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SEISMIC RISK MAPS FOR THE UPDATE OF THE COLOMBIAN SEISMIC CODE

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ABSTRACT

The objective of the study was to produce the seismic risk maps for the new edition of the Colombian Seismic Code, in process of being enacted at the present moment. The new maps replace those included in the 1984 Code. Tectonics of Colombia were reevaluated including data from recent studies. An enlarged catalog of seismic events including earthquakes up to January 1995 was employed. The new maps include a seismic zoning with low, moderate and high seismic risk regions, an effective peak ground acceleration map and a damage threshold map with a short mean return period. Seismic risk parameters were determined for all municipalities in the country. The study was performed by the Universidad de los Andes, the Colombian Association for Earthquake Engineering, and Ingeominas, a government agency.

KEYWORD

Colombia; Seismic Risk; Colombian Tectonics; Colombian Code

INTRODUCTION

In 1991 the Seismic Risk Subcommittee of Committee AIS 100 "Seismic Building Code Requirements" of the Colombian Association for Earthquake Engineering (AIS), started work on an update of the seismic risk maps of the Colombian Seismic Code (Ministerio de Obras Públicas, 1984). The maps contained in the 1984 (Ministerio de Obras Públicas, 1984) Code were developed also by the Colombian Association for Earthquake Engineering (García, *et al.*, 1984).

TECTONICS

The tectonics of the northwestern corner of South America is complex, to say the least. The fact that the Nazca, South American and Caribbean Plates converge in Colombian territory makes the tectonics of the region specially challenging. The border between the Caribbean and South American plates is undefined. The structural geology of the country had been studied with different degrees of detail. In general a good mapping of large fault systems had been done for mining and petroleum exploration purposes. Special exploration have been done on a routine basis for the large hydroelectric projects with participation of leading world consulting firms. All this information was available for the identification of the main faulting systems (París, 1993). They are shown in Fig. 1. In general the faulting in Colombia has a predominant N-S direction in coincidence with the three main chains of mountains. Of these the Central chain is the oldest and the Eastern the younger.

