SEISMIC RISK EVALUATION STUDIES FOR ZONES WITH SCARCE AMOUNT OF DATA

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Abstract. Several methods to evaluate the seismic risk in areas with insufficient seismic information are described.

The definition of seismic source zones is obtained through the enhancement of the seismic patterns, using spatial strain energy release and density of epicenters, together with the tectonic information.

It is shown that the yearly rate of earthquake occurrence could be evaluated using the total strain energy release, for a time period, and a particular source zone.

An intensity attenuation law for eastern Venezuela is developed.

Introduction.

Seismic risk evaluation is fundamental in zones with moderate seismicity, but high population and investment concentration. For developing countries, a damaging earthquake could produce a temporary break down of their economy and, often, their support for seimological research is insufficient and, consequentely, scarce seismic information exist.

Local seismicity and its tectonic patterns are the primary sources for seismic risk studies, but where no local seismic data exist, most of the information comes from teleseismic recording that has a high magnitude threshold, and therefore, not normally sufficient for standard procedure seismic risk evaluation.

This paper presents some methodologies that could be used to somehow overcome the lack of enough seismic instrumental data.

The required input for seismic risk analyses are: 1) Definition of seismic source zones; 2) recurrence magnitude relation; 3) rates of earthquake occurrence; 4) upper and lower magnitude bounds; and 5) attenuation laws.

Definition of seismic sources.

When the tectonic complexity of the area is too high and not completely known or when deep geological structure are unobservables, it is very difficult to define seismic sources associated with active faults, situation that is worsen when all the instrumental seismic information had been obtained by distant stations. The correlation of the seismicity with tectonic features is, therefore, much more difficult, and it seems to be no other way, for modelling the seismicity, than using area sources with difuse activity, assuming to occur randomly and with equal probability throughout the area.

The proposed method makes use of the enhancement of the seismicity patterns, using the graphic representation of the seismic strain energy release and density of epicenters, together with the tectonic patterns, including focal mechanism studies.

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First, through a depth frequency study, the zone of interest is divided in focal depth ranges, in our case, for eastern Venezuela, three depth ranges were defined: 0-27, 28-70 and 71-300 Km.

The strain energy release maps, for each depth range, are obtained evaluating the total "energy flux", through a moving circular window with an area equivalent to one fourth of a quadrant of one geographical degree. This window is moved in steps of 0.25°, all over the region and at each point the value of log$\sqrt{E}$ is evaluated, summing the energy contribution of each event occured inside of window; for earthquakes with unknown magnitude, a minimum value is assigned, in accordance with the lower magnitude threshold existing for the time of its occurrence. Finally, countour lines are drawn using the information obtained at each window's position.

Similarly, countour lines for density of epicenters are obtained counting the number of events at each window's position.

Computer Programs had been developed to evaluate and draw the above mentioned maps.

Using those maps together with the tectonic and seismotectonic information, the task of defining reliable seismic sources zones is much simplified and well determined.

Recurrence magnitude relations. When the amount of seismic data for each seismic source zone is not enough for a direct mean square fit or maximum likelyhood determination of the "a" and "b" parameters of the well known acumulative recurrence relation (Eq. 1):

$$\log N(m) = a - b\,m \qquad (1)$$

the "b" value is found for a much larger area, including adjoining seismic sources, or either taking an average of "b" for a greater area with similar tectonic patterns. This is done taking into account that the b values have little fluctuations within a seismic region. It could also be found by applying the Gumbel's extreme value theory, using historical and instrumental seismic data.

Rates of earthquake occurrence. Generally, any seismic sample has an upper and lower threshold, the first being due to the short time span compared with the long return period of large earthquakes, and the lower bound is determined by the sensitivity of the recording network, often not enough to detect small events. Therefore to find the yearly rate of occurrence ν (above a lower bound magnitude) it is required to know the "a" value of the recurrence relation and, from Eq. 1, obtain ν.

