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Application of Sponheuer and Blake models in the seismic hazard evaluation: The case of Messina Straits

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Attenuation is fundamental in the description of a seismic event, determining the spatial distribution of intensity associated with it. Knowing the influence of the attenuation coefficients on the values of the maximum expected intensity for North-Eastern Sicily, the necessity arises to quantify the »weight« of the attenuation models and of the respective coefficients on the intensity estimates.

A first evaluation is presented here using the Sponheuer and Blake models. The comparison of the maps of expected intensity, obtained from the cross-use of the laws allows a first critical estimate, showing the greater adaptability of the Sponheuer model to describe the attenuation of intensity for the investigated area.

Primjena Sponheuerovog i Blakeovog modela pri procjeni seizmičkog hazarda: Slučaj Mesinskog tjesnaca

Prikazana je procjena utjecaja primjene dva različita modela atenuacije intenziteta potresa na iznose očekivanih maksimalnih intenziteta. Usporedbom karata koje prikazuju očekivanu razdiobu makroseizmičkog intenziteta na području sjeveroistočne Sicilije, zaključeno je da upotreba Sponheuerovog modela omogućuje pouzdanije zaključke.

Introduction

The evaluation of seismic hazard for a given area requires particular care in the composition of the input files to the computer program. A previous study (Bottari et al., 1992), carried out for the Straits of Messina area, quantified the »weight« of some input parameters: extension of source zones, laws of frequency-intensity distribution, maximum intensity associated with historical events and respective error; furthermore, first evaluation of the influence of the attenuation coefficients on the values of expected intensity was made.

In order to optimize the evaluation methods for seismic hazard, and consequently the results in respect to the seismic history of the region, an accurate estimate of the influence of the attenuation models employed for the calculation of the coefficients associated with the zonation of the investigated area becomes necessary.

The analysis carried out fits into this context with a double aim: to quantify the »weight« of the attenuation coefficients on the intensity projection and the »weight« of the attenuation model used for the calculation of the values of maximum expected intensity. The calculation of expected intensity values was carried out using the McGuire computer program (1976) in the version proposed by Saegesser and Mayer-Rosa (1978), referred to as the McGuire code hereafter. For the aims of the research it was modified by introduction of the attenuation law different than that of Sponheuer, which was inserted in the original version of the code. In particular, Blake's law was introduced in order to make a first comparison of the results.

The choice of Blake's law as an alternative to the law inserted in the calculation code is supported by studies carried out in the area. It is aimed at both evaluating the applicability to the single macroseismic field (Bottari et al., 1979) and at testing the suitability to describe the distribution of intensity with distance for the whole area of Southern Italy (Pietrafesa et al., 1991).

Research method

The investigated area circumscribes the Strait of Messina in a radius of about 40 km (Figure 1). For the study it is necessary to know the seismic history of a wider region (A), that includes the area (a), for which the hazard is to be evaluated. The seismicity of the investigated area (a) is conditioned by the seismicity of the region (A).

The knowledge of the tectonically active structures aids the definition of zoning, and for the region under study the outline proposed by Ghisetti and Vezzani (1982) was referred to, as shown in Figure 2. The set of the utilised seismic events (Figure 3) was taken from the PFG Catalogue (Postpischl ed., 1985), assuming V °MCS as the minimum threshold for the selection.

The analysis involves two successive phases, characterized by a series of cross comparisons by using two different attenuation models (Sponheuer and Blake) of intensity with distance from the epicentre.