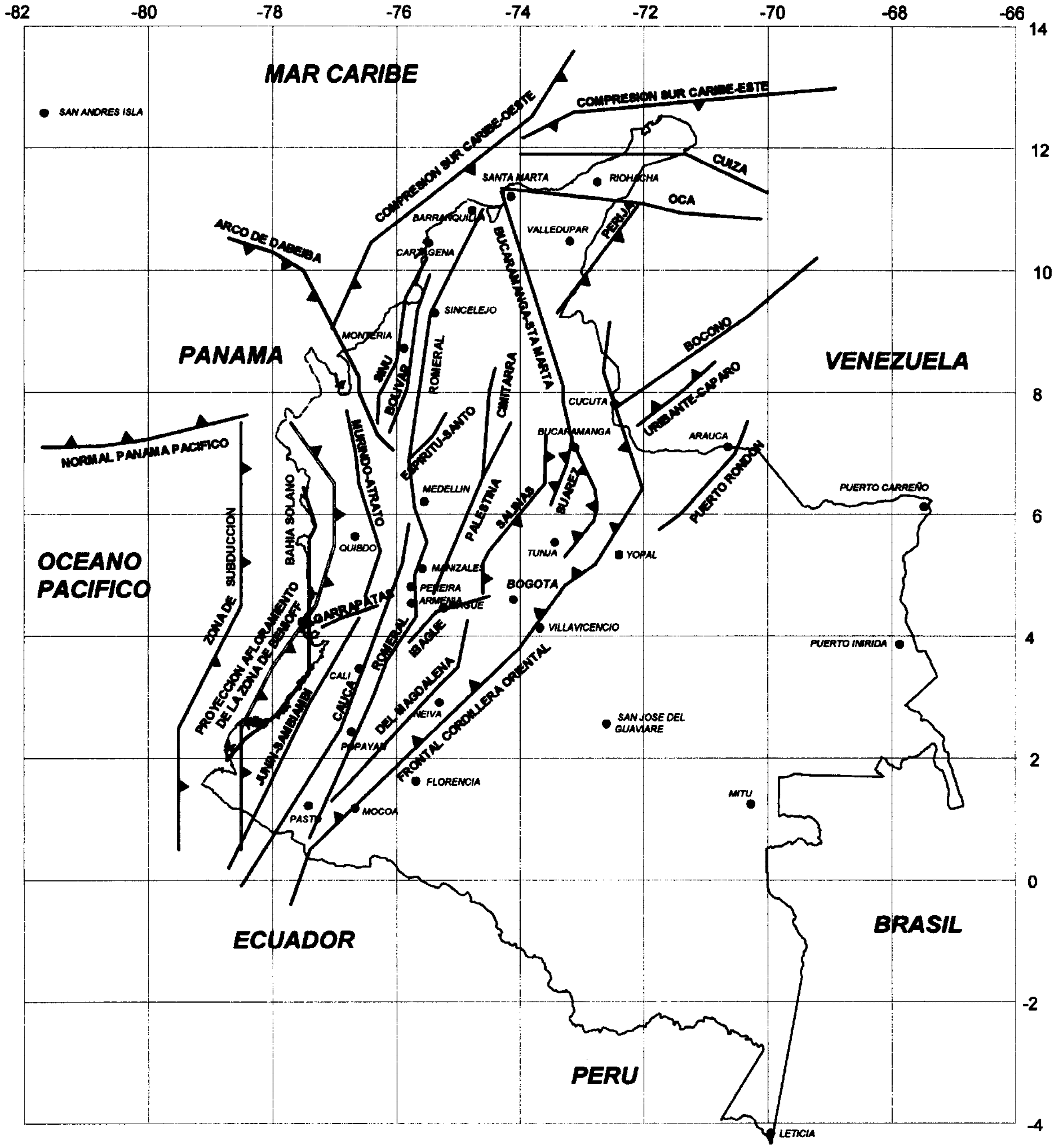


Fig. 1 Main seismotectonic systems in Colombia

The main seismotectonic accident is the Subduction zone in the Pacific Ocean. It is caused by the bending of the Nazca Plate as it subducts under the South American Plate. In the Colombian Pacific Coast there is evidence of its existence from a point south of the Equatorial Line to 8^{o} North. The ability to produce very large magnitude earthquakes of this subduction zone is known and the December 12, 1979 $\mathbf{M_s}$ = 7.9 earthquake certainly was produced by it. A Benioff zone develops with different dip angles that can be obtained from E-W sections of plots of focus of earthquakes. Its activity varies but earthquakes up to 120-130 km of depth can be assigned to it. Besides this a large number of faults were identified. For the purpose of the study 32 systems of faults were studied in detail.

SEISMICITY OF COLOMBIA

Historic Seismicity

The first event of which a written record exists occurred in 1566, causing intensive damage in Cali and Popayán in the South West part of the country. The confidence on historic information on earthquakes is of varied quality. It must be taken into account that the country was scarcely inhabited (Colombia had four million inhabitants in 1900 for an area of 1,130,000 km^2) and the greatest part of the population was concentrated in the Andean part of the country, as it is at the present.

Instrumental Seismicity

The instrumental seismicity of Colombia begins with the installation of the first seismographic station in 1922. Seven permanent seismographic stations scattered through the country were operated by the Geophysics Institute of the Javeriana University in Bogotá, from 1957 to 1993. In 1993 the Colombian Seismological Network, administered by Ingeominas, a Colombian government agency, started operation. Currently it has 14 permanent stations, linked via satellite to a main processing center located in Bogotá. During 1996, this network will be expanded to 19 permanent stations. Besides, more than a 100 strong motion accelerographs operate in the country.

During 1969 and 1970 the formation of the catalog of Colombian earthquakes was initiated at the Universidad de los Andes, Bogotá, under the supervision of Prof. Alberto Sarria. The work by J. E. Ramírez S. J. (Ramírez, 1975) was used as the main source of information. This first catalog was used in the initial studies of seismic risk and the production of the first seismic zoning maps for Building Code purposes (Atuesta, 1972). In 1979 Interconexión Eléctrica S.A., the government agency that manages the high voltage electric network of the country, sponsored a project in which all the seismographs recorded in Colombian stations that the Geophysics Institute had in its archives. 3886 events were processed. In 1982 an update of the catalog was performed for project SISRA (CERESIS, 1986), sponsored by the Centro Regional de Sismología para America del Sur - CERESIS (Regional Seismological Center for South America). With this update the number of processed events increased to 4784, 1206 historic and 3758 instrumental. In 1988 a new update was performed which increased the number of registered events to 5557.

