11 WCEE
Copyright © 1996 Elsevier Science Ltd
Paper No. 146. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

EMPIRICAL ATTENUATION ACCELERATION LAWS FOR VRANCEA INTERMEDIATE EARTHQUAKES

S. STAMATOVSKA, D. PETROVSKI

Institute of Earthquake Engineering and Engineering Seismology
University "St. Cyril and Methodius", Skopje, Republic of Macedonia

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).

KEYWORDS

Peak Ground Acceleration, Attenuation Law, Mathematical Model, Regression Coefficient, Standard Deviation

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, are reduced 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.

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 manufactured by Kinemetrics, within the Romanian network of strong earthquake recording instruments. 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).

Onehundredandseventitwo 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 totally 190 horizontal and 80 vertical components.

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 medium effect and their values for referent soil with shear wave velocities of $Vs \geq 700$ m/s have been determined. In the studies, the method of regression analysis for the selected mathematical model of the functional relationship has been applied. By including also parametric analysis of several parameters affecting PGA, the effect of the earthquake origin mechanism as well as the non-homogeneity of the seismic wave propagation region have been indirectly taken into consideration. As a result, two different attenuation laws for PGA have been obtained.

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:

$$Acc = e^{b} e^{b_M} (Rh + C)^{b_R} \varepsilon, \sigma_{\ln Acc} \qquad (1)$$

$$Rh^2 = (\mathrm{Re}/\rho)^2 + h^2 \qquad (2)$$

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

where:

Acc - horizontal peak ground acceleration (PGA) in cm/s^2
M - Richter magnitude
Rh - hypocentral distance in km
C - constant
ε - variable, representing the uncertainty in PGA.
The uncertainty results from the assumption of a log-normal distribution of PGA about the regression law
Re - epicentral distance in km.
h - hypocentral depth in km.
ρ - function
α - azimuth of instrument site in respect to energy propagation pattern
a - parameter defining the relation between the semi-axes of the ellipse , or a:b = a:1
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

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

where:
Acc - horizontal PGA in cm/s^2; Re - 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 calculation of e, the following equation is obtained:

$$\ln Acc = b_0 + b_1 \ln\left(\frac{\text{Re}}{\rho}\right) + \varepsilon \tag{5}$$

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

Table 1.

Regression coefficients and standard diviation				Parameter	
Year	b_0	b_1	$\sigma_{\ln Acc}$	β(degree)	a : b
1977	7.79012	-0.74911	0.10876	10^0	3 : 1
1986	6.40762	-0.50715	0.37338	50^0	3 : 1
1990/1	5.82716	-0.38273	0.45593	25^0	3 : 1
1990/2	5.54723	-0.48271	0.57076	85^0	1.7 : 1

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 hypocentral distance, as calculated by equation (2). Multi-linear regression analysis is carried out for the following transform of equation (1):

$$\ln Acc = b + b_M M + b_R \ln(Rh + C) + \varepsilon \tag{6}$$

in which, lnAcc is dependent variable, while M and ln(Rh+c) is independent variable. By normalizing the values of Re/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.

Azimuth	Regression coefficients and standard diviation			
	b	b_M	b_R	$\sigma_{\ln Acc}$
BUCHAREST	-0.21056	1.29099	-0.80404	0.52385
VALENI	-1.51412	1.42459	-0.70275	0.51389
CERNA VODA	4.16765	1.11724	-1.44067	0.47607

Results. By the first regression analysis, the four non-homogenous attenuation laws for the occurred strong Vrancea Intermediate Earthquakes have been determined. Applying them, the isolines of horizontal PGA median are calculated as shown in Figs 1, 2, 3 and 4. The attenuation laws, determined for the azimuths of Bucharest, Valeni and Cerna Voda, are graphically presented in Figs 5 and 6. 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 (Fig. 5) and h = 150 km (Fig. 6).

Discussion of results. Since the non-homogenous law for the 1977 earthquake is determined by only four data, it has been accepted the value of $\beta = 10^o$. 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 by M, Re, h, the overloading of the data from the different processing methodologies, the soil-structure interaction effect (all the data are not taken on free field), 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 it is for the first time that 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.

