0264

# ATTENUATION LAWS OF SEISMIC MOVEMENT

**Juan D JARAMILLO[1] And Gloria E ECHEVERRI[2]**

## SUMMARY

A procedure is presented for estimating seismic attenuation, by considering a model of seismic radiation of the far field and through an anisotropic space. By means of theoretical modelation, it is shown the distribution of seismic intensity due to the effects of directivity and focusing, when in the latter the velocity lateral gradient of transmission of waves is incorporated. We express the need of incorporating the attenuation laws considering both the azimuthal effects and lateral heterogeneity from the propagation medium.

## INTRODUCTION

The quality of studies of seismic hazard required in the antiseismic codes basically depends on the possibilities of estimating the nature of important characteristics from the movements produced by an earthquake (Sarria, 1995). To describe the occurrence of earthquakes, -and afterwards to find out the relationships among the magnitude, the distance to the source and the seismic intensity of interest- some different laws of attenuation have been developed. Most of them are based on statistic analysis of data from strong movements, in function of the magnitude of the earthquake, the distance, and occasionally other parameters associated with the source, i.e. type of faults and different tectonic environments. The results from this research are traditionally resumed in curves, which include the maximum values of the selected parameters and spectral values. Nevertheless in the review of the results presented on national and international literature we found a high dispersion between the analyzed data and the proposed models (Joyner & Boore 1988, Idrriss 1991, Crouse 1991, Iai & Mukai 1992, Campbell 1993, Mc Verry 1993, Caillot & Bard 1993, Campbell & Bozorgnia 1994, Abrahamson & Silva 1997)

Considering the possibility that the models of seismic attenuation present a high dispersion by limiting the laws of attenuation to an isotropic behavior, it is proposed a procedure that considers variations in the movement´s intensity. This is implemented by including the parameters of the seismosources or the released energy in function of seismic moment and of the characteristics of propagation of waves through the medium, expressed in a model that includes the lateral inhomogeneities.

## COLOMBIAN SEISMIC-GEOLOGIC ENVIRONMENT

The whole western coast of South America is an active, subduction zone of an oceanic plate beneath the continental listosphere. Colombia is part of this area, since it is located in the northwestern corner of the South American continent. In this particular location, the Nazca oceanic plate, the continental South American plate, and the Caribbean oceanic plate convergence, producing thus a very complex tectonic framework in the Colombian territory. The convergence of plates has provided the dominant forces in the development of the geological structures of Colombia, with an architechure that Etayo et al., (1986) describe as made up of individual fragments of overlapping plates, reterred to as tectonic. Each terrain is characterized by having its own lithology, stratigraphy, structural style and geological history. These terrains are separated by faults with a predominant N-S to EN-SW direction as it is shown in the fig. 1, and in the geologic cross-section of the Colombian Andes (fig. 2).

[1] *Universidad EAFIT, Carrera 49 # 7 Sur-50, Medellín, Colombia. Email:jjarami@sigma.eafit.edu.co*
[2] *Universidad EAFIT, Carrera 49 # 7 Sur-50, Medellín, Colombia.*