For the present study, a new update was performed by Ingeominas, and is based in all available information at the moment. It contains 11088 records, including historical and instrumental events, and covers data from 1566 to January 1995. Statistics for the catalog are presented in Table 1.

Table 1. Characteristics of the seismic even catalog

	N° of events
Total content (1566-1995)	11 088
Non instrumental events (1566-1922)	293
Instrumental events (1922-1995)	10 796
Events from 1957 to 1995	10 546
Events from 1957 to 1995 with $\mathbf{M_s} \geq 3.00$	3 255
Events from 1957 to 1995 with $\mathbf{M_s} \geq 4.00$	1 185

Fig. 2 shows the epicentral location of all events contained in the catalog from 1566 to 1995 with magnitude $\mathbf{M_s}$ greater than 4.0, superimposed to the 32 main faulting systems in the country. The Andean part of the country, and the Pacific Ocean coast evidently report a greater number of seismic events, than the south eastern region, which corresponds to the Orinoco and Amazon River Basins.

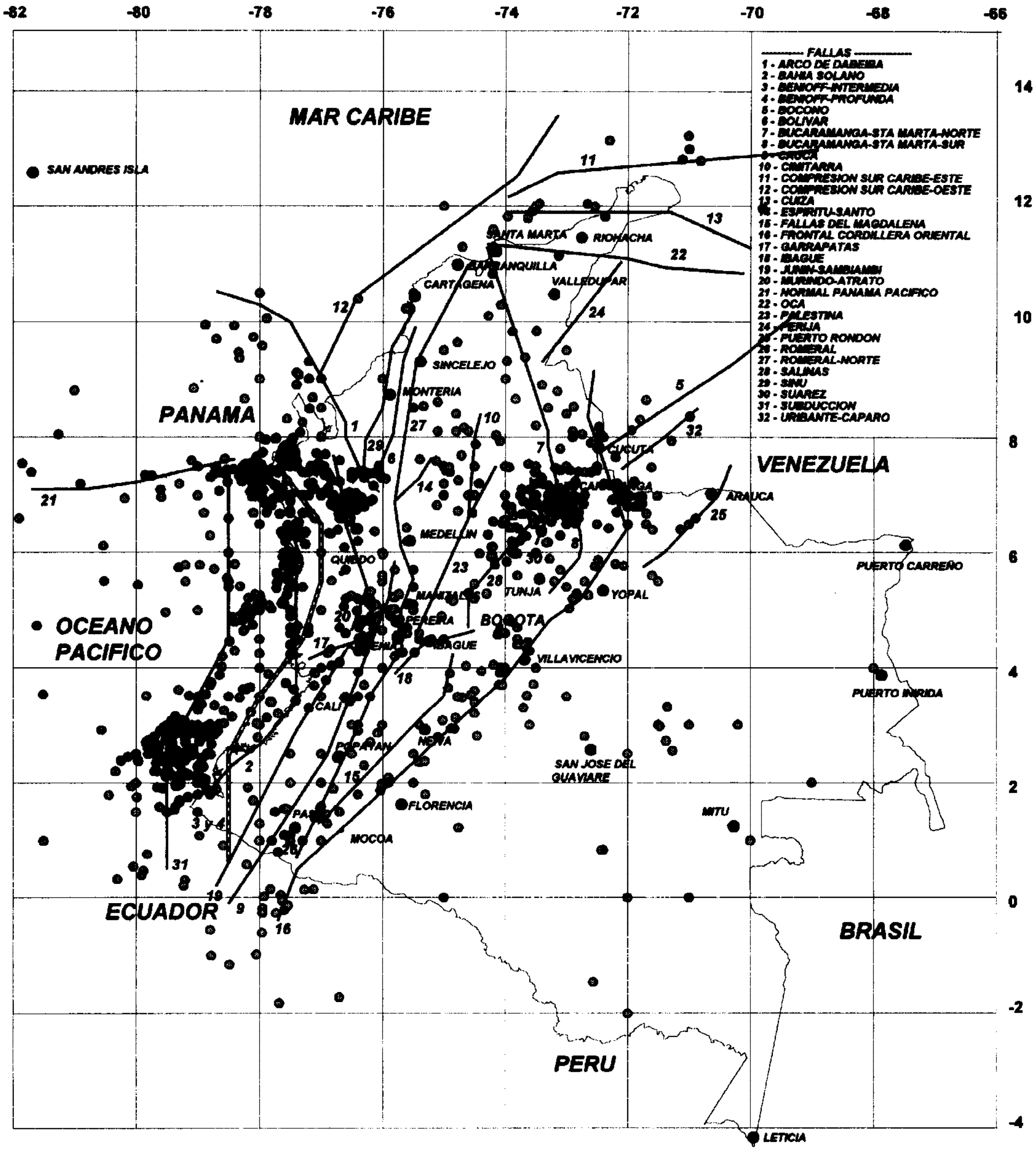


Fig. 2 Epicenter location for earthquakes with $\mathbf{M_s} \geq 4.0$ (1566-1995)

METHODOLOGY

The methodology employed in the seismic risk assessment of Colombia was:

Seismic event - faulting relationship

The seismic events of the catalog were assigned to the different seismogenic accidents when contained inside a volume of upper mantle limited by planes parallel to the fault at distances of 30 km at each side and a depth up to 60 km, taking into account the dip of the plane of the fault. This procedure permitted an assignation of 6461 of the 10088 events. The assigned and unassigned events were studied statistically in order to obtain β values for the magnitude regression as well as mean occurrence rates. The regressions of all the information assigned to all the seismogenic provinces for different time periods (1566-1995, 1922-1995, and 1957-1995) is shown in Fig. 3. The same procedure was used for all the faulting systems independently. Fig. 4 shows the regression for the Pacific Ocean Subduction zone.