In the first phase of the analyses the input files contain the coefficients obtained by using two different attenuation laws (Figure 4). In particular the Sponheuer model (1960) was used:

$$I_o - I_i = 1.3 \log \left(\frac{D_i}{h}\right) + 1.3\, \alpha\, (D_i - h) \qquad (1)$$

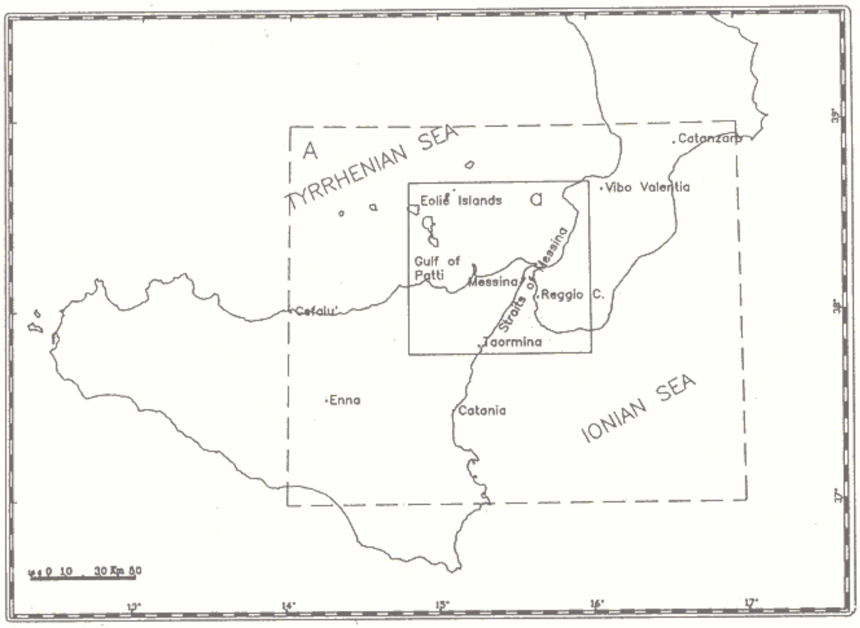


Figure 1. Investigated area. Region A is indicated by a dashed line. It has notable influence on the seismicity of the region a, indicated by a continuous line. For the region a the values of maximum expected intensity are evaluated.

and also an exponentially decreasing model:

$$I_i = I_o \exp(-\alpha\, D_i) \tag{2}$$

proposed for the area under examination by Bottari et al. (1979), derived from Blake's model. Here I_o and I_i are the epicentral and observed intensity, respectively, D_i is epicentral distance, h is the depth of the hypocentre, and α is the coefficient of intensity attenuation with distance. Both models were applied in their anisotropic formulation, identifying two distinct values of the coefficient for the two directions of maximum and minimum attenuation of intensity.

Moreover, modifying the original code through the introduction of the Blake model (1941):

$$I_o - I_i = \tau \log\left(\frac{D_i}{h}\right) \tag{3}$$

led to the composition of two input files using the law (3) in the formulation of both the isotropic (one value of τ) and anisotropic (two values of τ) fields.

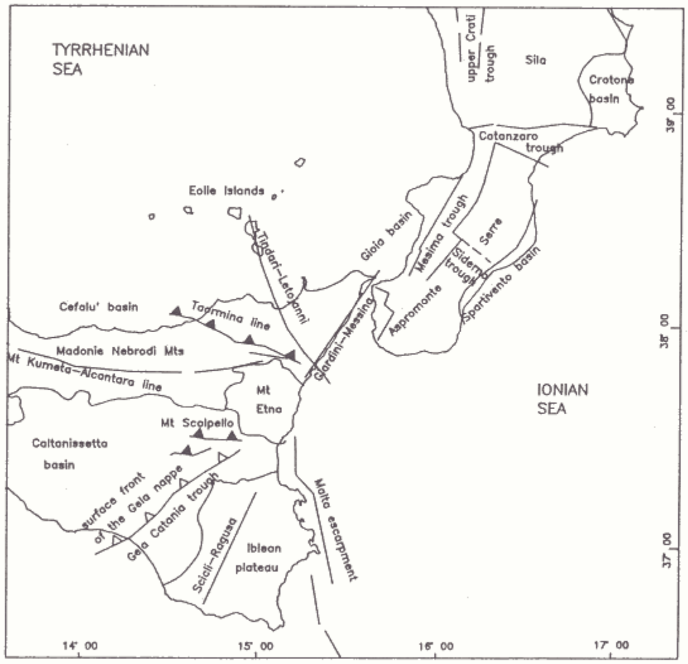


Figure 2. Geological-structural outline of the investigated region (by Ghisetti and Vezzani, 1982).

