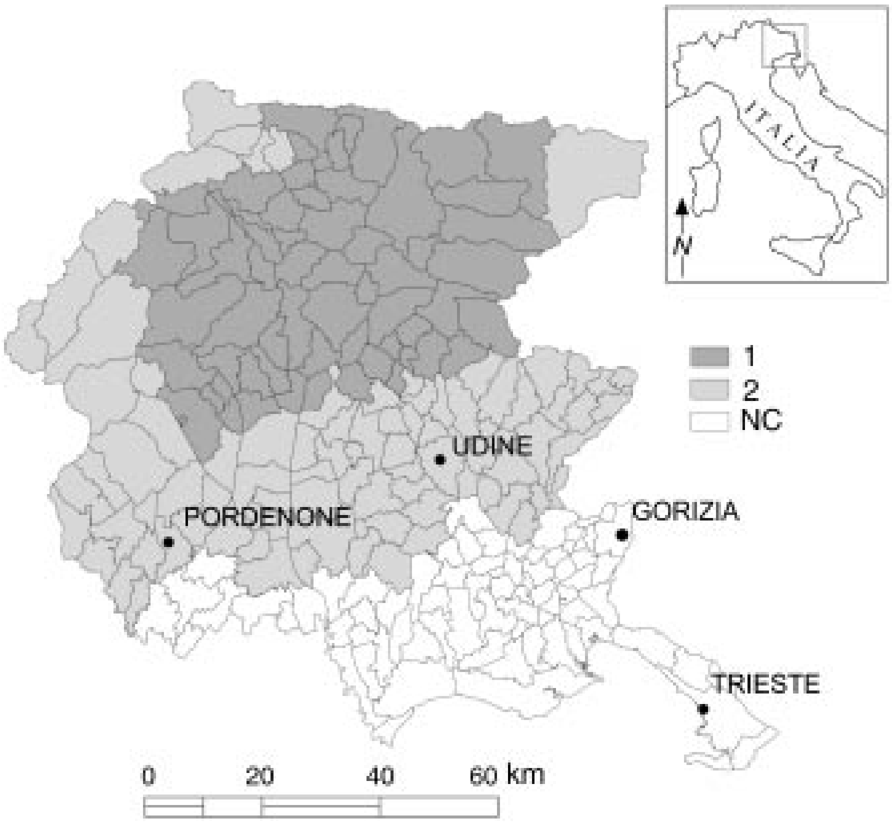

Figure 1. Present seismic zonation for the Friuli – Venezia Giulia region (Servizio Sismico del Consiglio Superiore dei Lavori Pubblici, 1986): the first category is more risky than the second one; NC means non-classified.

seismic code which was introduced soon after the violent 1908 Messina earthquake. The present national seismic zonation classifies 2965 out of the 8102 Italian municipalities and consists of 3 categories: the first is the most severe (it contains 368 municipalities), and the third collects only a few (99) municipalities in southern Italy, where even moderate shakings are expected to produce severe damage because of high building vulnerability. Figure 1 shows the present Italian seismic zonation for Friuli – Venezia Giulia (NE Italy).

An updating of the present seismic zonation (Figure 2) was recently prepared (Gruppo di Lavoro, 1999): it is based on completely reviewed databases and on a multi-parametric evaluation of hazard for which three parameters are considered. Two are mostly engineering forecasts, and one is based on historical records. The first two are modifications (different integration limits, see Peruzza *et al.*, 1998) of the original spectrum intensity (SI, Housner, 1952), which is defined as the integral of the response spectrum with 0.2 damping in the frequency range 0.4–10 Hz. The first parameter is the uniform hazard spectrum intensity with a 475-year return

