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A NEW ATTENUATION LAW OF MACROSEISMIC INTENSITY

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SUMMARY

A few aspects of seismic hazard and risk are discussed in this paper, with particular reference to Italian conditions. In the field of hazard analysis, a new attenuation law of macroseismic intensity with epicentral distance, is presented. Then two aspects of seismic risk analysis are discussed, namely:
1) the distribution of resources devoted to seismic risk prevention among sites of different seismicity, and 2) the global cost-benefit ratio which is implicit in the Italian code.

INTRODUCTION

In Italy, a critical review of the seismic map is now in preparation. The Italian seismic map consists actually of a list of localities with the lateral force coefficient to be used, for each of them, in structural analysis. Thus the definition of the seismic map implies both hazard analysis and the choice of an acceptable risk level.

As far as hazard analysis is concerned, the historical-statistical approach provides the basic information. In the frame of this approach, the relation between macroseismic intensity and epicentral distance (attenuation law) plays a very important role. The attenuation law that has been used in the past for Italian earthquakes is expressed by the well known formula

$$I_o - I = a + b\ln D + cD \qquad (1)$$

where I_o is the epicentral intensity and I the intensity ad the distance D from the epicenter. The term blnD accounts for geometrical spreading, while the term cD accounts for absorption (Refs. 1,2).

Formula (1) does not comply very well with Italian data, as shown in Figg. 1,2 . In fact, formula (1) derives from the implicit assumption that the seismic energy is radiated from a point source. As a consequence, this formula is not reliable where distance is not large compared to the source dimensions. Moreover, following formula (1) the intensity decay $I_o - I$ does not depend on the epicentral intensity I_o, while the average trend of Italian earthquakes shows that the rate of attenuation is more rapid for small than for large earthquakes. To account for this fact it could be possible, in principle, to use different sets of coefficients a, b, c for each value of I_o. However, the number of available isoseismal maps for a given region is not high enough, in general, in order to reach a reliable definition of so many coefficients.

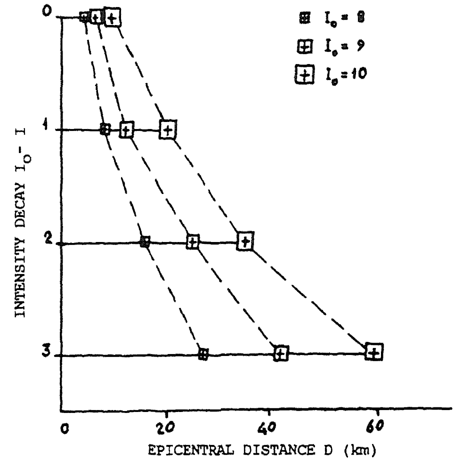

Fig. 1. Average attenuation for central and southern Italy

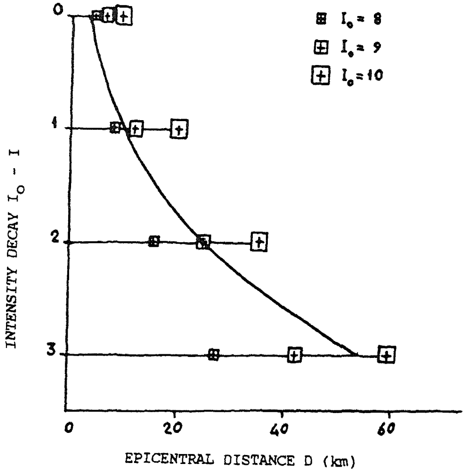

Fig. 2. Interpretation of the sample of Fig. 1 following formula (1).

The importance of the structure of the attenuation law in hazard analysis can be pointed out with the following example. Consider a site located at the center of a hypotetical homogeneous seismic zone. The correlation between intensity and return period for this site has been calculated assuming alternatively the experimental attenuation of Fig. 1 and the attenuation law (1) with the coefficients a, b, c derived from the same set of data (Fig. 3). The errors in evaluation of local hazard are very large. As a consequence, a new attenuation law has been worked out, suitable for the interpretation of Italian earthquakes (see next section).

As far as the choice of an acceptable risk level is concerned, Italian code is implicitly based on the following criterion: design with ductility factor m = 4 for the intensity that corresponds to a return period T = 500 years at the considered site (i.e. to 10 % exceedance probability in 50 years). Two main questions arise: 1) do we obtain in this way a reasonable distribution of the resources devoted to seismic risk prevention among sites of different seismicity? and 2) do we obtain a reasonable cost-benefit ratio? These questions are discussed in the last section.

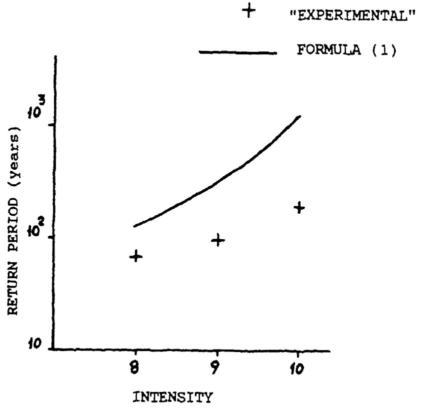

Fig. 3. Local hazard with experimental attenuation law and with formula (1).