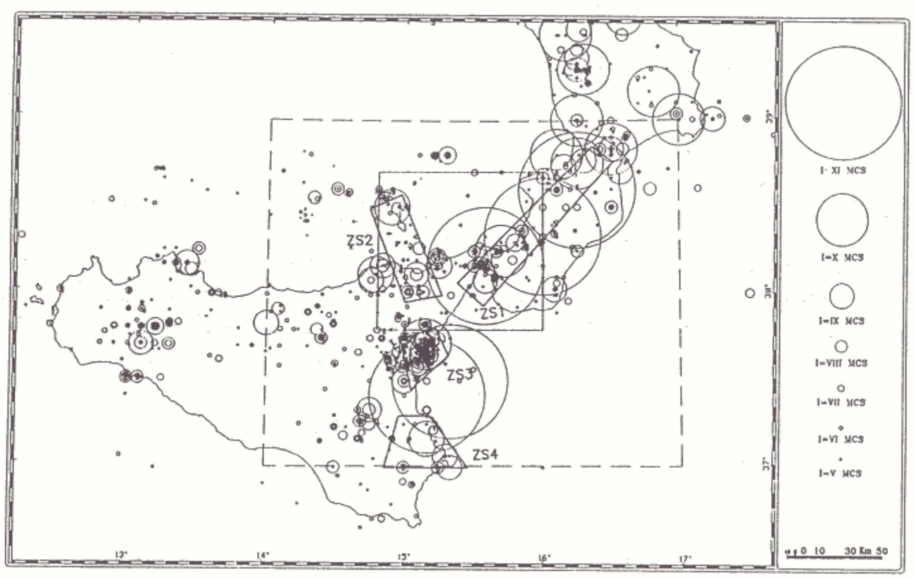


Figure 3. Epicentral map (with $I_0 \geq$ V °MCS) and representation of the seismic source zones of the area employed for the analysis. Each circle is proportional to the epicentral intensity according to the Båth and Duda relationship.

In the second phase of the analysis the two codes of distinct calculation were compared: the McGuire code in its original version and in its modified version. This was done in order to evaluate the »weight« of the attenuation model on the values of maximum expected intensity. For this the »homogeneous« use of the laws (1) and (3) is necessary, which means the use of the same law for the calculation of the attenuation coefficients and of the maximum expected intensity values.

The input file is composed of a series of parameters which describe entirely the zonation adopted for the analysis. Excluding the attenuation coefficients (which are the subject of the present study), their choice was made based on results presented in Bottari et al. (1992). As a condition for choice the minimization of the difference between the expected and observed intensity values was imposed. The zonation employed is the one shown in Figure 3.

Results

The maps of maximum expected intensity obtained from different input combinations and from the application of the two versions of the calculation code allow a cross-comparison shown in Figure 4.