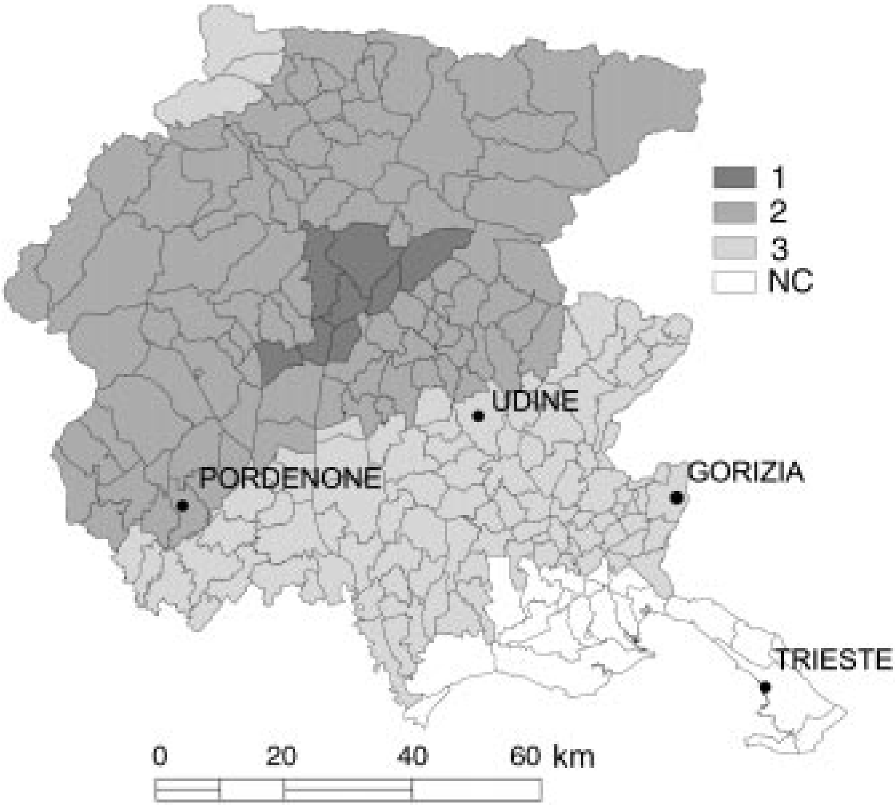

Figure 2. Proposed seismic zonation for the Friuli – Venezia Giulia region (Gruppo di Lavoro, 1999): the first category is more risky than the second one, which is more risky than the third; NC means non-classified.

period (SI475) computed in the frequency range 0.5–5 Hz: it quantifies the expected destruction in the long term. The second is the spectrum intensity in the 2–10 Hz range with a 100-year return period (SI100): it considers the expected damage in the short term. The third parameter is the maximum observed intensity (I_{max}), that represents the actual knowledge of shakings experienced in the past (Figure 3). These three quantities have been combined giving higher priority to SI475 for its correlation to the Eurocode EC-8 (Eurocede8-Part5, 1994). More precisely, a municipality is seismically classified if it exceeds a threshold value of SI475, or if it exceeds a threshold value of both SI100 and of I_{max}. This criterion provides, tentatively, a protection against rare, violent earthquakes, as well as against frequent damaging events.

The aim of the present work is to introduce into probabilistic hazard estimates, through proper attenuation relationships, a first order approximation of soil conditions, defined at the administrative scale of the municipalities. The effect of this operation has been checked against the maximum observed intensity and to the present (Servizio Sismico del Consiglio Superiore dei Lavori Pubblici, 1986)

