



Non-homogeneous attenuation acceleration laws for Vrancea intermediate earthquakes

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ABSTRACT: Determination of non-homogenous laws for the horizontal PGA have been carried out for the Vrancea Intermediate Earthquakes. Mathematical models, including non-equal attenuation in two orthogonal directions have been used. The regression analysis method have been applied. The investigations have been carried out applying the compiled data bank of records from occurred earthquakes from Vrancea Intermediate Earthquakes (March 4, 1977; August 30, 1986; May 30, 1990; and May 31, 1990).

1 INTRODUCTION

For the investigations of the seismic zonation and seismic hazard evaluation, it is necessary to determine the functional relationships of the ground motion characteristics and the earthquake parameters. The studies of the functional relationships, performed so far, refer to determination of empirical strong ground motion models, taking instrumental data from occurred earthquake records as the basis for investigation.

Presented hereinafter, are the investigations for determination of empirical strong ground motion models for the horizontal peak ground acceleration (PGA) for the Vrancea Intermediate Earthquake.

2 DATA ON OCCURRED STRONG EARTHQUAKE

The investigations are carried out on the basis of established bank of available accelerograms of the occurred strong intermediate earthquakes of March 4 1977, August 30 1986, May 30 1990 and May 31 1990. Most of the accelerograms are taken by SMA-1 instruments, within the Romanian strong earthquake recording network. Data processing has been carried out by three Romanian institutions: INFP (Institute of Earthquake Physics, Bucharest); INCERC (Building Research Institute, Bucharest) and GEOTEC (Institute of Geotechnical and Geophysical Studies, Bucharest). 172 horizontal and 75 vertical components of the established data bank have been obtained on the territory of Romania. In addition, available data obtained by SMA-1 instruments of the strong motion network in Bulgaria and former Yugoslavia have been included. The records taken in Bulgaria have been processed by CLSMEE (Central Laboratory for Seismic Mechanics and Earthquake Engineering, Sofia) while the records taken

at Nish have been processed at IZIIS (Institute of Earthquake Engineering and Engineering Seismology, Skopje). The established data bank contains 190 horizontal and 80 vertical components.

3 NON-HOMOGENOUS ATTENUATION LAWS FOR HORIZONTAL PGA

Non-homogenous attenuation laws for horizontal peak ground acceleration (PGA) have been studied and determined. Both horizontal components have been used. The values of the horizontal PGA are corrected for the site soil effect so that they refer to the referent soil with shear wave velocities of $V_s \geq 700$ m/s. In the studies, the method of regression analysis for the selected mathematical model of the functional relationship has been applied. By including several parameters affecting PGA in the analysis, the effect of the earthquake origin mechanism as well as the non-homogeneity of the seismic wave propagation in the region have been indirectly taken into consideration. As a result, two different attenuation laws for PGA have been obtained.

3.1 Attenuation Law 1

It is determined using double regression analysis for a selected mathematical model of functional relationship between the horizontal PGA and the earthquake parameters, and the assumed log-normal probability distribution function for PGA as random variable.

Mathematical Model - The following mathematical model of the functional relationship has been applied:

$$Acc = e^b e^{b_M M} (R_h + C)^{b_R} \varepsilon; \sigma_{\ln Acc} \quad (1)$$

$$R_h^2 = (R_e / \rho)^2 + h^2 \quad (2)$$

$$\rho = \sqrt{\frac{1 + tg^2 \alpha}{\alpha^{-2} + tg^2 \alpha}} \quad (3)$$

where:

- Acc - horizontal peak ground acceleration (PGA) in cm/s^2
- M - Richter magnitude
- R_h - hypocentral distance in km., corrected due to inhomogeneity.
- C - constant.
- ε - variable, representing the uncertainty in PGA. A log-normal distribution of PGA about the regression law is assumed.
- R_e - epicentral distance in km.
- h - hypocentral depth in km.
- ρ - function that characterizes the non-homogeneous attenuation
- α - azimuth to the instrument site in respect to energy propagation pattern
- a - Ratio between the semi-axes of the ellipse
- b, b_M and b_R - regression coefficients
- $\sigma_{\ln Acc}$ - standard deviation

Regression Analysis. In the first regression analysis non-homogenous attenuation laws are determined for each of the occurred Vrancea Intermediate Earthquakes. The following mathematical functional relationship has been applied

$$Acc = e^{b_0} \left(\frac{R_e}{\rho}\right)^{b_1} \varepsilon, \sigma_{\ln Acc} \quad (4)$$

where:

Acc - horizontal PGA in cm/s^2 ; R_e - epicentral distance in km; ρ - function given with equation (3); b_0 and b_1 - regression coefficients and $\sigma_{\ln Acc}$ - standard deviation.