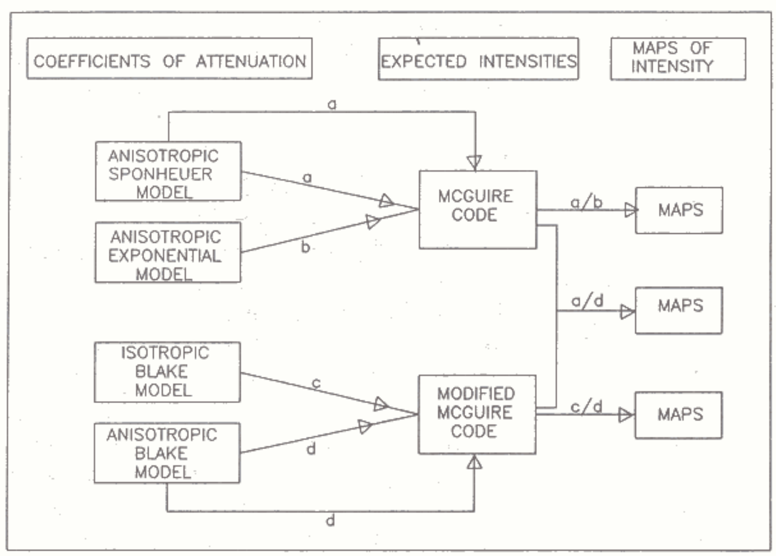


Figure 4. Table of comparisons made throughout the analysis. In the first column the models used for the calculation of the coefficients for each source zone are listed. In the second column the attenuation models inserted in the two versions of the code employed for the analysis are listed. The third column shows the comparisons between the maps of maximum expected intensity.

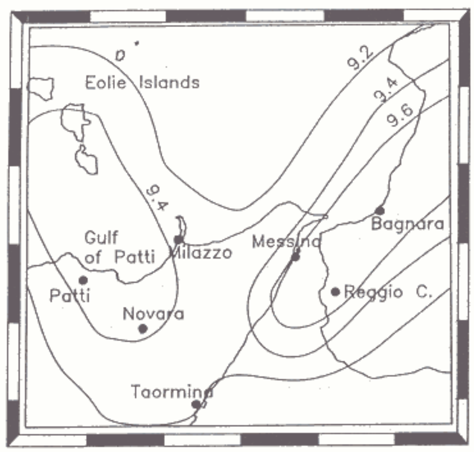
In particular, the first phase of the analysis concentrates on the first two comparisons aimed at quantifying the weight of the attenuation coefficients on the projections of intensity (maps a/b and c/d in Figure 4). The second phase involves the third comparison (maps a/d in Figure 4) which aims at quantifying the influence of the attenuation model on the values of projection.

The compared maximum expected intensity maps correspond to the return periods of 200 and 500 years respectively. The choice of the return period T = 200 years comes from evaluations of completeness of the catalogue estimated for the region to about 180 years (Epstein and Lomnitz, 1966; Knopoff and Kagan, 1977; Mulargia and Tinti, 1984; Tinti and Mulargia, 1984). The choice of T = 500 years enables the verification in terms of maximum expected intensity for a significantly longer period of time compared to the seismic history of the region examined. The historical maximum of intensity within the time span of the Catalogue (about 1000 years) is XI °MCS, corresponding to the earthquake of the Strait of Messina of 28.12.1908. Moreover, for the last 200 years the catalogue is certainly complete for events with intensity equal or larger than the threshold chosen to select the seismic events to be used for the survey; T = 500 years guarantees the completeness for the events of higher intensity ($I_0 \geq$ VIII °MCS) and therefore nearer to the historical maxima in the area.

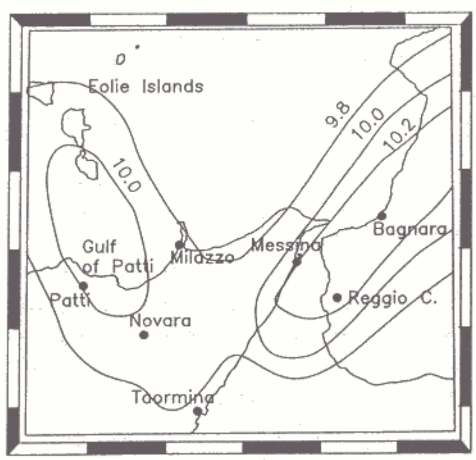
In order to represent the values of the estimated intensity the step of 0.2 °MCS was chosen. Even though this choice cannot be considered as conceptually correct, (the representation step generally adopted corresponds to 0.5 °MCS), it was nevertheless used in order to better highlight the variations of expected intensities with varying the attenuation coefficients and models used.