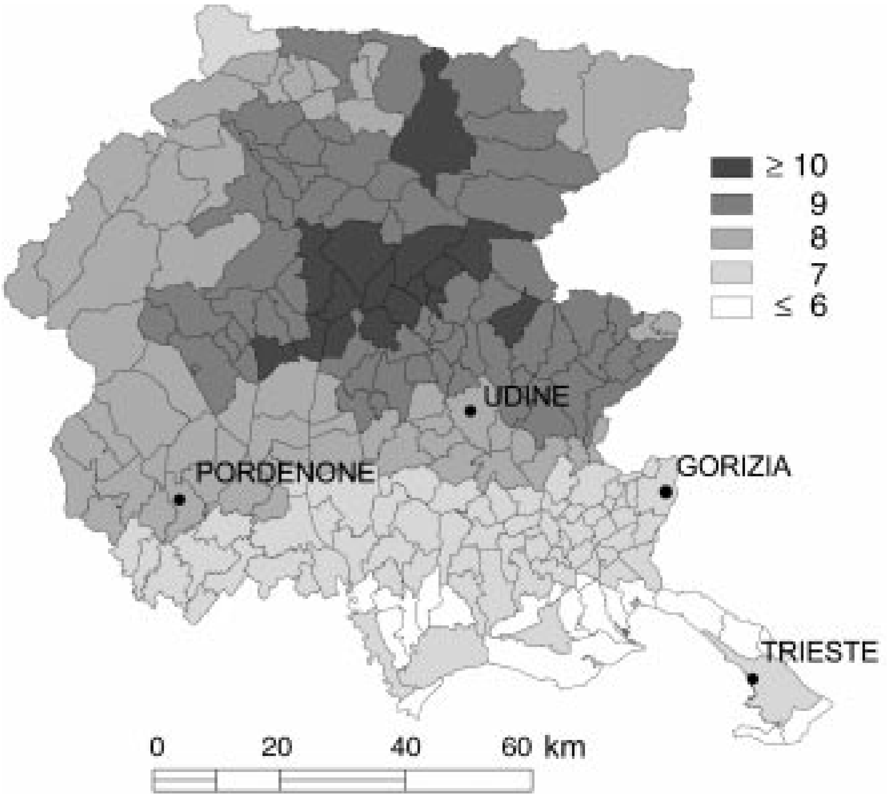

Figure 3. Maximum observed intensity (MCS scale) in Italy (from Molin *et al.*, 1996).

and the proposed (Gruppo di Lavoro, 1999) seismic zonation. Hence, we want to investigate if the difference between expected (in terms of PGA) and observed (in terms of intensity) shakings can be explained simply by soil conditions.

2. Site Condition Dependent Hazard Maps

There is an ongoing project to evaluate the seismic risk in the Friuli – Venezia Giulia region run by the three regional scientific institutions traditionally involved in this field and, more generally, in geology, seismology and engineering seismology: OGS, and the universities of Trieste and Udine. In the first phase of this project, four soil conditions were considered for the territory of Friuli – Venezia Giulia with the Ambraseys *et al.* (1996) classification for defining attenuation relationships. In this way, different propagation properties can be introduced in the PSHA procedure, and maps referring to different soil typologies can be obtained. The subdivision has been proposed (Dipartimento Scienze Geologiche Ambientali Marine, 1999) on the basis of the lithological characteristics (prevailing lithotype class) of the soil in the 30 surficial metres, as can be defined from bibliography and geological surveys. The definition of a municipality's typical soil is not trivial because, obviously,