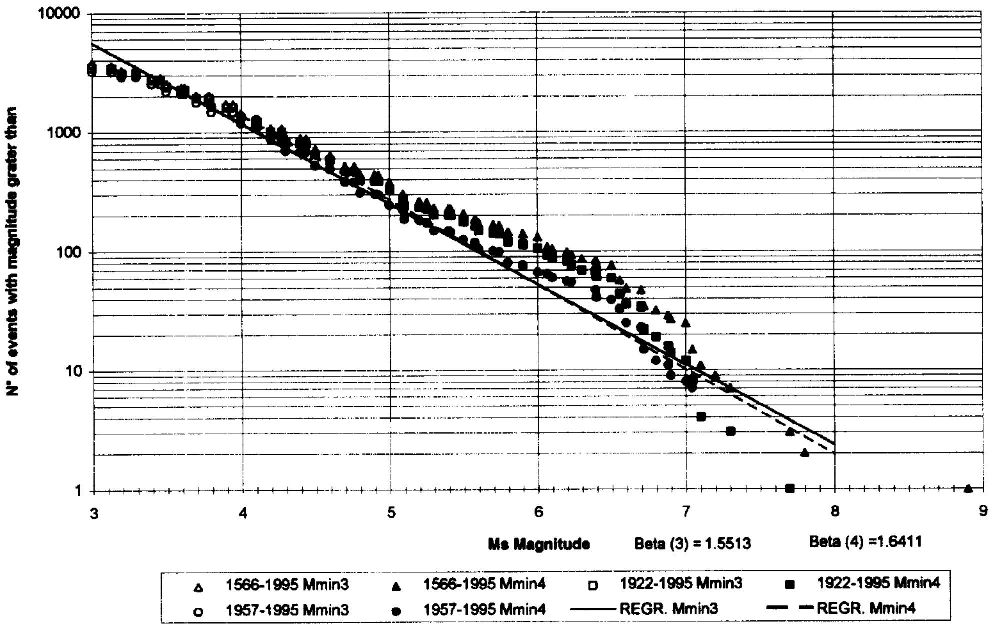


Fig. 3 Richter regression for all the information in the catalog

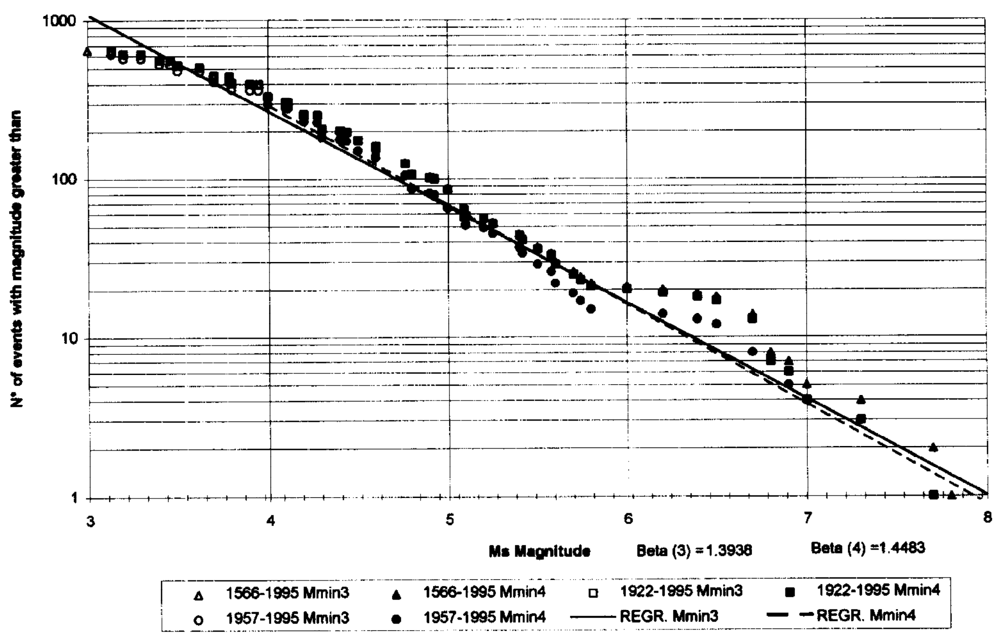


Fig. 4 Richter regression for the information assigned to the Pacific Ocean Subduction Zone

Seismic risk assessment

Using a probabilistic line source seismic risk model (Der Kiureghian and A. H-S. Ang, 1975), values of maximum possible horizontal peak ground acceleration were obtained. This model takes into account the contribution to risk at each point of interest of the known and unknown faults, the later represented by the unassigned earthquakes. Curves of peak horizontal acceleration against probability of excedance (or mean return period) were plotted for the main cities of the country and at all the crossings of meridian with parallel, at half a degree intervals. The curves were obtained for different levels of uncertainty correction due to fault rupture length and attenuation equations. The levels of uncertainty correction used were 50%, 90% and 99%. Fig. 5 shown this information for Bogotá.

