MICROZONATION OF THE CITY OF MEDELLÍN

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SUMMARY

Medellín, the capital of the Department of Antioquia , is located at the north west corner of Colombia, on a 1 500 m high valley crossed by a river bearing its same name. Located on an active seismic region, the city is under the influence of several earthquake sources, mostly far and deep. The uncertainties about the origins and magnitude of the critical earthquakes which could reach the city, as well as the lack of knowledge about the local characteristics that could affect the structural response of its constructions, prompted the Municipality of Medellín to order the reevaluation of the seismic hazard and the microzonation of the city.

Based on its findings, the study proposed a 14 zone division of the city with associated design parameters for each one of them. The microzonation was adopted by the city under a municipal decree ordering its application.

INTRODUCTION

Medellín, the capital of the Department of Antioquia , is located at the north west corner of Colombia, on a 1 500 m high valley crossed by a river bearing its same name. Founded in 1675, its development started at the valley's lower lands, but with the 20th century came an accelerated growth that filled the basin, pushing developers to build onto the steep hills. Today, a 2 million people city, Medellín densely populates most of the valley's 110 km², including its mountainsides.

Located on an active seismic region, the city is under the influence of several earthquake sources, mostly far and deep. Recent tremors occurred on november 1979 (0,03g) and october 1992 (0,015g). Despite the disparity of their intensities, the latter caused far more damage than the former, mainly due to the urbanistic transformation the city underwent during the 80's, when apartment buildings sprawled everywhere and its population almost doubled. More than 11 million dollars were lost in property damages, most of it nonstructural.

This large amount of losses inflicted by a seism of relatively low intensity worried authorities about the destructive potential of less frequent more intense earthquakes. A study ordered by the Municipality after the 1992 earthquake, estimated over 250 million in losses under a scenario similar to the 1979 earthquake.

Furthermore, recent seismic activity had evidenced the presence of significant effects associated to geological, geotechnical and topographical local characteristics.

The uncertainties about the origins and magnitude of the critical earthquakes which could reach the city, as well as the lack of knowledge about the local characteristics that could affect the structural response of its constructions, prompted the Municipality of Medellín to order the reevaluation of the seismic hazard and the microzonation of the city.

To this effect, an interinstitutional, interdisciplinary group was formed. The team included two universities, Universidad EAFIT (a private college) and Universidad Nacional de Colombia (the main state owned university

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in the country), one government agency, INGEOMINAS (National Institute of Geo-Sciences, Mining and Chemistry), and a private company, INTEGRAL (an internationally recognized Colombian consulting firm based in Medellín).

Based on its findings, the study proposed a 14 zone division of the city with associated design parameters for each one of them. The microzonation was adopted by the city under a municipal decree ordering its application.

SEISMIC INFORMATION ANALYSIS

The Center for Seismological Data Processing (CPIS), an office of the School of Engineering of the Universidad Nacional, is in charge of analysing the seismological information collected from the national network of seismographs and other national and international sources. The National Network of Seismographs, RSNC for its name in spanish, was established in 1993 and today operates 19 stations, constantly connected via satellite to a center of operations in Santafé de Bogotá.

In addition to data from the RSNC, CPIS collected and processed information form National Seismic Catalogue, which contains historic and instrumental seismic information.

COLOMBIAN GEODYNAMIC FRAME OF REFERENCE

Due to its location at the north west corner of South America, Colombia displays a high seismic activity. This activity is generated by a complex geodynamic frame of plate convergence, with the participation of, at least, three tectonic plates (Nazca, Caribe and South America) and two blocks or microplates (Panama microplate and the Andean Block). Some of the results of this complex plate interaction can be seen in Figure 1 where one year seismic activity, as registered by RSNC, is shown. It is evident here that most of the activity is concentrated along the Andean mountain ranges and along the Pacific Coast, where the Nazca plates is subducing the South America plate.

Several studies (Alzate, 1994, Coral, 1987, Estrada, 1998, García, 1984) have shown that there are many sources of earthquakes in Colombian territory, associated with different tectonic processes. The main of the identified in sources of potencially destructive earthquakes are presented Figure 2