Attenuation Law 2

It is determined using single regression analysis for a mathematical model of the functional relationship given by the following equation:

$$Acc = e^{b} e^{b_M} \left\{ \left[\left(\frac{\text{Re}}{\rho} \right)^2 + h^2 \right]^{1/2} + C \right\}^{b_R} \varepsilon; \sigma_{\ln Acc} \qquad (7)$$

i.e., the distribution of the horizontal PGA is elliptical. A normal probability distribution function for the lnPGA 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 relation between the semi-axes of the ellipse and the constant C. The minimum standard deviation of $\sigma_{\ln Acc} = 0.48884$ is obtained for $\alpha = 85^o$ or $\beta = 5^o$; the relation between the semi-axes of the elipse is 1.2:1 and the value of the constant C = 30 km, i.e. the following attenuation law has been determined:

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

$$Rh^2 = \left(\frac{\text{Re}}{\rho} \right)^2 + h^2; \rho^2 = \frac{1 + tg^2\alpha}{a^{-2} + tg^2\alpha}; a{:}b = 1.2{:}1 \qquad (8)$$

Applying equation 8, the median of the horizontal PGA has been calculated for a magnitude M and hypocentral depth the same as of the occurred earthquakes of 1986 (M = 7, h = 131 km), May 30, 1990 (M = 6.7, h = 99.1 km) and May 31 1990 (M = 6.1, h = 89.1 km) and the value of $\alpha = 0^o$, $\alpha = 40^o$ and $\alpha = 89^o$ (Fig. 7). Presented in Fig. 8 is the area of distribution of the horizontal PGA of 200 cm/s^2, 100 cm/s^2, and 50 cm/s^2, determined as median and median plus one standard deviation, for an expected earthquake as the one occurred in 1977 (M = 7.2, h = 109 km).

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

CONCLUSIONS

The determined non-homogenous horizontal PGA laws for the Vrancea Intermediate Earthquake in these investigations are of particular importance since it is for the first time that mathematical models including non-homogenous attenuation in both orthogonal directions , i.e., elliptic distribution have been applied. The reported investigations so far (Radu et al., 1994), (Lunga and Coman, 1995) are carried out only by the application of the Boore-Joyner's empirical model of non-homogenous attenuation (Boore and Joyner, 1982). Therefore, the contribution of these investigations is of particular importance.

REFERENCES

D.M. Boore and W.B. Joyner (1982) "The empirical prediction of ground motion", Bull. seism. soc. Am. 72, S43-S60

C. Radu et al. (1994), "Uniform hazard response spectra for Vrancea earthquakes in Romania", 10th ECEE, Vienna, Aug. 28 - Sept. 2, 1994.

D. Lunga and Ovidiu Coman (1995) "Experience database of Romanian Facilities subjected to the last three Vrancea Earthquake, Part I, Probabilistic hazard analysis to the Vrancea earthquake in Romania" , Contract No. 8223/EN, Prepared for IAEA, Vienna, Austria.