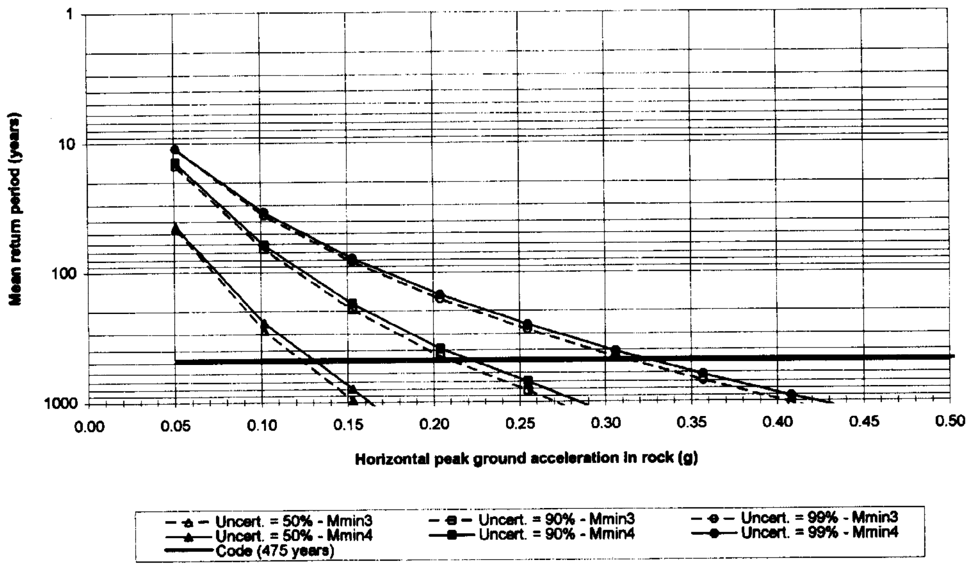


Fig. 5 Recurrence relationship for horizontal peak ground acceleration for Bogotá

With this information it was possible to plot maps that show peak ground acceleration for a mean period of return of fifty years and probabilities of excedance of 0.363, 0.10 and 0.05 and corrections due to uncertainties of 0.90 and 0.99. Using the maps and the historic information the country was divided into three zones: high risk, intermediate risk and low risk. These zones are shown in Fig. 6.