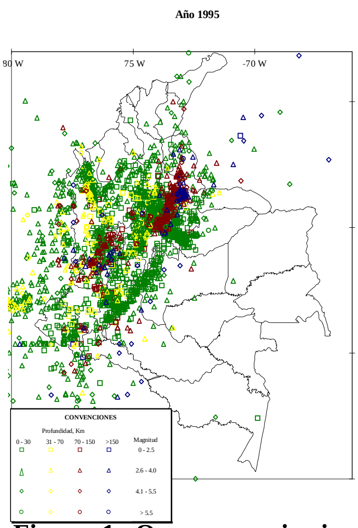


Figure 1. One year seismic activity registered by RSNC

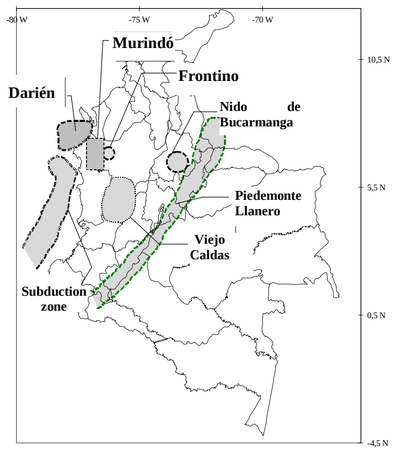


Figure 2. Main sources of earthquakes in Colombia

The seismic hazard represented by these sources to Medellín depends in great measure of their distance to the city. Based on the records studied and on the general characteristics of the types of soil found in Medellín, the region comprised by the coordinates 4º and 10º north and 72.5º and 80º west was selected as its influence zone. Earthquakes generated out of this zone are considered to suffer such an attenuation that thaey would not represent a meaningful danger. Incidentally, this region produces approximately 70% of the total seismic activity of the country.

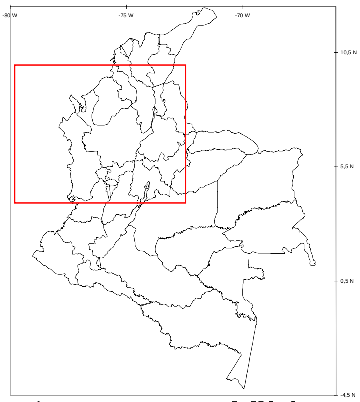


Figure 3. Medellín´s region of seismic influence

RSNC magnitude measurements are based on Richter´s scale. Most of the events recorded in the region of influence had small magnitudes. However, 36 tremors exhibited magnitudes greater than 5,5, on the Richter scale. The strongest movement recorded by the RSNC within the region occurred on september 2nd, 1997, with a magnitude of 6,8, located some 100 miles south of Medellín and some 100 km deep, in a seismic source known as ***Viejo Caldas***. This region produces eartquakes of medium depth associated with the subduction process of the Nazcla plate under the South America plate on the Wadati-Benioff surface.

More than half of all earthquakes recorded by RSNC since its inception in 1993, had their origins at depths between 120 km and 200 km. Most of them had their hypocenter some 150 miles notrh east of Medellín, at a site known as ***Nido de Bucaramanga*** (Bucaramanga´s nest) which has an unusually high activity.

Another important source of seismic activity with destructive potential to the city of Medellín is the region known as Murindó. It is located some 100 mile north west of the city and its activity is the consequence of the collision between Panama microplate and the Andean block and of the subduction of Nazca under Colombia. However, most of the activity could be traced to active faults that are themselves a result of the important compressive regime of the region, since almost 80% of the eartquakes in the region are recorded with depths of less than 35 km.

COMPLETENESS ANALYSIS

From the available data a tridimensional plot was made of the events location and depth. The yielding graph is shown in Figure 4, where the Benioff surface is suggested.

All the information of the RSNC, were analysed for completeness, together with the information from the National Catalogue, which has both instrumental and historical data. As shown in Figure 5, the collected data

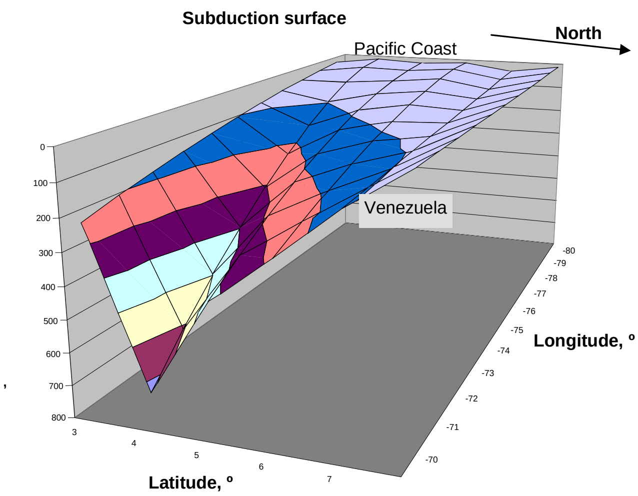


Figure 4. Benioff surface

seems to be complete for magnitudes Ms greater than 3 ($M_L > \sim 4$).

All data under this limit was discarded. Then, the remaining information was separated into ranges of magnitude (3 to 3,9, 4 to 4,9, etc.), and the number of accumulated events for each group was plotted against date. The date from which the data is considered complete is identified locating the point after which the curve changes sharply its slope and stays approximately constant thereafter. The data from dates prior to the completeness point was discarded for each group.

After defining the complete part of the catalogue, the data was grouped according to the main tectonic characteristics and the activity of the different regions of the country.

The superficial data, with depths of less than 35 km, was classified into nine different seismic zones.