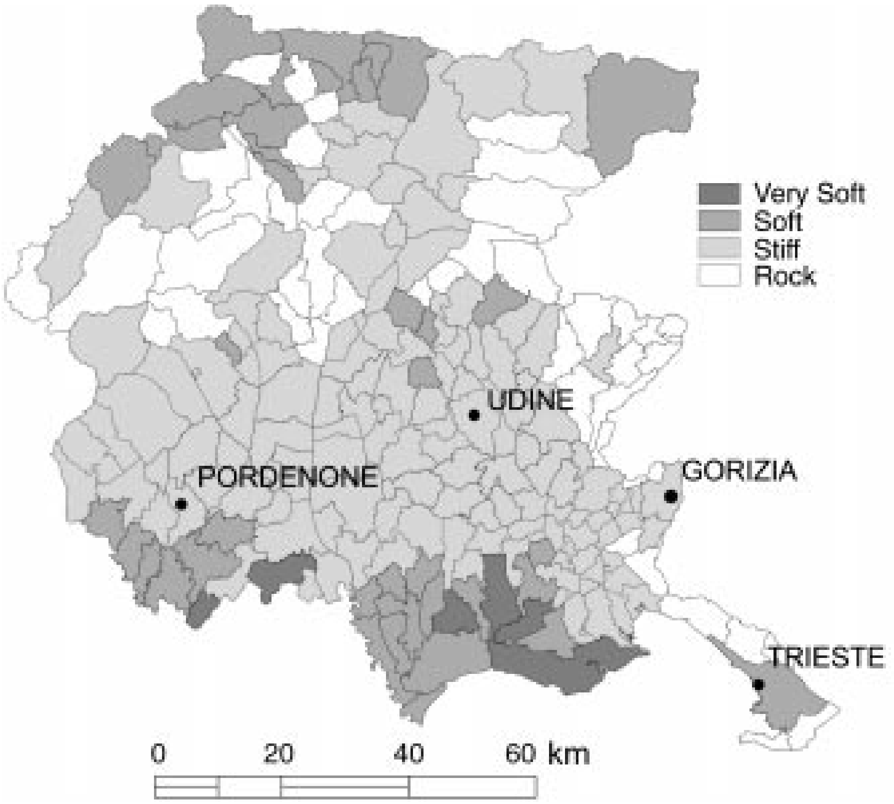

Figure 4. Typical soils for the municipalities of the Friuli – Venezia Giulia region (see text for the explanation).

different soils are present in the same municipality, even in very close districts. Considering that PSHA will never be able to take site effects into account, and that urban planners use risk estimates linked to administrative units anyway, a rough working assumption has been used before detailing more homogeneous portions of the territory: the mean soil, where the majority of the buildings are located, has been defined as the typical municipality soil. This definition has severe limitations, but nevertheless represents the first step towards improved accuracy.

From a geographical point of view, the Friuli – Venezia Giulia region is dominated by the mountains north of Udine and by the plain to the south. Figure 4 shows the simplified soil classification of its municipalities according to the previously described criterion. The patchwork pattern is given by the valleys, where urban settlements are generally located, as well as by the Karst limestone, that characterises the Trieste neighbourhood. The former produce alluvial deposits and soft soil conditions in the northern sector as well.

The PSHA was performed according to the Bender and Perkins (1987) algorithm, which uses the general, consolidated Cornell (1968) approach, by introducing soil dependent PGA attenuation relations (Ambraseys *et al.*, 1996) into the standard processing. Thus, three different hazard maps have been obtained (the few, very soft soil municipalities were merged into the soft soil ones as no specific attenuation is available for them) for a 475-year return period (90% non-exceedence probability in 50 years); the mapped values represent the expected values plus one standard deviation of the attenuation relations considered. Figure 5(a) shows the expected PGA values on rock: the general shape reflects the geometry of the seismogenic zones (SZ's) considered, as was expected from the Cornell (1968) approach. In particular, PGA exceeds 0.32 g in three municipalities in central Friuli, while the area with values exceeding 0.28 g is quite wide, and covers all the sector of the foothills. Figure 5(b) collects the hazard value for each municipality according to its typical soil. This map shows, then, a better approximation of the actual shaking observable during an earthquake. It will be hereafter referred to as hazard map in free-field conditions. In contrast to the usual hazard maps, the shakings do not show a regular pattern, and the variations reflect the administrative borders associated with soil condition irregularities. In this map the PGA values range from 0.08 g to more than 0.4 g. The maximum values pertain to several municipalities in the foothills, but the hazard also increases in the southernmost region.

A comparison between the actual observed intensity map (Figure 3) and the maps of the predicted values (Figure 5) shows the remarkable influence of the SZ geometry in the PSHA estimates, that are only partly masked when considering the soil typologies. It must be said that the seismogenic zonation (Meletti *et al.*, 2000) used here is the same one designed to calculate the seismic hazard of the whole Italian territory (Slejko *et al.*, 1998) and, therefore, needs greater detail when used for local, specific purposes.