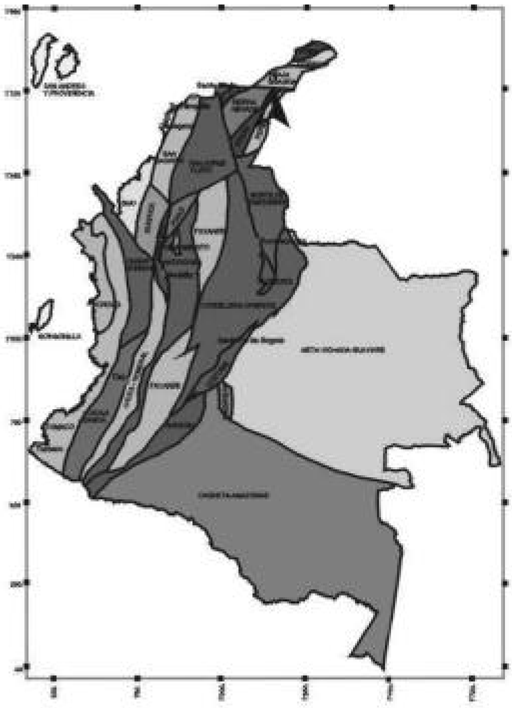

**Fig.1. Map of the geologic terrains of Colombia according to Etayo 1986.**

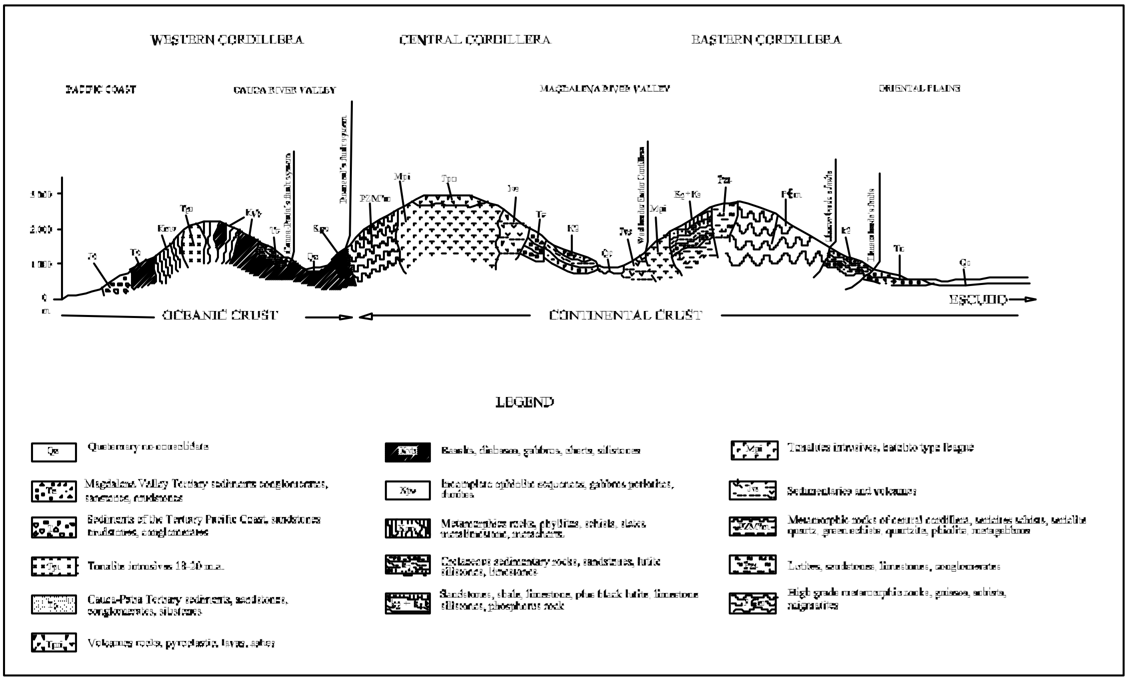


Fig. 2. Geologic cross – section of the Colombian Andean between latitudes 3º y 4º north

## SEISMIC INTENSITY DISTRIBUTION OF SOME COLOMBIAN EVENTS

In the majority of seismic events in Colombia, a strong spatial correspondence between the distribution of intensities and the regional structures has been found, this indicating a clear anisotropy of the attenuation. The isosista major axis has a direct relation with the straight of the faults systems and the geological bodies, which has a general N-S to EN-SW straight. This tendency evidences the important effects of faults and geologic bodies in the attenuation of seismic movements. The isosistas map in fig. 3 shows the distribution of intensities for some events (Sarria 1995). In the other hand, it is important to keep in mind that the attenuation relationships so far proposed, are an able to satisfactorily explain the distribution of the seismic energy.