A NEW ATTENUATION LAW

A detailed analysis of the data from which Fig. 1 has been derived suggests a first condition for the new attenuation law:

$$\frac{D_{i+1} - D_i}{D_i - D_{i-1}} = \psi \quad , \quad [i \geq 1] \tag{2}$$

with ψ independent of both i and I_o.

Moreover, the data suggest

$$\frac{D_1 - D_o}{D_o} = \psi_o \tag{3}$$

with $\psi_o < \psi$.

Finally, the data show the ratio

$$\frac{D_o\,(I_o = j+1)}{D_o\,(I_o = j)} = \frac{D_i\,(I_o = j+1)}{D_i\,(I_o = j)} = \Phi \tag{4}$$

is fairly independent of both i and j.

Obviously, the attenuation law must also satisfy the compatibility condition

$$D_i = D_o \quad \text{for } i = 0 \tag{5}$$

Conditions (2), (3), (4), (5) are satisfied by the following attenuation law (Ref. 3):

$$D_i = D_o \left(1 + \psi_o \frac{\psi^i - 1}{\psi - 1}\right) \tag{6}$$

i.e. $$i = I_o - I = \frac{1}{\ln \psi} \left[1 + \frac{\psi - 1}{\psi_o} \left(\frac{D_i}{D_o} - 1\right)\right] \tag{7.1}$$

$$\frac{D_o\,(I_o = j+1)}{D_o\,(I_o = j)} = \Phi \tag{7.2}$$

It remains to define a reference value for D_o. This can be done as follows. Using equation (6) derive from the experimental values D_i a mean value $\bar{D}_o$ for each I_o. Then impose that the reference value of D_o, through eq. (7.2), minimizes the deviations from the mean values $\bar{D}_o$.

The coefficients that define the attenuation law (7), for the sample of Fig. 1, are :

$\psi_o = 1.07$, $\psi = 1.58$, $\Phi = 1.36$, $D_o(I_o = 10) = 9.3$ km.

The new attenuation law fits very well the statistical data (Fig. 4). As a consequence, the calculation of local hazard, too, is very satisfactory (Fig. 5).

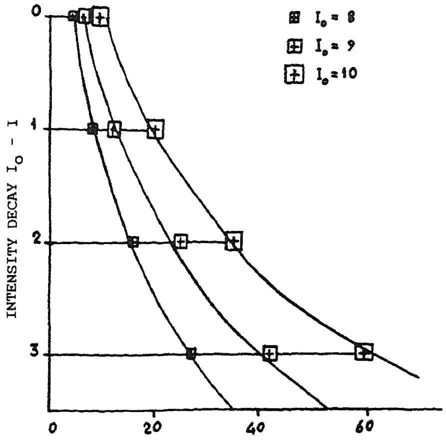

Fig. 4. Interpretation of the sample of Fig. 1 following formulas (7).

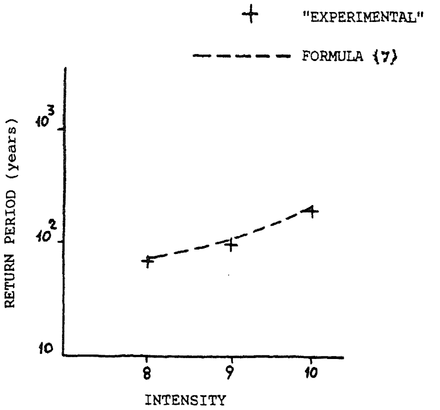

Fig. 5. Local hazard with experimental attenuation law and with formulas (7).

ON THE CHOICE OF ACCEPTABLE RISK

Fig. 6 shows the correlation between return period and peak ground acceleration for two sites. Site A is one of the most seismic sites in Italy, for which the code suggests a lateral force coefficient $C_A = 0.1$.

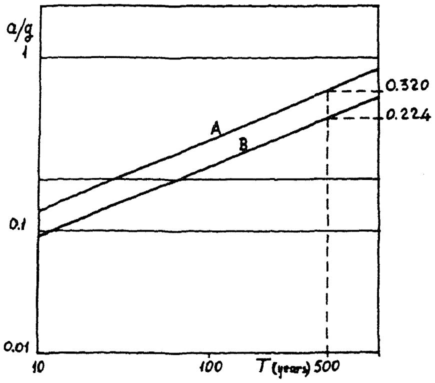

Fig. 6. Local hazard at two Italian sites.
Code design coefficients: $C_A = 0.10$, $C_B = 0.07$
Distribution ratio: $C_A/C_B = 1.43$.

Taking into account the type of formula in which this coefficient has to be used, the design peak ground acceleration leading to a ductility factor m = 4 is a = 0.32 g, which corresponds to a return period T = 500 years, i.e. to an exceedance probability 10 % in 50 years.

Site B is a less seismic site, with a(500) = 0.224 g and a design coefficient $C_B = 0.1 \times 0.32/0.224 = 0.07$. In other words, the criterion T = constant leads to a distribution ratio $C_A/C_B = 1.43$.

