

## **A Procedure for Estimating the Seismic Hazard Generated by Vrancea Earthquakes and its Application. II. Attenuation Curves**

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*Abstract.* In this paper is continued the elaboration of an estimation method of the seismic hazard, a method based on a research made by the same authors in a previous paper. The goal of this paper is to build the attenuation curves and to prepare the results obtained for the “etalon (reference)” earthquake for other major earthquakes in Vrancea.

*Key words:* “etalon (reference) “ earthquake; attenuation curves, macroseismic map.

### **1. INTRODUCTION**

The present paper is based on a research made by the same authors in a previous paper (Enescu et al.,[1]), in which there are presented the basic elements necessary to understand the future approaches regarding this subject - the seismic hazard generated by the Vrancea earthquakes. In order to fully understand the contents of this scientific work, the authors recommend a lecture of the previous paper (Enescu et al.,[1]).

Marza and Pantea [2] made the attenuation curves for the Vrancea earthquakes using the macroseismic maps existing at that time. We tried to use the same attenuation curves for the macroseismic intensity  $I$ , but we obtained results in contradiction to the maximum accelerations distribution for the ground movement (recorded at some seismic stations in the case of recent Vrancea earthquakes) and even to the macroseismic maps used in building those curves. For that reason, we considered necessary a method to eliminate, or to diminish the errors mentioned above, errors mentioned also in the previous paper (Enescu et al, [2]).

### **2. Attenuation curves for the “etalon (reference)” earthquake**

In order to build these attenuation curves, we used the isolines (isoaccelerations and isoseismals) of the “etalon (reference)” earthquake described by us (Enescu et al.,[1]) and presented in Figure 1 and Figure 2 of the present paper. We draw lines from the center characterized by the maximum intensity  $I_0$  (named “ $I_0$  point”) in different directions. Using the data from Figure 2, we obtained the attenuation curves, represented in Figures 3-14, as functions of the epicentral distance  $D$  and of hypocentral distance  $R$ , for different azimuths  $Az$ . The concept of “etalon (reference) earthquake” is fully explained by us in the paper of Enescu et al, [1]. In the scientific literature a set of equations is used for the attenuation curves. One of the equations is:

$$\text{Log } I - \text{Log } I_0 = a - b \log R, \quad (1)$$

where  $I_0$  is the maximum macroseismic intensity, observed when an earthquake occurs;  $I$  is the macroseismic intensity in a point on the Earth's surface, situated at the hypocentral distance:

$$R=(D^2+h^2)^{1/2};$$

where  $h$  is the hypocentral depth;  $a$  and  $b$  are the coefficients of equation (1)

One of the difficulties, which appear in the construction of attenuation curves in the case of all Vrancea's earthquakes, is that the earthquake epicentre doesn't coincide to the point of maximum macroseismic intensity (or of maximum ground acceleration). In order to solve this problem we consider Figures 15-16 and the following relation:

$$h'=(D_0^2+h^2)^{1/2}=h\left[1+\left(\frac{D_0}{h}\right)^2\right]^{1/2} \quad (3)$$

Because  $80<h\leq 160$ Km in the case of Vrancea's strong earthquakes, and  $D_0 = 23$  Km (Figure 16), it

results that the factor  $\left(\frac{D_0}{h}\right)^2$  is very small and we can consider  $h' \cong h$ . Consequently, this situation is as if the

epicentre  $E$  coincides to the point  $I_0$  (see Figure 17);  $M$  is the point situated at the hypocentral distance  $R$  (Figure 17).

### 3. An equation for the attenuation curves for Vrancea earthquakes

In order to prepare the results obtained for the "etalon (reference) earthquake" for other subcrustal Vrancea earthquakes, we must take into consideration the depth factor of the focus, which is different from one earthquake to another. Firstly, we tried to use a relation containing a function  $f(h)$ :

$$\text{Log } I - \text{Log } I_0 = a - b \log \frac{R}{f(h)} \quad (4)$$

$$\text{or} \quad \log \frac{I}{I_0} = a' - b \log R, \quad (4')$$

$$\text{where} \quad a' = a + b \log f(h) \quad (5)$$

Using the data from Figures 3-14, we computed by using the least square method the coefficients  $a'$  and  $b$  from relation (4') and the coefficient  $a = a' - b \log f(h)$  for different azimuths  $Az$ .

Because the fault plane solution is practically the same for all earthquakes in Vrancea with magnitudes  $M_{GR} > 6.5$  (6.7) (see Enescu and Enescu, [3];[4]) and because the position of the epicentre varies a little from one earthquake to another (Figure 16), we considered that the attenuation curves from Figures 3-14 are valid for all subcrustal Vrancea's earthquakes with  $M_{GR} > 6.5$  (6.7), with  $h=135$  km (depth of etalon earthquake) and characterized by the same propagation direction of the rupture in the focus as the etalon earthquake.  $M_{GR}$  is the Gutenberg-Richter magnitude.