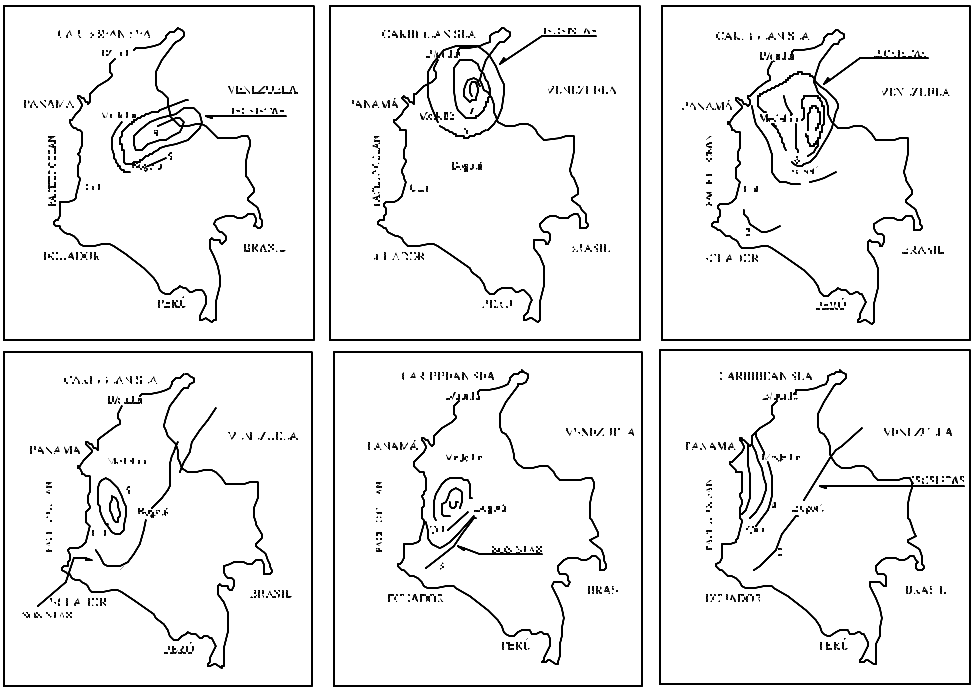


Fig. 3 Seismic intensity distribution of some Colombian events

## PROPOSAL FOR A SEISMIC INTENSITY ATTENUATION MODEL

Based in the previous considerations, and analyzing available geophysical models and mathematical expressions to describe the generation, transmission and dissipation of seismic energy (e.g. Haskell model, crack model, circular fault model, barrier model, roughness model,), we selected the following procedure taken from Aki (1980), that could be referred to as the "Seismic radiation model of the far field".

### Hypothesis

***Seismic source.***

Dislocation is considered as a point-source on which a system of forces representing the fracture are acting. The geometry of the fault is established from the orientation parameters in the fracture plane: are the strike, the dip of the plane, the rake and, the depth (figure 4)

Based on this hypothesis, an elementary model to represent the mechanism of an earthquake can be defined by a shear zone located on a plane surface, whose dimensions are small compared to the distance from the point of observation. Thus, a shear fracture is assumed to be equivalent to a system of two pairs of orthogonal forces without a resulting moment. A system known as a double couple of forces.

***Radiation pattern.***

The diagram of the radiation pattern of the amplitude of the P and S waves for a double couple of forces in a point source is assumed. This diagram is defined by a series of lobes, where the form of the radiation is function of $f$ and i, and the direction of the ray off and of $f_s, d, l$, this defining the fault´s geometry for a dislocation with an arbitrary orientation (figure 4).

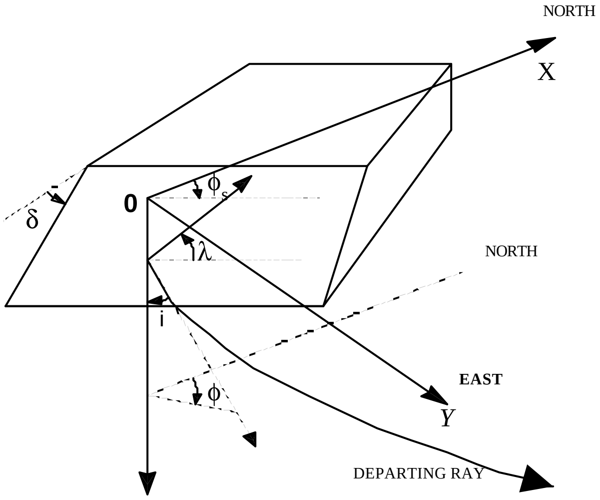


Fig 4. Configuración of the fault plane: the strike angle $f_s$, and the dip angle $d$ and, slip defined by the rake angle $l$. The relationship of the off angle $i$ and azimut $f$ which represents the direction of the ray.