By logarithm transformation of equation (4), the following is obtained:

$$\ln Acc = b_0 + b_1 \ln\left(\frac{R_e}{\rho}\right) + \varepsilon' \quad (5)$$

for which the linear regression analysis is applied. The regression coefficients b_0 and b_1 , the standard deviation $\sigma_{\ln Acc}$, the main direction of seismic energy propagation (angle β), the ratio between the semi-axes of the ellipse in two orthogonal directions for each occurred strong earthquake and their values have been determined as presented in Table 1.

Table 1. Regression coefficients and standard deviation

Earthquake	b_0	b_1	$\sigma_{\ln Acc}$	β (degree)	α
March 4, 1977	7.79012	-0.74911	0.10876	10^0	3
August 30, 1986	6.40762	-0.50715	0.37338	50^0	3
May 30, 1990	5.82716	-0.38273	0.45593	25^0	3
May 31, 1990	5.54723	-0.48271	0.57076	85^0	1.7

The second regression analysis is carried out for the mathematical model given by equation (1). The following are the data for the regression analysis: horizontal PGA, magnitude and corrected hypocentral distance, as calculated by equation (2). Multi-linear regression analysis is carried out for the following transform of equation (1):

$$\ln Acc = b + b_M M + b_R \ln(R_h + C) + \varepsilon' \quad (6)$$

in which, $\ln Acc$ is dependent variable, while M and $\ln(R_h + C)$ is independent variable. By normalizing the values of R_e / ρ by the azimuth, non-homogenous attenuation laws are possible to be determined for different azimuths. Herewith, the attenuation laws for the sites azimuths of Bucharest, Valeni and Cerna Voda are calculated. The regression coefficients and the standard deviations for these laws are given in Table 2.

Table 2. Regression coefficients and standard deviation

Azimuth	b	b_M	b_R	C (km.)	$\sigma_{\ln Acc}$
BUCHAREST	-0.21056	1.29099	-0.80404	40.	0.52385
VALENI	-1.51412	1.42459	-0.70275	40.	0.51389
CERNA VODA	4.16765	1.11724	-1.44067	40.	0.47607

Results The attenuation laws, determined for the azimuths of Bucharest, Valeni and Cerna Voda, are graphically presented in Fig 1. They are calculated as median with magnitudes $M = 6$, $M = 6.5$, $M = 7.0$ and $M = 7.5$ and hypocentral depth $h = 90$ km.

Discussion of results. In the second regression analysis, only data of the earthquakes of August 30 1986, May 30 1990 and May 31 1990 have been used. The calculated values of standard deviation (Table 1 and Table 2) are still high. It is due to the distribution of the data for M , R_e , h , the influence form different processing methodologies and the approximate correction for the effect of site soil conditions (there are no complete data on the soil characteristics of the instrumented sites). Despite this, the results are particularly important since mathematical models with elliptical distribution have been applied. Also, the results from the determined attenuation laws by different azimuths can be directly applied into the seismic hazard methodology, which has currently been applied in the world practice.

3.2 Attenuation Law 2

It is determined using single regression analysis for the mathematical model of the functional relationship given by equation: (1), i.e., the distribution of the horizontal PGA is elliptical. A normal probability distribution function for the $\ln PGA$ has been assumed. Multi-linear regression analysis has been carried out. The regression coefficient b , b_M and b_R are determined by finding of the minimum standard deviation for varied values of the azimuth, the ratio between the semi-axes of the ellipse and the constant C . The minimum standard deviation of $\sigma_{\ln Acc} = 0.48884$ is obtained for $\beta = 5^\circ$; the ratio between the semi-axes of the ellipse is 1.2 and the value of the constant $C = 30$ km, i.e. the following attenuation law has been determined:

$$Acc = e^{3.49556} e^{1.35431M} (R_h + 30.)^{-1.58527}; \sigma_{\ln Acc} = 0.48884$$

$$R_h^2 = (R_e / \rho)^2 + h^2; \rho^2 = (1 + tg^2 \alpha) / (a^{-2} + tg^2 \alpha); a = 1.2 \quad (7)$$