Figures 5.1 and 5.2 show the maps corresponding to the two return periods considered, obtained by using the original McGuire code and by introducing the attenuation coefficients calculated by the laws (1) and (2) (Figures 5.1a, 5.2a and 5.1b, 5.2b respectively). The use of coefficients calculated by the law (2) is translated into an increase in the maxima of expected intensity equal to approximately 0.4 °MCS for both return periods considered. The 500 years projection reveals an increase of 0.6 °MCS of the maximum values, which are closer to those historically observed in the area (Figure 6a).

The maps represented in Figure 7 are derived by the use of the code modified by introducing the law (3), for the two return periods of 200 and 500 years (Figures 7.1 and 7.2 respectively). The trend of the isolines does not show differences in the maximum values of intensity adopting isotropic and anisotropic attenuation coefficients. However, an increase in the areas enclosed by single isolines occurs when anisotropic coefficients are used (compare Figures 7.1a – 7.1b and 7.2a – 7.2b). The increase of the intensity values ammounts to 0.6 and 0.4 °MCS, for return periods of 200 and 500 years. Adopting the isotropic formulation of the Blake's law reveals differences in



a b



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Figures 5.1 (top) and 5.2 (bottom). Maps of the maximum expected intensities (comparison a/b of Fig. 4) obtained by the use of the original McGuire code for the return periods of T = 200 years (Fig. 5.1) and T = 500 years (Fig. 5.2) (a): attenuation coefficients for each source zone calculated by the law (1); (b): coefficients calculated by the law (2).

amplitude of the range of variability of the expected intensities for different values of the return periods considered; in particular, for a period of 200 years, the intensity values vary within a range of 2 °MCS which is reduced to 1.8 °MCS for the period of 500 years. The introduction of anisotropic coefficients conditions the amplitudes of the ranges of variability, reducing them to a single value of 1.4 °MCS for both return periods considered (Figure 6b).

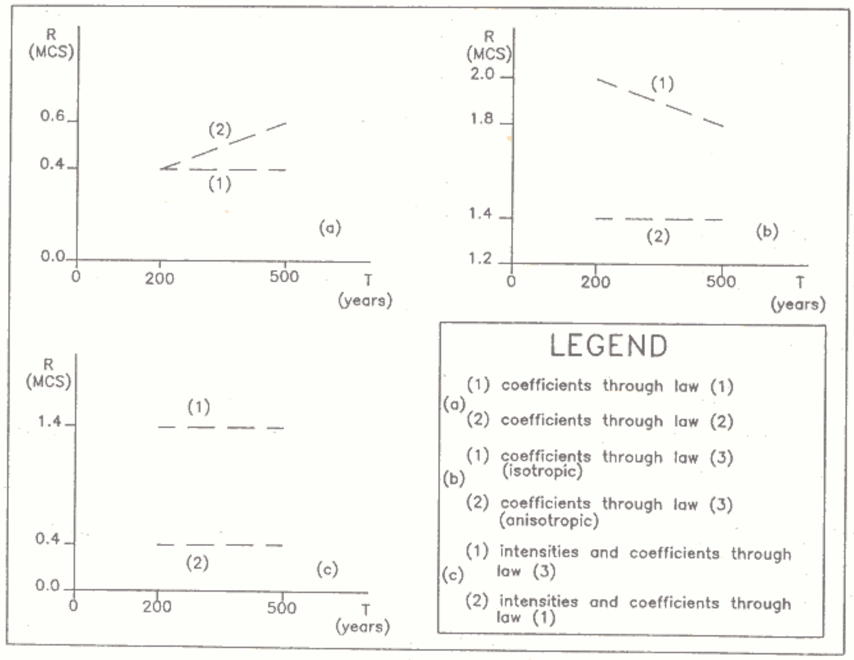
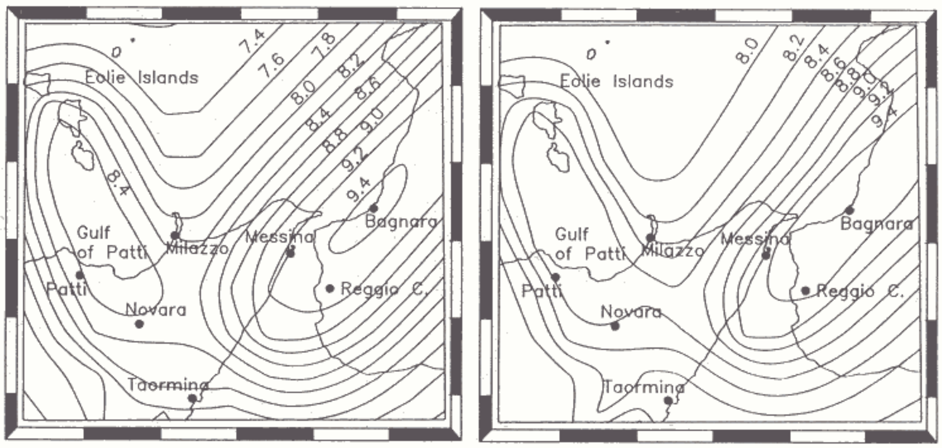