The azimuthal distribution of amplitudes is then related to the source's geometry by the following expressions:

$$F^{P} = sin^2 i(\cos^2 fM_{xx} + sin2fM_{yy} + sin^2 fM_{yy} - M_{zz}) + 2sini\cos i(\cos fM_{xz} + sinfM_{yz}) \quad (1)$$

$$F^{SV} = sini\cos i(\cos^2 fM_{xx} + sin2fM_{xy} + sin^2 fM_{yy} - M_{zz}) + \cos 2i(\cos fM_{xz} + sinfM_{yz}) \quad (2)$$

$$F^{SH} = sini\left[sinf\cos f(M_{yy} - M_{xx}) + \cos 2fM_{xy}\right] + \cos i\left[\cos fM_{yz} - sinfM_{xz}\right] \quad (3)$$

Where

$$M_{xx} = -(sind\cos l sin2f_s + sin2dsinl sin^2 f_s) \quad (4)$$

$$M_{xy} = M_{yx} = (sind\cos l\cos 2f_s + sin2dsinl sinf_s\cos f_s) \quad (5)$$

$$M_{yy} = (sind\cos l sin2f_s - sin2dsinl\cos^2 f_s) \quad (6)$$

$$M_{xz} = M_{zx} = -(\cos d\cos l\cos f_s + \cos 2dsinl sinf_s) \quad (7)$$

$$M_{yz} = M_{zy} = -(\cos d\cos l sinf_s - \cos 2dsinl\cos f_s) \quad (8)$$

$$M_{zz} = sin2dsinl \quad (9)$$

***Propagation.***

Propagation is considered to be more suitable for the study of the geometric propagation through the classic theory of rays, where the seismic ray is made up of tiny elements normal to the waves´front. The differential equation for a ray, in spatial coordinates, is:

$$\frac{d}{ds}\left(\frac{1}{c}\frac{d\mathbf{x}}{ds}\right) = \nabla\left(\frac{1}{c}\right) \qquad (10)$$

here c is the medium waves velocity of transmission and x it is the vector of position that defines the trajectory of the ray.

From above, it is clear the necessity to know the crust structure for the precise determination of the trajectory of the rays. In order to do so, crust models considering one or more gradients are used. These models must include geologic characteristics of the tectonic blocks, in terms of their physical properties, i.e. density of the media $r$, and the longitudinal and transversals wave's speeds $a_s, b_s$ respectively.

***Geometric attenuation.***

The geometric attenuation considers variations of energy transported by seismic waves inside the Earth. This energy spreads in time over a progressively bigger space. Therefore, the density of energy is continually diminishing away from the source. The geometric attenuation is evaluated as 1/R, where R is a function of the transversal area of a defined tube, given by the trajectories of rays leaving out at angles very close to the source. R increases with the distance between the seismic source and the observation point.