3. Considerations on the Free-Field Hazard Map

The hazard maps (Figure 5) represent a statistical forecast, only partly reflecting the shakings actually experienced. The most rigorous image of the real past shakings is given by the maximum observed intensity (Figure 3). The behaviour of the PGA versus the maximum observed intensity is, thus, investigated (Figure 6); the longer return time of 1000 years has been considered to be a better approximation of the maximum expected shaking at the site. Theoretically, an improvement in the PGA versus maximum felt intensity correlation is expected, moving from rock PGA to free-field PGA, as the maximum observed intensity also reflects the contribution of local soil conditions. Actually, this is not so and Figure 6(b) shows more dispersed PGA values corresponding to the same maximum felt intensity as Figure 6(a) does. It is interesting to note the log-linear correlation for mean PGA values (diamonds in Figure 6) and macroseismic intensity. The scattering of the PGA values related to the same intensity degree is remarkable, but it is not greater than the dispersion

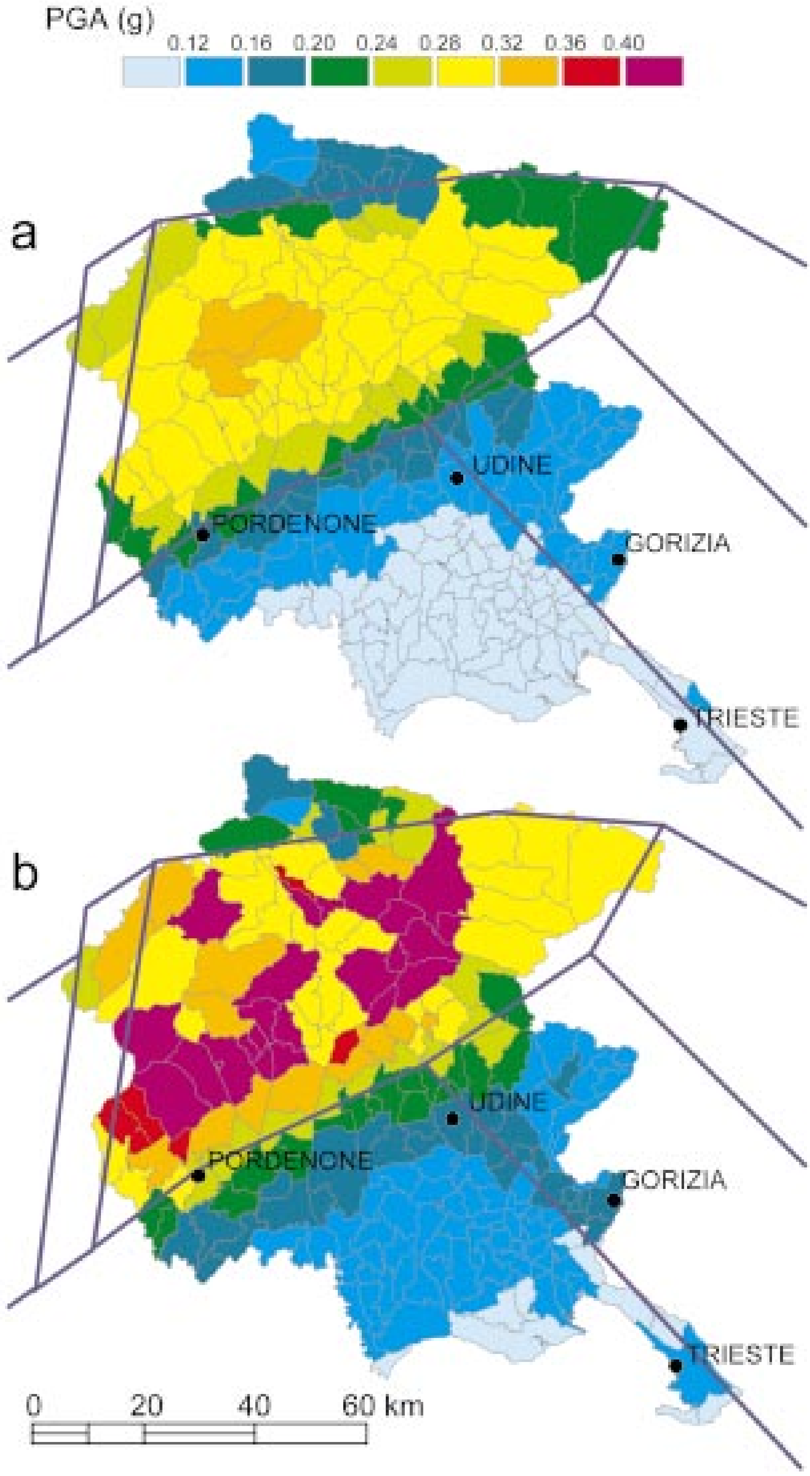

Figure 5. PGA with a 475-year return period in the Friuli – Venezia Giulia region for rock (a) and in the free-field (b).