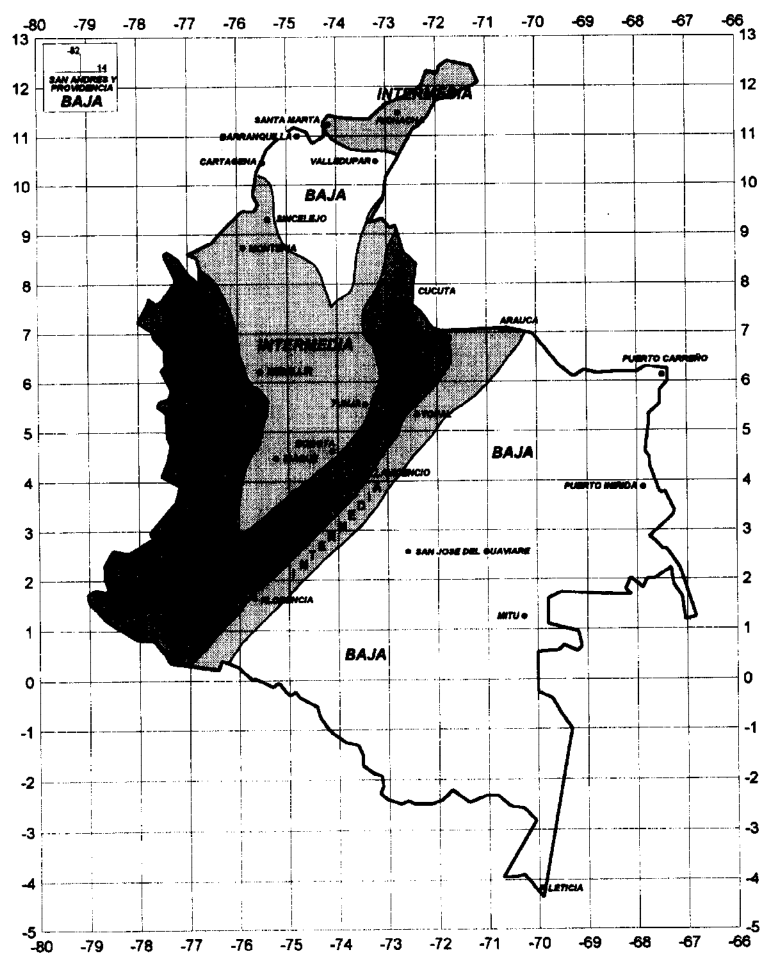
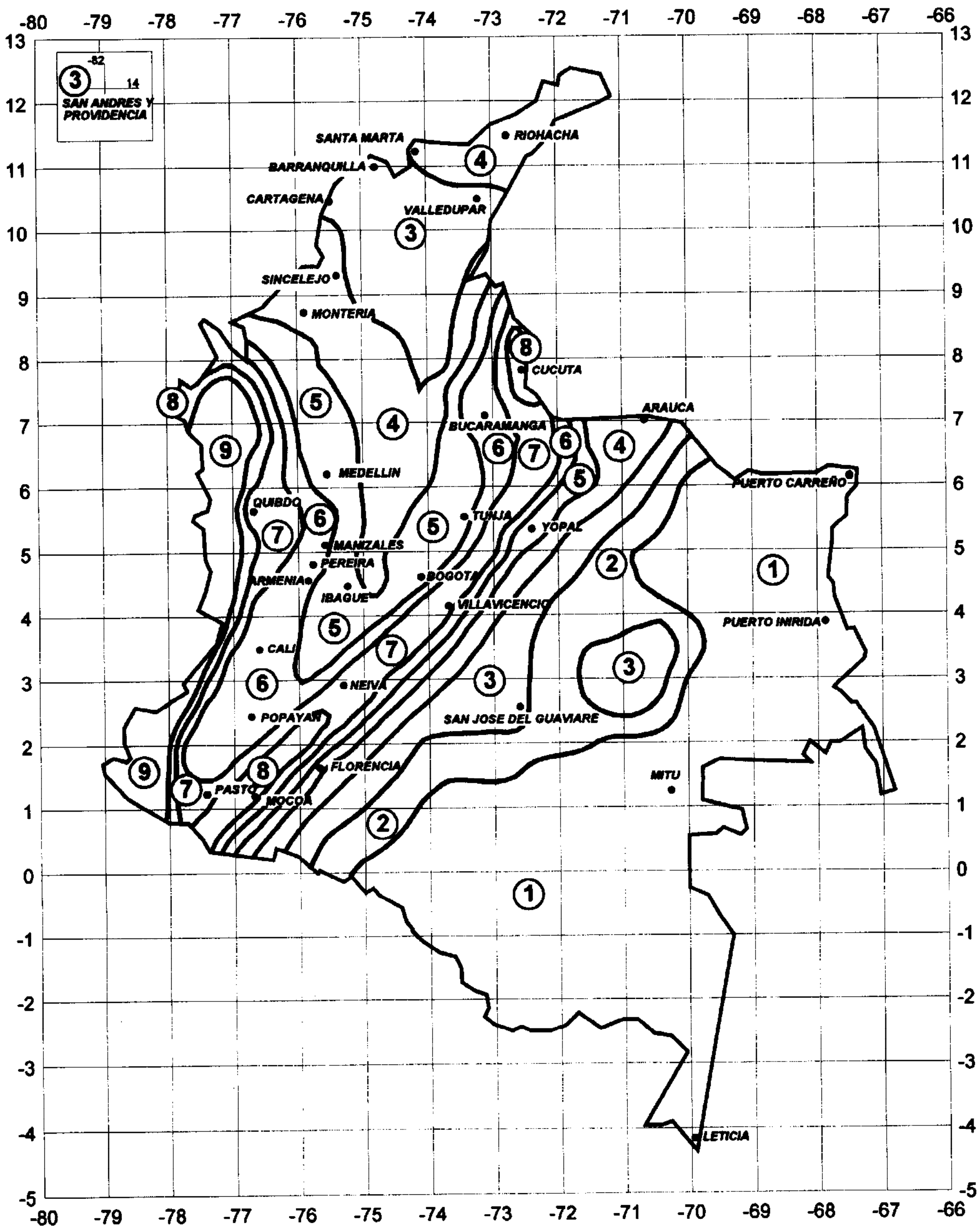


Fig. 6 Seismic zoning map
(low risk = bajo, moderate risk = intermedio, and high risk = alto)

Two additional maps, one for values of Effective Peak Ground Acceleration -- A_a, Fig. 7, with a probability of excedance of 10% in fifty years, corresponding to a mean return period of 475 years; and one for values of acceleration, A_d, to be used to identify a damage threshold for design of essential facilities, with a probability of excedance of 80% in 15 years, corresponding to a mean return period of 10 years. The values given in these last maps were adjusted by the Committee with regard to historic evidence and the availability of strong motion records.



Region	A_a
1	0.05
2	0.075
3	0.10
4	0.15
5	0.20
6	0.25
7	0.30
8	0.35
9	0.40
10	0.45

Fig. 7 Map of values of A_a

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