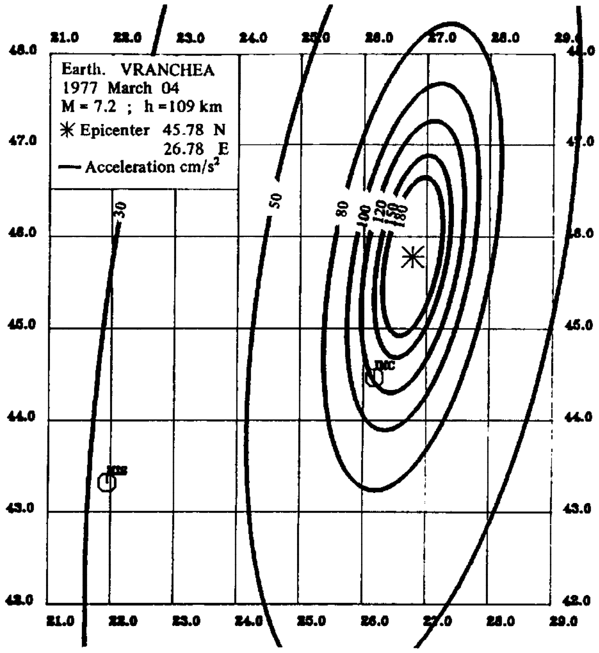


Fig. 1

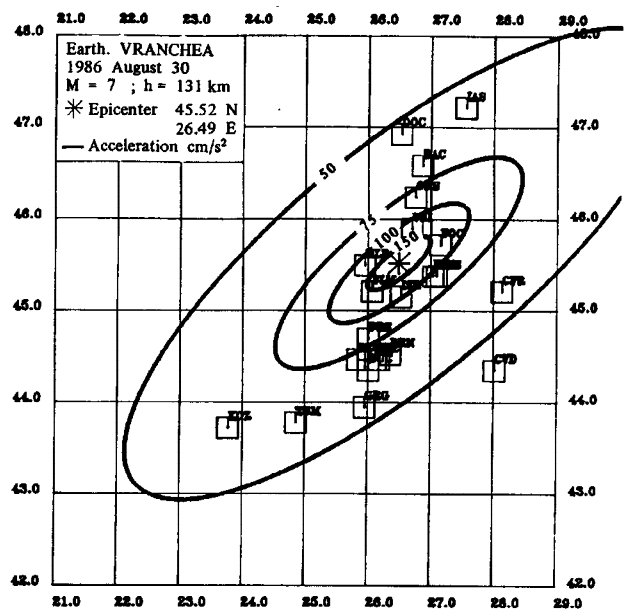


Fig. 2

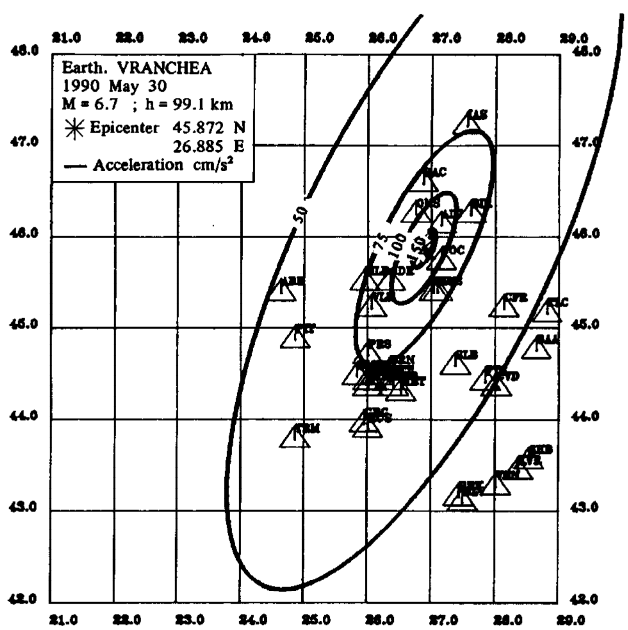


Fig. 3

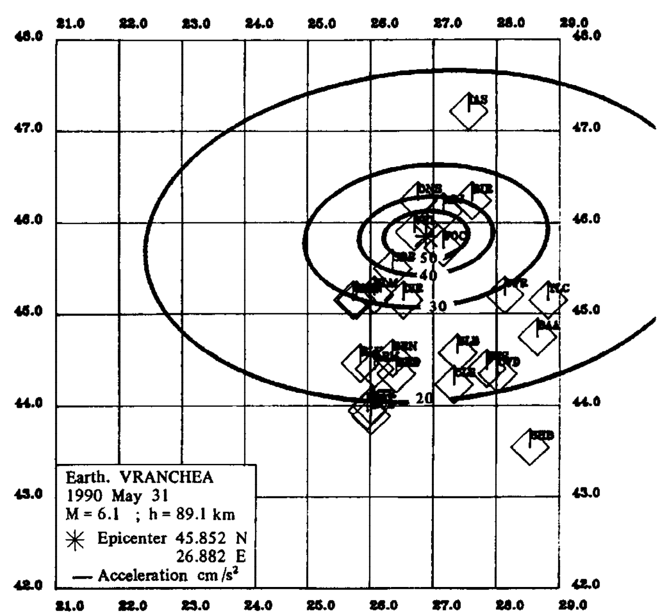


Fig. 4

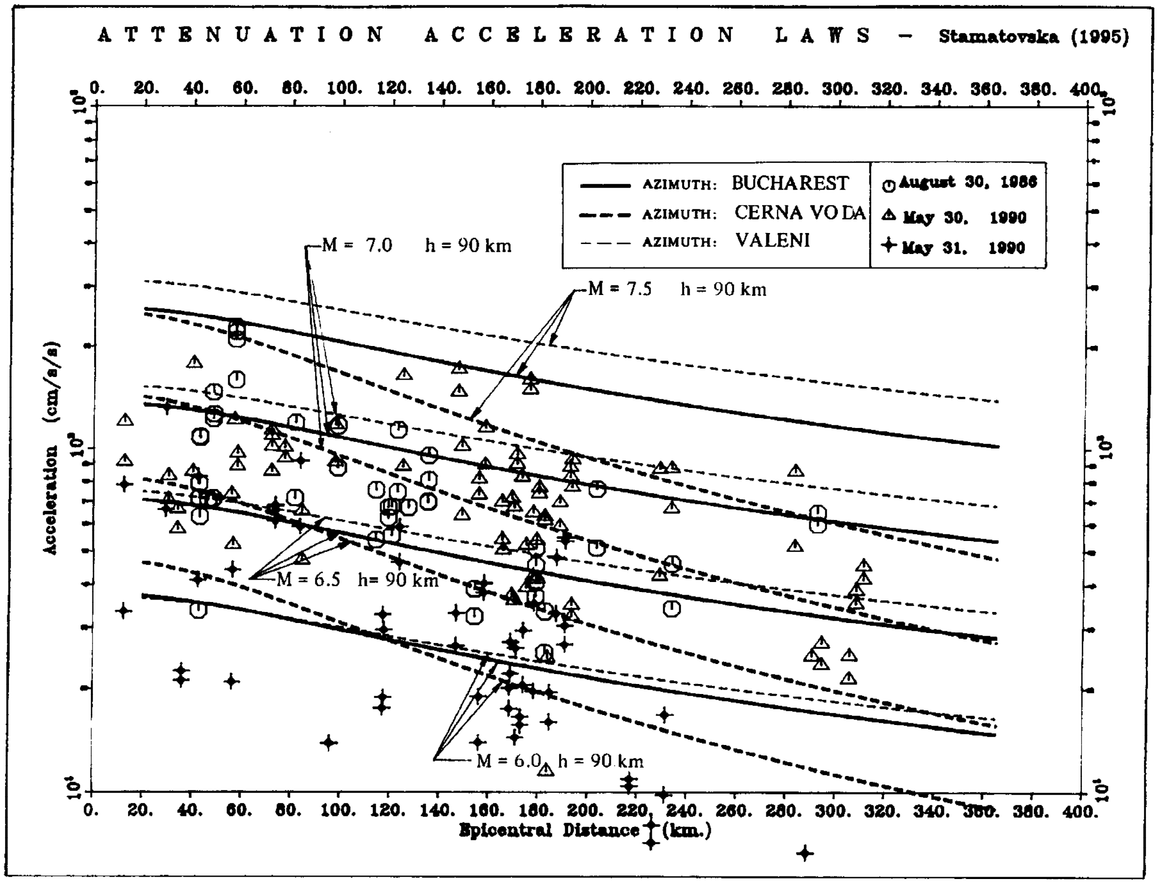

ATTENUATION ACCELERATION LAWS – Stamatovska (1995)
AZIMUTH: BUCHAREST
AZIMUTH: CERNA VODA
AZIMUTH: VALENI
August 30, 1986
May 30, 1990
May 31, 1990
M = 7.0 h = 90 km
M = 7.5 h = 90 km
M = 6.5 h= 90 km
M = 6.0 h = 90 km
Acceleration (cm/s/s)
Epicentral Distance (km.)