***Dissipation of energy.***

The dissipation of energy is introduced from a coefficient of physical attenuation that depends on the nature of the materials forming the medium. This allows us to consider factors such as: the energy that vanishes by the viscous processes during the propagation of the seismic wave, the possible non-linear behavior of the rock, the declination in the frequency, etc. According to available information, this decrease seems to be exponential in terms of the frequency $w$, the time and, the factor of quality Q.

$$e^{-\frac{wt}{2Q}} \qquad (11)$$

***Calculation of displacement***

Using the formulation presented by Aki (1980), and keeping in mind the theory of rays, we can calculate the displacement by means of the following expressions:

$$U_k^P(x,t) = \frac{1}{4 r_s a_s^3}\frac{1}{R} F \quad \dot{M}_{pq}\left(t - \frac{R}{a_s}\right) e^{-\frac{wt}{2Q}}. \qquad (12)$$

$$U_k^S(x,t) = \frac{1}{4 r_s b_s^3}\frac{1}{R} F \quad \dot{M}_{pq}\left(t - \frac{R}{b_s}\right) e^{-\frac{wt}{2Q}}. \qquad (13)$$

## POSSIBILITIES OF THE PROPOSED MODEL

We write a computer program, turning the proposed physical model in a tool that estimates the relationships of amplitude of the seismic movement, in function of the established hypotheses.

Results of the model are reported in fig. 5. This figure illustrates the spatial variation of the seismic intensity for different values of the geometric parameters that define the source, and also the effects of directivity and focusing, this last effect is due to the gradients of the mechanical properties of the medium. As a result, it is clear the necessity for including the models of seismic attenuation involving the azimuthal effect from a physic anisotropic space. These factors drastically influence the distribution of the intensity, that is basic for the understanding the phenomena. The non consideration of them could be an explanation for the disperssion of the analyzed data.