For the two sites, a cost-benefit analysis has been carried out for a standard residential building on the basis of the procedure illustrated in Ref. 4 and summarized by Figures 7,8,9 .

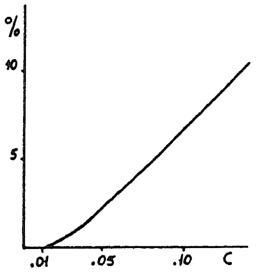

Fig. 7. Initial extra-cost for seismic design (%) versus design coefficient C.

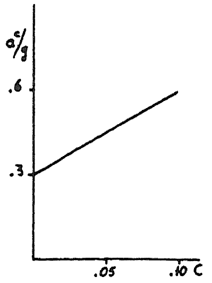

Fig. 8. Peak ground acceleration a^c/g leading to collapse versus design coeffcient C.

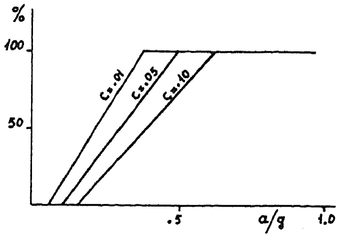

Fig. 9. Damage ratio (%) versus peak ground acceleration.

The cost and damage were translated into dollars/person/year based on the following data: accomodation of 25 m^2 per person; Italian market prices for 1987; 1 dollar = 1300 liras; capital investement at 10 % p.a.; nominal life of the building 100 years. The expected number of victims has been evaluated through the assumption that, when the building collapses, 50 per cent of the inhabitants die. The total cost D, at the two sites, has been obtained by summing up the initial extra-cost, the expected future damage and the economic consequences of the loss of human life at 400.000 $ per victim (Fig. 10).

Call now ΔD the cost variation when C is increased by ΔC, and let ΔL be the number of lives saved thanks to the same ΔC. The ratio $\mu = \Delta D/\Delta L$ is the marginal cost of a saved life, which is obviously a function of C (Fig. 11).

The value $C_A = 0.1$ suggested by the code corresponds to the minimum monetary cost and, as a consequence, to $\mu_A = 0$. A reasonable distribution ratio should be to adopte the same marginal cost of a saved life at all sites (this criterion minimizes the expected number of victims for a given total amount of resources devoted to seismic risk prevention). The condition $\mu_A = \mu_B$ leads to $C_B = 0.061$ and to a distribution ratio $C_A/C_B = 1.64$.

As shown in Ref. 4, the calculation model adopted here is robust as far as the ratio C_A/C_B is concerned. The final result is not influenced in an appreciable way by uncertainties in the hypoteses nor even by the reference value C_A. Thus, a first conclusion is that the distribution ratio suggested by the criterion T = constant looks not so bad. In order to obtain μ = constant it would be only necessary to increase slightly C_A/C_B . An advantage of the criterion μ = constant is that this criterion can be applied also in the case in which the curves of Fig. 6 have different slopes, while in this case the application of the criterion T = constant becomes uncertain.

As far as the global cost-benefit ratio is concerned, to adopte $\mu = 0$ for the code does not seem an acceptable choice: it corresponds to the principle that it is not worthwhile for the community to pay a single dollar to save a human life. Thus the suggestion is to increase the design coefficient C_A at the reference site. However, this conclusion deserves further discussion and research effort because the absolute values of μ are more sensitive to uncertainties in the hypoteses than the ratio C_A/C_B corresponding to the condition μ = constant.

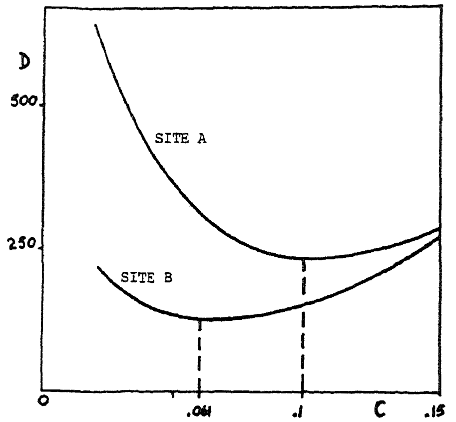

Fig. 10. Total cost D of seismic design (dollars/ year /person) versus design coefficient C.

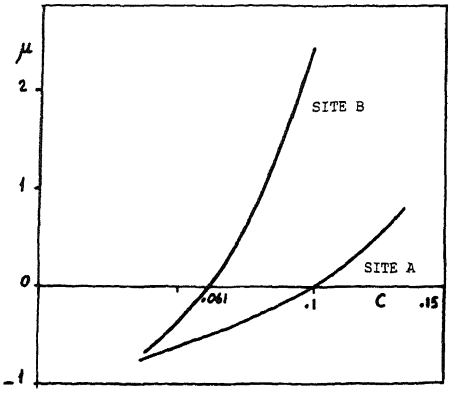

Fig. 11. Marginal cost μ of a saved life (million dollars/saved life) versus design coefficient C.
Distribution ratio (μ=constant): C_A/C_B= 1.64.

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