When the seismic sample, of a particular source zone, is not enough to obtain a and b, a could be calculated knowing the b value and the total source's strain energy release, as shown next

Combining Eq. 1 with Eq. 2

$$\log E = \alpha + \varepsilon\, m \qquad (2)$$

the following is obtained: $\log N(E) = a + \frac{b\,\alpha}{\varepsilon} - \frac{b}{\varepsilon} \log E \qquad (3)$

where N(E) is the number of events with energy release greater or equal to E. Replacing the constant, it could be written:

$N(E) = A \cdot E^{-B}$ (4), where $A = 10^{\left(a + \frac{b\alpha}{\varepsilon}\right)}$ and $B = b/\varepsilon$

It is through that, for each zone, a maximum magnitude earthquake could exist, where N(E) = 1, and the energy release will be :

$$E\max = A^{1/B} \qquad (5)$$

Eq. 5 could be more properly written using the unitary step function $\mathcal{U}(x)$:

$$N(E) = A \cdot E^{-B} \left[1 - \mathcal{U}\,(E - E_{\max}) \right] \qquad (6)$$

The density function could be derived from the distribution function of Eq. 6.

$$f(E) = -\frac{dN}{dE} = A \cdot B \cdot E^{-(B+1)} \left[1 - \mathcal{U}(E - E\max) \right] + A \cdot E\max^{-B} \cdot \delta\ (E\max - E) \qquad (7)$$

being δ the Delta function.

The total strain energy release, in a time period, is obtained through the summation, or better, by the integration of E·N(E).

$$\Sigma E_{TOT} = \int_o^{E\max} E \cdot f(\tau)\ d\ E \qquad (8)$$

from Eq. 7 and 8: $$\Sigma\ E\ TOT = \int_o^{E\max} \left\{ A \cdot B \cdot E^{-B} \left[1 - \mathcal{U}(E - E\max) \right] + A\ E_{\max}^{1-B}\ \delta(E\max^{-E}) \right\} dE \qquad (9)$$

being B always < 1: $$\Sigma E_{TOT} = \frac{AB}{1-B} \left[E^{1-B} \right]_o^{E\max}$$

and $$\Sigma\ E_{TOT} = \frac{A^{\frac{1}{B}} \cdot B}{1 - B} = \frac{b}{\varepsilon - b} \cdot 10^{\left(\frac{a\varepsilon + b\alpha}{b}\right)} \qquad (11)$$

In our case, all magnitudes had been normalized to body waves magnitudes, and the values of $\alpha = 5.8$ and $\varepsilon = 2.4$ were used. The b value is always close to 1.0.

The value of the total strain energy release, $\Sigma\ E_{TOT}$, for a time period and for a particular source zone is easily obtained. Minimum possible magnitude are assigned to those events with unknown magnitude. The value of $\Sigma\ E_{TOT}$ is almost insensible to the contribution of low magnitude quakes, therefore, the completness of the used seismic catalogue is not critical, because all large events are surely being recorded.

With the b value and $\Sigma\ E_{TOT}$, the value of a is obtained from Eq. 11, and with Eq. 1 the yearly rate of occurrence is obtained. Testing this method with samples of known a values shows an excellent agreement.

Upper and lower magnitude bounds. Generally, the lower magnitude bound is taken as the minimum eartquake size of engineering interest, normally around $m_b = 4.0$ to 4.5.

For the upper bound level, although it has been shown that its uncertainty has little influence in seismic risk evaluation, several technics could be used taking into account historical and instrumental records and the physical characteristic of the main active faults.

Attenuation laws. Using newspapers information and local reports, the intensity of the main events, with known magnitude, was evaluated, and by a multiple regression, the following attenuation relation was obtained for eastern Venezuela:

$$I = 4.77 + 1.47\ m_b - 1.69\ \ln R;\ \sigma = 1.68 \qquad (12)$$

where I = MM intensity, m_b = body waves magnitude, R = hypocentral distance and σ = standard deviation.

Using Eq. 13 developed by Murphy and O'Brien, from worldwide data, Eq. 14 was obtained for peak ground acceleration.

$$\log a_H = 0.25 \cdot I + 0.25 \qquad (13)$$

$$\ln a_H = 3.32 + 0.85 \cdot m_b - 0.97 \cdot \ln R;\ \sigma\ \ln a = 0.95 \qquad (14)$$

Applications. All the above technics were used to obtain a seismic hazard map for eastern Venezuela, by means of a computer program developed by Mc Guire (1976)

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