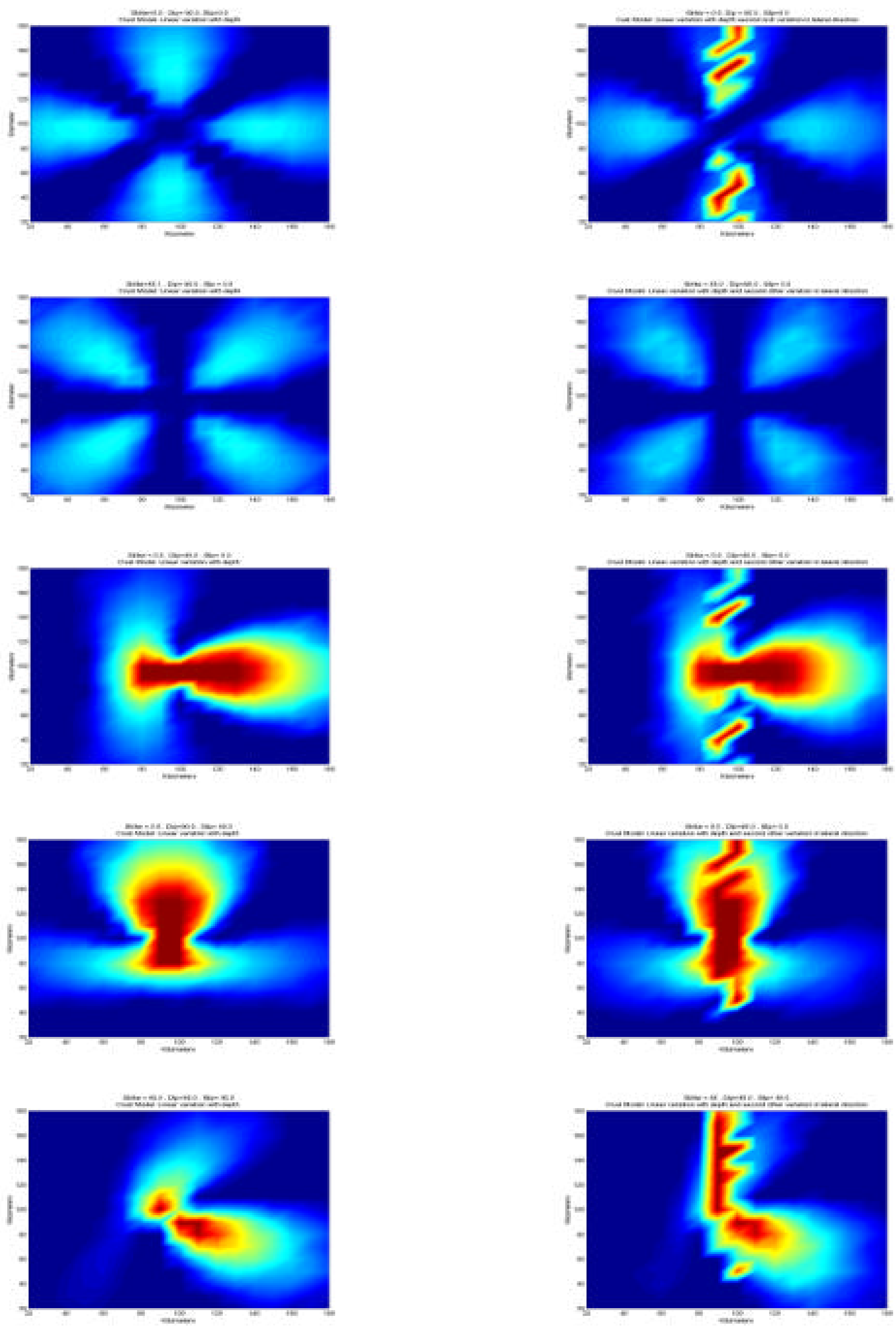

Fig.5. Changes in the distribution of seismic intensity due to directional effect and spatial heterogeneity. The variation of distribution with the focal parameters is shown by the vertical direction, whereas the alteration of the distribution due to the incorporation of the lateral gradient of the velocity of transmission waves, c, is shown in the horizontal.

## IMPLEMENTATION OF THE MODEL IN SEISMIC HAZARD STUDIES

The model could be easily implemented in studies of seismic hazard by, introducing the traditional mathematical expressions of the intensity and magnitude for each seismic source – place. The effect of source and trajectory, including the distance, will be involved in the estimated relationships, which are particular for each source-place seismic couple.

## CONCLUSIONS

The above considerations offer the elements for proposing a dynamic model for interpreting the attenuation records of the seismic energy and a functional form to estimate it. In a way, that the model substantially reduces the dispersion found in the available models.

With the purpose to strengthen the model, efforts are directed to improving the crust model. The model used today in Colombia, and in many regions of the world, is extremely simple, consisting of three of more horizontal layers of homogeneous rock. It is necessary to use a simplifed geologic, but in a logical way: i. e., by grouping similar rock units or pretrogenetic groups bearing in mind their lithology, limits, structural style, stratigraphy, and historical evolution.

Nowadays we are exploring the methodology that will be used in the calibration of the model, based on seismic instrumental information from the Colombian National Network of accelerographs, the Seismic National Network, and the Network of the Instituto Geofísico de los Andes. We are in the process of appling computational structures of neuronal artificial networks or we applying the concepts of bayesian statistics.

## REFERENCES


Abrahamson, N. A. and Shedlock K., (1997), Overview, Seismological Research, 68:1, pp 9-23

Aki, K. and Richards, P. G., (1980), Quantitative Seismology, W. H. Freeman, vol 1, pp 63-121

Campbell, K. W. (1993), Comparison of Contemporary Strong-Motion Attenuation Relationships, Proceedings of the International Workshop on Strong Motion Data, Vol. 2, California, pp 49-82.

Etayo F. et al. (1986), Mapa de terrenos geológicos de Colombia, publ. Esp. Ingeominas, Bogotá, 14 : 235 p.

Iai, S., Matsunaga, Y., Morita, H., Sakurai, H., Kurata, E. and Mukai, K. (1993), Attenuation of Peak Ground Accelerations in Japan, Proceedings of the International Workshop on Strong Motion Data, Vol. 2, California, pp 3-22.

McVerry, G. H., Dowrick, D. J., Sritharam, S., Cousins, W. J. and Porritt, T. E. (1993), Attenuation of Peak Ground Accelerations in New Zealand, Proceeding of the International Workshop on Strong Motion Data, Vol. 2, California, pp 23-38.

Sarria, A. (1995), Ingeniería Sísmica, ECOE Ediciones y Ediciones Uniandes, Santa Fe de Bogotá, Colombia, 569 p.