Consequently, in order to extend the results obtained for the "etalon earthquake" to the other Vrancea's earthquakes, we considered necessary to take into account the propagation direction of the rupture in the focus. Using a factor of the following form fulfills this condition:

$$c(\alpha, \gamma) \cdot \delta [i(X, Y, Z), f(X, Y, Z), \beta]. \quad (6)$$

where : OXYZ is the axis system of the seismic source;  $\delta$  is the directivity factor of the rupture propagation which is a constant parameter for a given earthquake and it is function of the positions of initial (i) and final (f) points of the rupture;  $c(\alpha, \gamma)$  gives the influence of the rupture propagation direction on the source directivity;  $\alpha$  and  $\gamma$  are the source spherical coordinates;  $\beta$  is the fault plane dip.

By taking into account the relations (4) and (6), we wrote the following relation for an earthquake of depth  $x$ , characterized by the directivity parameter  $\delta$  of the rupture propagation and by the function  $c(\alpha, \gamma)$ :

$$\log \left( \frac{I}{I_0} \right)_{\delta, x} = a - b \log \left( \frac{R}{f(h)} \right)_x + c(\alpha, \gamma) \cdot \log \delta (X, Y, Z, \beta). \quad (7)$$

In the case of the "etalon earthquake" we wrote:

$$\log \left( \frac{I}{I_0} \right)_{\delta_e, 135} = a - b \log \left( \frac{R}{f(h)} \right)_{135} + c_e(\alpha, \gamma) \cdot \log \delta_e (X, Y, Z, \beta), \quad (8)$$

where the index "e" refers to the "etalon earthquake".

Because the analysis is made relative to the etalon earthquake, it follows that  $\log (\delta_e) = 0$ .

Subtracting relation (8) from relation (7), it resulted that:

$$\log (I)_{\delta, x} = \log (I_0)_{\delta, x} + \log \left( \frac{I}{I_0} \right)_{\delta_e, 135} + b \log \left[ \frac{\left( \frac{R}{f(h)} \right)_{135}}{\left( \frac{R}{f(h)} \right)_x} \right] + c(\alpha, \gamma) \log \delta (X, Y, Z, \beta) \quad (9)$$

The relation (9) represents the equation of the attenuation curves for any depth  $x \geq 80$  Km of the Vrancea foci and for any propagation direction of the rupture in the focus. The calculations are valid for any azimuths and epicentral distances  $D$  (or hypocentral  $R$ ). In this way all values of  $(I)_{\delta, x}$  can be obtained, in order to build the isoseismal map for any subcrustal Vrancea's earthquake of maximum intensity  $(I_0)_{\delta, x}$ .

The method of building the isoseismal and isoacceleration maps corresponding to different magnitude of Vrancea's earthquakes and also the maps related to some of them will be given in the next paper of this series which tries to solve the hazard problem generated by the Vrancea strong earthquakes.

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**FIGURE CAPTION**

- Fig. 1-Isoacceleration map of the “etalon (reference)” earthquake;  
Fig. 2-Isoseismal map of the “etalon (reference)” earthquake.Seismic intensity values refer to  
the isolines traced out,not to intervals between two consecutive isolines;  
Fig. 3-Attenuation curves corresponding to the “etalon (reference)” earthquake for  $Az=0^{\circ}$ ,  $15^{\circ}$   
and  $30^{\circ}$ ;  
Fig. 4-Same as Fig.3,for  $Az=45^{\circ}$ ,  $60^{\circ}$  and  $75^{\circ}$  ;  
Fig. 5-Same as Fig.3,for  $Az=90^{\circ}$  and  $105^{\circ}$  ;  
Fig. 6-Same as Fig.3,for  $Az=120^{\circ}$  and  $135^{\circ}$  ;  
Fig. 7-Same as Fig.3,for  $Az=150^{\circ}$  and  $165^{\circ}$  ;  
Fig. 8-Same as Fig.3,for  $Az=180^{\circ}$ ,  $195^{\circ}$ ,  $210^{\circ}$  and  $225^{\circ}$  ;  
Fig. 9-Same as Fig.3,for  $Az=230^{\circ}$ ,  $240^{\circ}$ ,  $245^{\circ}$  and  $255^{\circ}$  ;  
Fig.10-Same as Fig.3,for  $Az=258^{\circ}$  and  $263^{\circ}$  ;  
Fig.11-Same as Fig.3,for  $Az=270^{\circ}$  and  $285^{\circ}$  ;

Fig.12-Same as Fig.3,for  $Az=300^{\circ}$  and  $315^{\circ}$  ;

Fig.13-Same as Fig.3,for  $Az=330^{\circ}$  and  $345^{\circ}$  ;

Fig.14-Same as Fig.3,for  $Az=353^{\circ}$  and  $38^{\circ}$  ;

Fig.15-Explanatory sketch for the relation (3);

Fig.16-Epicentres E and  $I_0$  points corresponding to the four strong and major earthquakes

( $M_{GR} \geq 6.7$ ) occurred in the last 62 years:November 10,1940 ( $M_{GR}=7.4$ );March 4,1977 ( $M_{GR}=7.2$ );August 30, 1986( $M_{GR}=7.0$ ) and May 30,1990( $M_{GR}=6.7$ )(after Enescu et al,[1]);

Fig.17-Explanatory sketch for the relation (3) and the approximation  $h' \cong h$ .