Figure 6. Graphic representation of the variations of maximum expected intensity as a function of the return period. (a): diagram corresponding to Figs. 5.1 and 5.2; (b) diagram corresponding to Figs. 7.1 and 7.2; (c): diagram corresponding to Figs. 8.1 and 8.2.

In our opinion, given the results of this comparison, there is a first indication of the greater adaptability of the Sponheuer model for the application in surveys of seismic hazard. This can be confirmed by comparing obtained results by the »homogeneous« use of the two laws in question.

Figure 8 shows the maps compiled by the use of two versions of the McGuire code for chosen return periods (Figures 8.1 and 8.2). The attenuation coefficients for a single source zone were calculated adopting the Sponheuer and Blake models respectively. Both models were applied in the anisotropic formulation, in conformity with the trend of the single macroseismic fields available for the area, which show clear anisotropy of distribution of intensity with distance.

From the comparison of the maps a noticeable difference in the areal distribution of the values of the maximum expected intensity is clear in the two cases. In particular, adopting the Sponheuer model results in an increase of the maximum values of expected intensity equal to 0.2 °MCS, accompanied by an increase of the area enclosed by single isolines, and this can be interpreted in a noticeable increase of the intensity minima of 1.2 °MCS with respect to the values obtained by the use of the Blake model. The distribution



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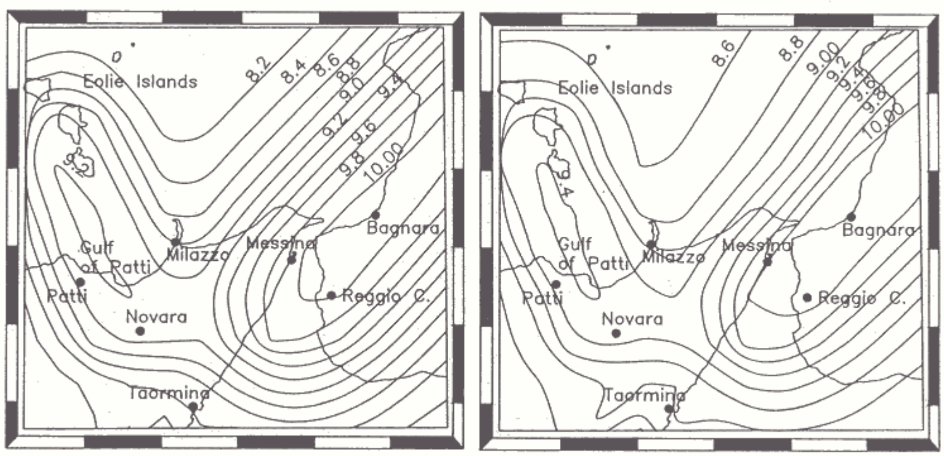