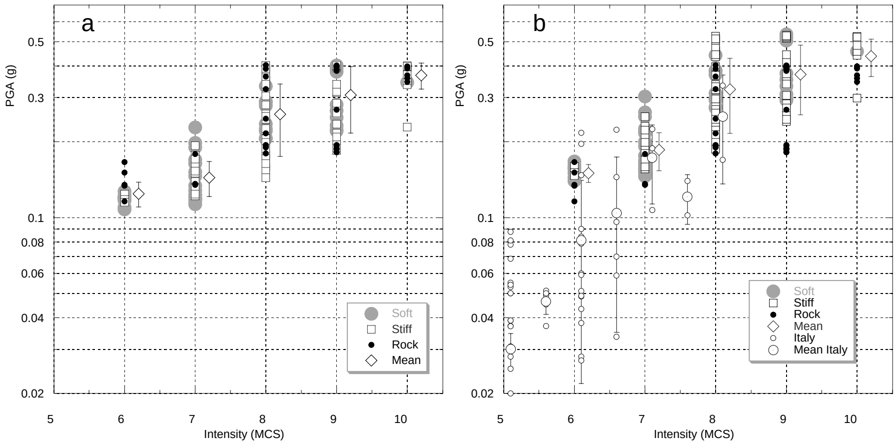

Figure 6. Comparison between PGA with a 1000-year return period, on rock (a) and in the free-field (b), and the maximum observed intensity for the Friuli – Venezia Giulia region. Different symbols mark the different soil categories (see legend). The diamond is the mean PGA value of each intensity class and the bar displays the standard deviation. Small open circles indicate the data used by Margottini *et al.* (1992), the large open circles are their mean values and the bars show the standard deviation. The Margottini *et al.* (1992) data and the mean values are shifted slightly to the right for a better view.

found by Margottini *et al.* (1992) when analysing the data for the Italian territory (small open circles in Figure 6(b)).

To further investigate this aspect, the difference between observed and forecasted values has been analysed in Figure 7. The left y-axis, reports the difference between the maximum observed intensity, converted into PGA with the Margottini *et al.* (1992) relation, and the PGA on rock with a 1000-year return period (DPGA). Whereas on the x-axis, the municipalities have been sorted by increasing intensity value, as shown by the solid line on the right y-axis. Different symbols mark the soil type of the municipality. Two observations can be made from Figure 7. If the soil type had a dominant effect on the maximum observed intensity, the symbols would be grouped showing positive DPGA values for soft-soil municipalities and negative values for rocky ones. This is not the case, as the symbols show a wide dispersion around the zero value and no systematic effect can be detected. Secondly, the increasing trend of DPGA's suggests a bias in the Margottini *et al.* (1992) relation.

Some tentative conclusions can, therefore, be derived.

(1) The maximum felt intensity occurred in particular site conditions, which may be different from the municipality's conditions; it is common, that high intensity values assigned in the past, be related to single local ruins (e.g. destructions of castles situated in extreme positions such as at the top of hills or on bad soil) and are, therefore, not representative of the areal mean damage. Following these considerations, the high intensity in some municipalities of low expected PGA may, perhaps, be justified by morphological or site effects.