Fig. 5

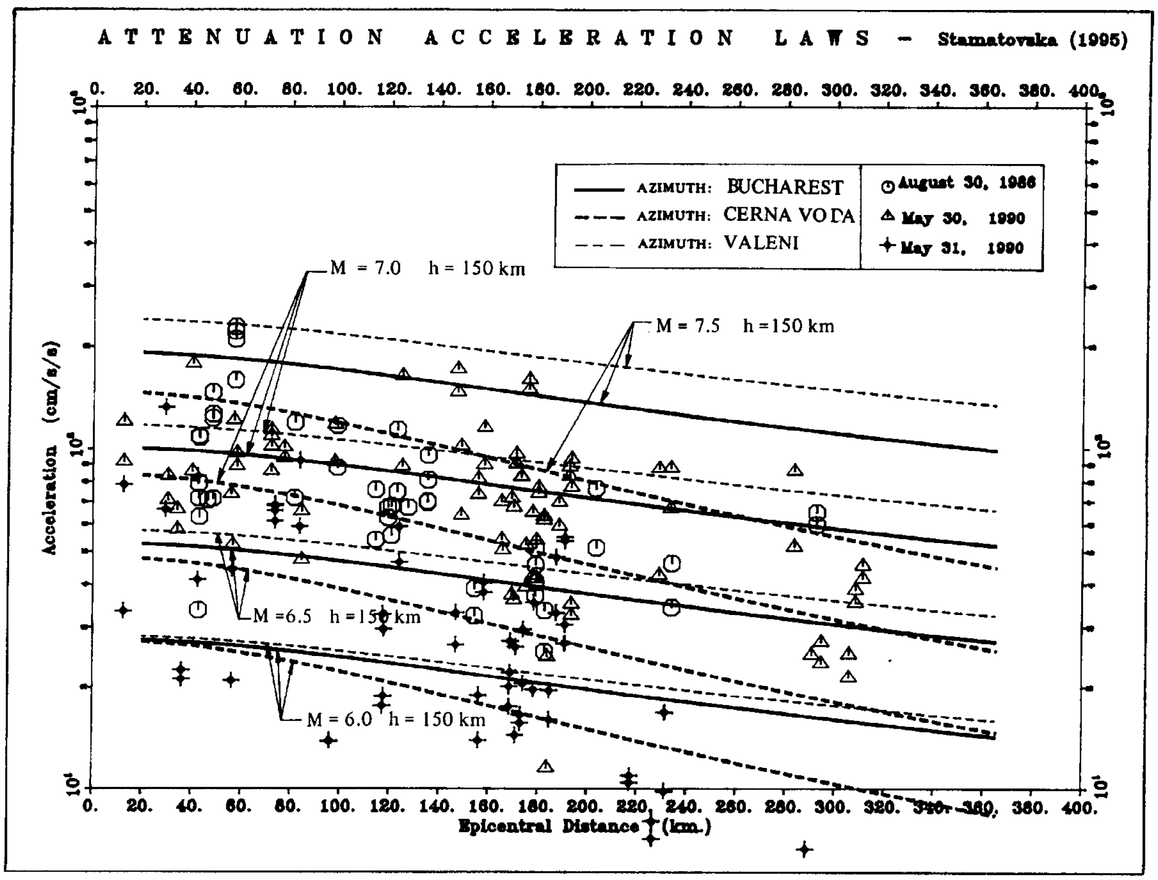