Applying equation (7), the median of the horizontal PGA has been calculated and presented (Fig.2) for a magnitude M and hypocentral depth the same as of the occurred earthquakes of 1986 ($M = 7$, $h = 130$. km), May 30, 1990 ($M = 6.7$, $h = 100$. km) and May 31, 1990 ($M = 6.1$, $h = 90$. km) and the value of $\alpha = 0^\circ$, $\alpha = 40^\circ$ and $\alpha = 90^\circ$.

The application of this law in the seismic hazard analysis requires adjustment of the existing seismic hazard methodology.

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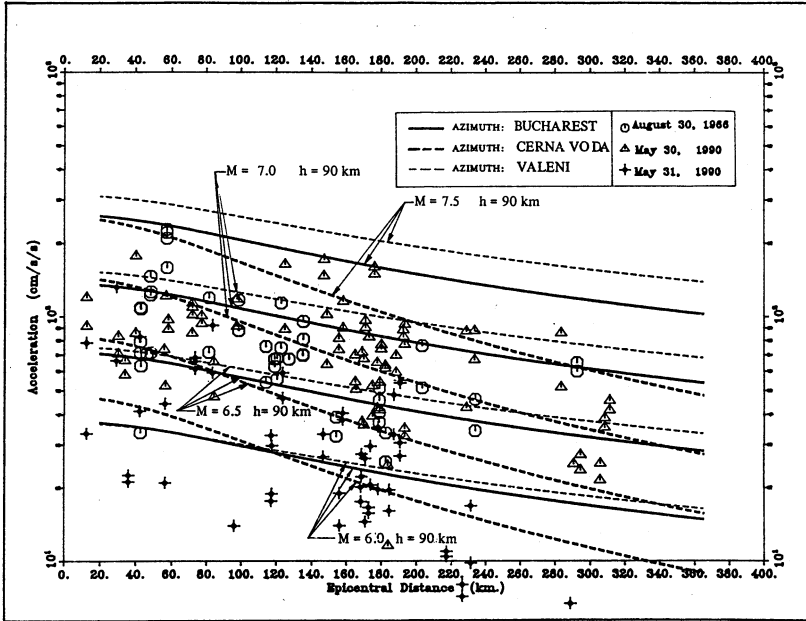


Fig. 1 Attenuation Acceleration Law 1

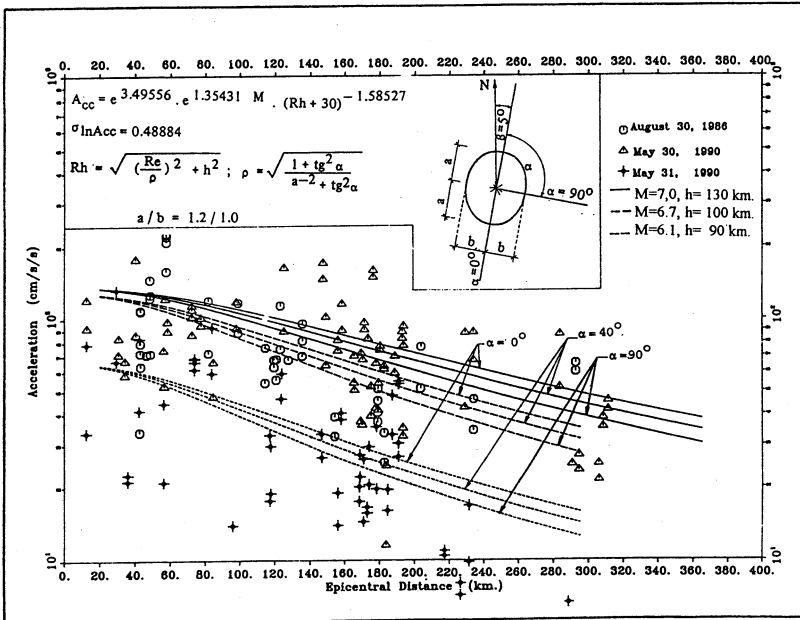


Fig. 2 Attenuation Acceleration Law 2