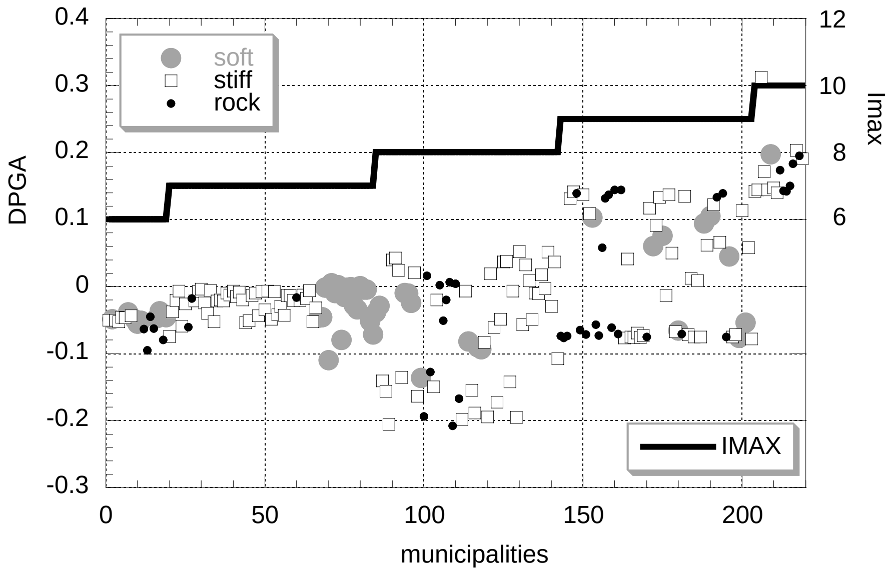

Figure 7. Difference between maximum observed intensity of the municipality, converted into PGA by the Margottini *et al.* (1992) relation, and PGA with a 1000-year return period on rock. Municipalities are sorted by increasing intensity values. Different symbols indicate the soil typology. The solid line represents the municipality intensity value.

(2) The PSHA is strongly influenced by the shape of the SZ's used in the computation (Bender and Perkins, 1987): the evident differences between the expected PGA (Figure 5) and the maximum observed intensity (Figure 3) maps can depend on the fact that not all the SZ's have yet manifested their maximum potential.

Theoretically, the free-field hazard map, previously cited, should describe the actual regional hazard better than the usual maps that refer to rock conditions or to an average soil. It would be important, now, to quantify the improvement obtained, if any. For this reason a comparison with the hazard estimates in the seismic zonation is proposed. Our reasoning, regarding this comparison with the zonation, is based on the assumption that the proposed seismic zonation (Figure 2) is better than the present one (Figure 1) since it is based on completely revised data and methods (see Slejko *et al.*, 1998), and on various hazard parameters: different expected shakings are modelled together with the observed ones. Consequently, the free-field PGA map should suit the proposed zonation better than the rock PGA map.

Figure 8 shows the distribution of the PGA referred to rock for the 219 municipalities in Friuli – Venezia Giulia, considering the present zonation (Figure 8(a)) and the new, proposed one (Figure 8(b)). In Figure 8(a), the municipalities classified in the second seismic category are completely mixed with those of the first category and the non-classified ones. In Figure 8(b), the second category is well distinguished from the third, which is rather mixed with the few non-classified

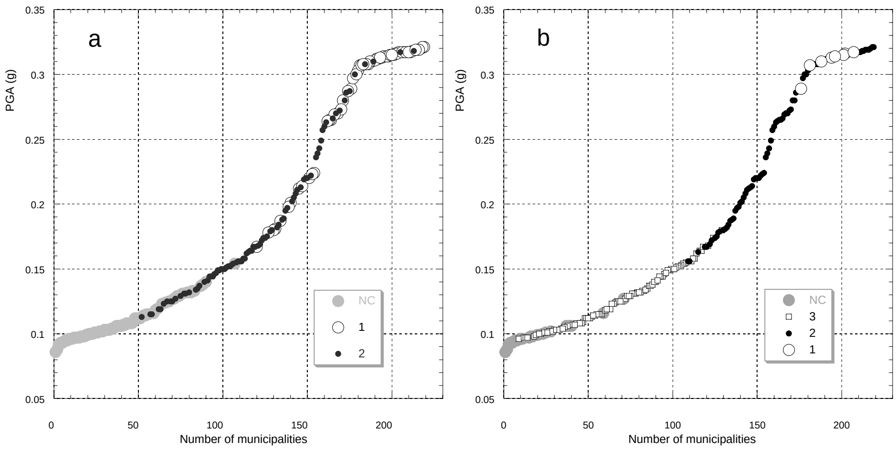

Figure 8. Distribution of PGA with a 475-year return period on rock with respect to the present (a), and the proposed (b) seismic zonation.

municipalities. The first category collects municipalities in the upper part of the curve where some of the second category also appear. The comparison between the two graphs demonstrates that the proposed zonation divides the municipalities according to the PGA on rock better than the present zonation. This was expected because some of the hazard parameters on which the new proposed zonation is based (spectrum intensity) derive from a procedure similar to that for PGA.