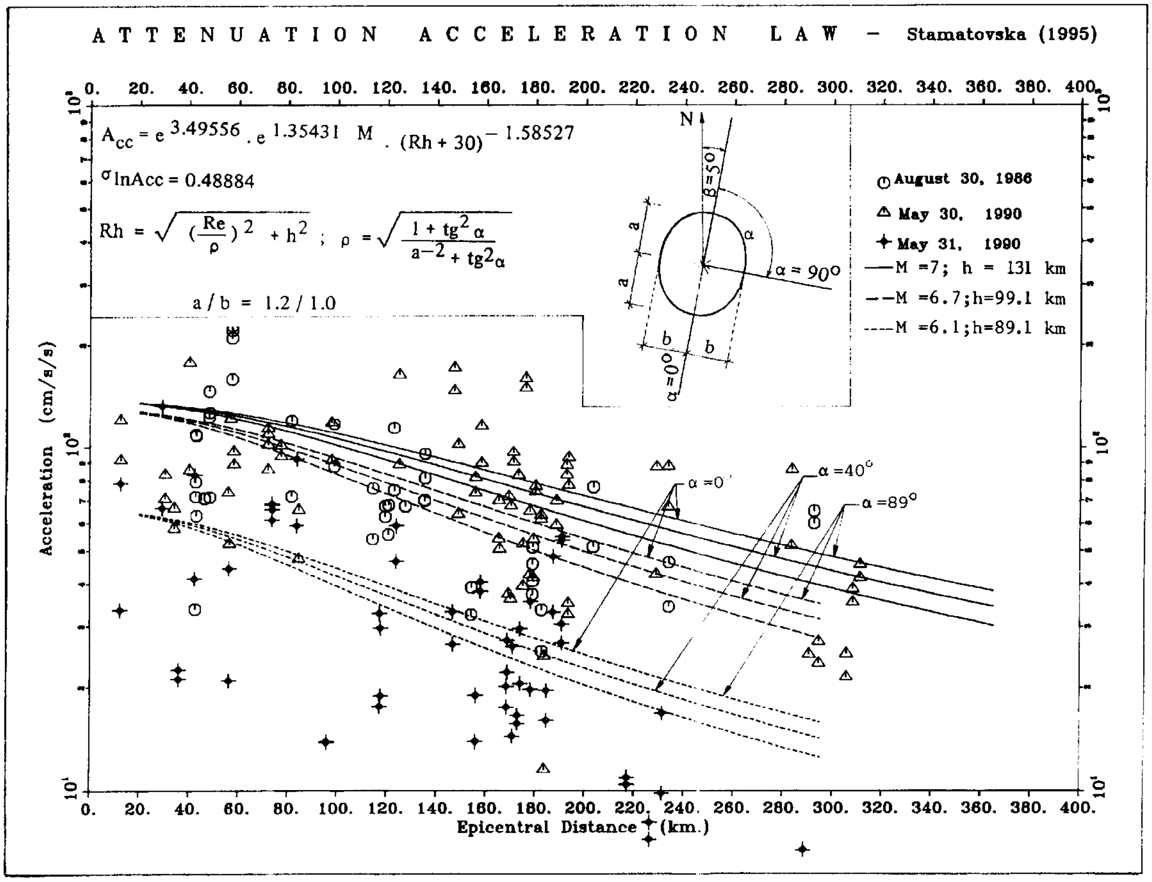
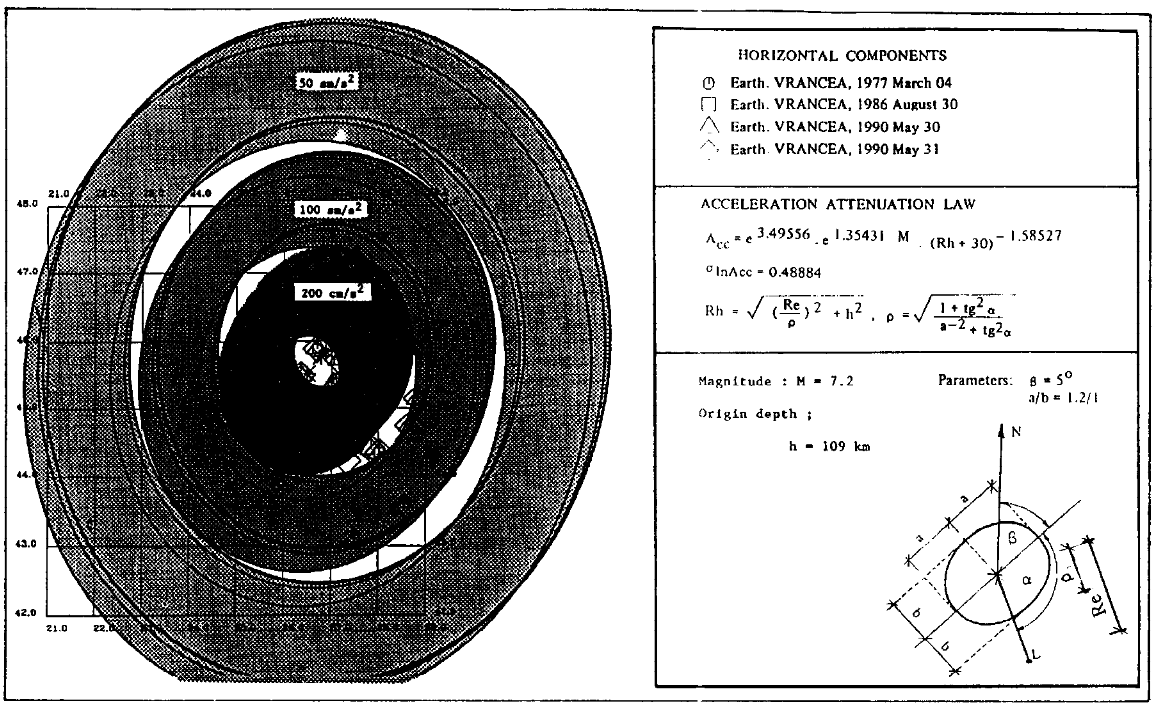