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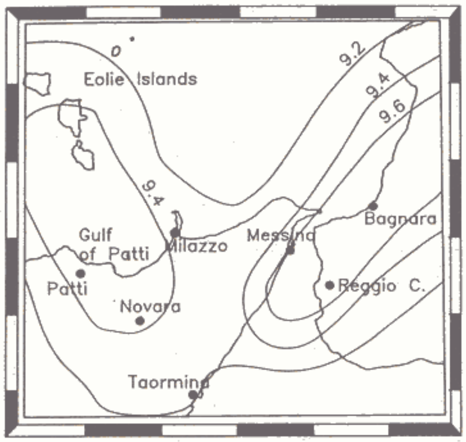
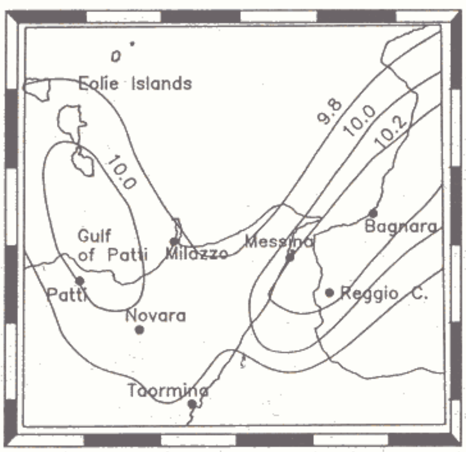
Figures 7.1 (top) and 7.2 (bottom). Maps of the maximum expected intensities (comparison c/d of Fig. 4) obtained by the use of the modified McGuire code with the return periods of $T = 200$ years (Fig. 7.1) and $T = 500$ years (Fig. 7.2). (a): attenuation coefficients for each source zone calculated by the law (3) applied in the isotropic formulation; (b): coefficients calculated by the law (3) in the anisotropic formulation.

of the maximum expected intensities for the two cases is very different (Figure 6c). The map derived from the Blake model shows a greater decrease of intensity when compared to the one derived from the Sponheuer model. As already noted, more pronounced attenuation of intensity with distance results from the use of the Blake's model.





Figures 8.1 (top) and 8.2 (bottom). Maps of the maximum expected intensities (comparison a/d of Fig. 4) obtained by the »homogeneous« use of the laws (1) and (3) with the return periods T = 200 years (Fig 8.1) and T = 500 years (Fig 8.2). (a): use of original McGuire code and of the law (1) for the calculation of the coefficients for each source zone; (b): use of the modified McGuire code and of the law (3) in the anisotropic formulation for the calculation of the coefficients for each source zone.

Finally, from Figure 6 it can be deduced that, contrary to what is obtained by the use of different models for the calculation of the coefficients and expected intensities, the variations of expected intensities remain constant for the two return periods consequent to the »homogeneous« use of the models.

Conclusions

In the seismic hazard evaluation the best possible conditions are sought in order to minimize the difference between the observed historical values and those expected. A suitable modelling of intensity with distance contributes to this aim.

A comparison was made of the results obtained by the use of some attenuation models widely used in the literature and of an exponential model derived for the Calabro-Siculo area.

It can be concluded that of the two models taken into consideration, the Sponheuer model is certainly the one which gives better evaluation of seismic hazard. Although the homogeneous application of the attenuation models create distribution of expected intensity with a higher degree of reliability, it can be said that the combination of the Sponheuer's model (calculation of intensities) with the exponential model (calculation of the coefficients) gives satisfactory results for seismic hazard evaluations.

The results of this first analysis supply elements for evaluation and comparison useful for the preestablished objectives; however, considering attenuation models recently proposed in literature (Grandori et al., 1991) seems advisable in order to optimize the values of input parameters to the modified McGuire code.

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