In Figure 9, the free-field PGA distribution is shown with respect to the present (Figure 9(a)) and the proposed (Figure 9(b)) zonation. A moderate improvement in the seismic category division can be seen with respect to Figure 8. In fact, Figure 9(b) shows a better agreement between PGA values and the proposed zonation than Figure 8(b), with the exception of three municipalities in which the first category was proposed to have been assigned mainly due to the maximum observed intensity (Gruppo di Lavoro, 1999).

4. Conclusions

Seismic hazard maps for administrative purposes have to consider soil conditions. This information should be included in the whole process of seismic hazard assessment, not only as an addition or multiplication factor of rocky-based estimates. Future GIS applications will allow greater detail, and a direct involvement of the technical staff of each municipality. It is time for Italy to make some simplifications. A schematic definition of dominant soil conditions at municipality level in the Friuli – Venezia Giulia region (Figure 4) was proposed during the first phase of the project for regional seismic risk map definition. The subdivision is driven by geological and geotechnical considerations on soil type where the majority of the buildings are located: an approximation that is valid for most of the small administrative units. Then, PSHA was computed (Figure 5) and the free-field PSHA was

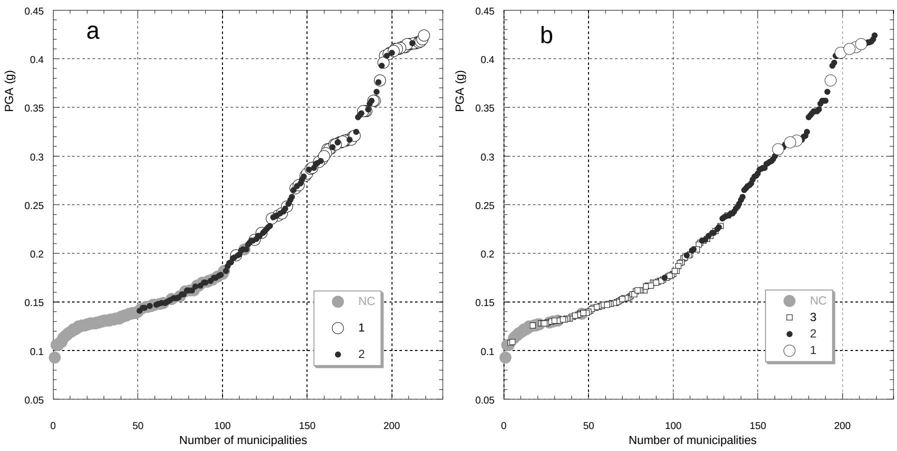

Figure 9. Distribution of PGA with a 475-year return period in the free-field with respect to the present (a) and the proposed (b) seismic zonation.

defined according to three soil types. The free-field PSHA is expected to better describe possible shakings. The truth of this statment has been checked first by comparing the maximum observed intensity (Figure 3) with the long-term expected PGA (Figures 6 and 7) where no significant correlation is detected: we believe the reasons lie in possible local damage affecting the maximum intensity estimates, and in what areal seismogenic sources represent for modelling the real ones. The second check considered the PGA distribution with respect to the present seismic zonation and the more robust one, which was recently proposed (Figures 8 and 9); a moderate improvement is seen when passing from standard rock estimates to free-field values, but progress has not reached expectations.

This, in any case, is a preliminary contribution of an ongoing project. More significant investigations are needed before stating that a national/regional seismic zonation based on a free-field hazard map is better than one based on average soil conditions.

Acknowledgements

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