ATTENUATION ACCELERATION LAWS – Stamatovska (1995)
AZIMUTH: BUCHAREST
AZIMUTH: CERNA VODA
AZIMUTH: VALENI
August 30, 1986
May 30, 1990
May 31, 1990
M = 7.0 h = 150 km
M = 7.5 h =150 km
M =6.5 h = 150 km
M = 6.0 h = 150 km
Acceleration (cm/s/s)
Epicentral Distance (km.)

Fig. 6



ATTENUATION ACCELERATION LAW – Stamatovska (1995)
$A_{cc} = e^{3.49556} \cdot e^{1.35431\ M} \cdot (Rh + 30)^{-1.58527}$
$\sigma_{\ln Acc} = 0.48884$
$Rh = \sqrt{(\frac{Re}{\rho})^2 + h^2}$; $\rho = \sqrt{\frac{1 + tg^2\alpha}{a^{-2} + tg^2\alpha}}$
a / b = 1.2 / 1.0
August 30, 1986
May 30, 1990
May 31, 1990
— M =7; h = 131 km
– – M =6.7;h=99.1 km
---- M =6.1;h=89.1 km
α =0°
α =40°
α =89°
β=5°
α = 90°
Acceleration (cm/s/s)
Epicentral Distance (km.)

Fig. 7



50 cm/s²
100 cm/s²
200 cm/s²
HORIZONTAL COMPONENTS
Earth. VRANCEA, 1977 March 04
Earth. VRANCEA, 1986 August 30
Earth. VRANCEA, 1990 May 30
Earth. VRANCEA, 1990 May 31
ACCELERATION ATTENUATION LAW
$A_{cc} = e^{3.49556} \cdot e^{1.35431\ M} \cdot (Rh + 30)^{-1.58527}$
$\sigma_{\ln Acc} = 0.48884$
$Rh = \sqrt{(\frac{Re}{\rho})^2 + h^2}$, $\rho = \sqrt{\frac{1 + tg^2\alpha}{a^{-2} + tg^2\alpha}}$
Magnitude : M = 7.2
Parameters: β = 5°
a/b = 1.2/1
Origin depth ;
h = 109 km

Fig. 8