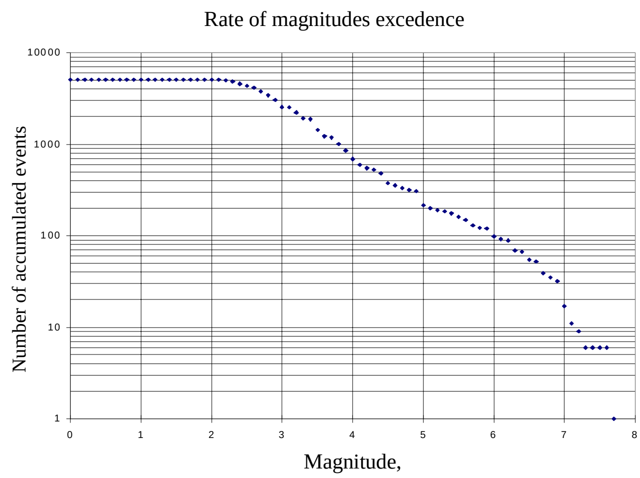


Figure 5. Rate of magnitude recurrence

Three zones covering the subducing end of the Nazca plate: Urabá-Panamá at the north end, and two subduction zones, 1 and 2; one zone comprising the region of Murindó where there is a clear lump of high activity; three zones along the Andean mountains, dividing the region in north, central and south, according to groups of events recorded; one zone including the northern part of the country, all the way up to the Atlantic sea shore; and finally, a zone along the eastern flank of the Andean mountain ranges.

For each zone, values for ***b*** and $\boldsymbol{\lambda}$, as showm in Table 1. The precision of events location is not fine enough to assign each eartquake to a particular fault, specially in a country with so many different fault systems. Therefore, recurrence curves were drawn for each entire region.

Seismic zones were then characterized according to their activity, based on geological and neotectonic studies observations.

As for the sources of deep activity, based on the data available on events, lines of equal depth were drawn for the whole of the subduction region. Two zones were defined, a local subduction, right under the city, and the subduction south of the city, on what is called Viejo Caldas.

The division approximately models the crease suggested by the plot of the Benioff surface.

Table 1. *b* and λ values for each zone

SEISMIC ZONE	*b*	λ
Piedemonte	0,64	1,09
Andean north	0,80	0,56
Andean Center	0,79	0,23
Andean south	0,42	0,56
Murindó	0,69	1,23
Urabá-Panamá	0,54	1,63
Subduction 1	0,64	1,24
Subduction 2	0,70	1,89
Atlántica	0,34	0,39

ESTIMATE OF SEISMIC HAZARD

Colombia´s network of accelerographs is quite new so the approximation to attenuation equations developed locally so far are based on inconclusive data. Therefore, the equations used were taken from experience of other countries, and were selected according to the tectonic environment and the faulting mechanisms to more accurately model local conditions.

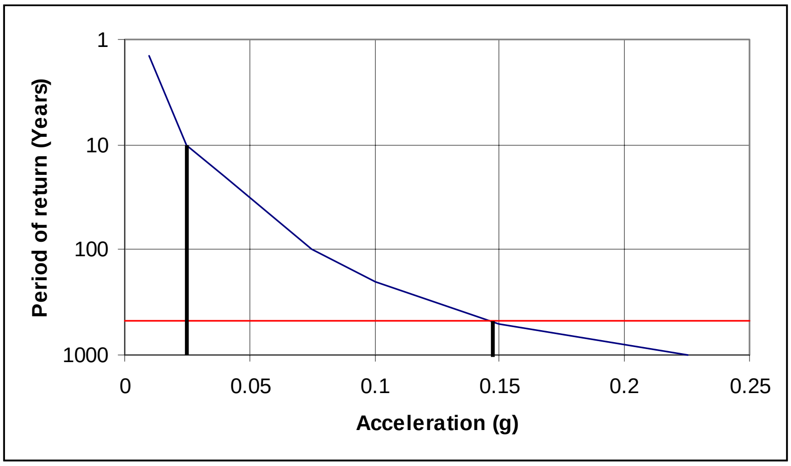


Figure 6. Seismic hazard plot

A probabilistic approach was used to estimate each fault recurrence curve. A specialized software was applied to each branch of a tree of probability bearing all probable values.

Combining the participation of each source, a seismic hazard curve was plotted as shown in Figure 6. Ground accelerations for both design and service earthquakes, Aa and Ad, respectively, are indicated. Aa, at 0,15g, corresponds to a period of return of approximately 475 years, whereas Ad, at 0,03g, corresponds to a 10 year return period, both for a 90% confidence factor.

SEISMIC INSTRUMENTATION OF THE CITY OF MEDELLÍN

Medellín is located on a valley, 1 500 m above mean sea level. The valley itself is called Aburrá. 22 accelerographs were placed on independent stations, distributed on the urban area of the valley, according to topographic, geotechnic, and geologic criteria. Each station was provided with a digital state-of-the-art accelrograph but the instruments were not connected on real-time. Data from the network is collected continually by the machines, but each station is visited only once a month to recover the information on a lap top computer. All sensors are directed to detect simultaneously the north-south direction, the east-west direction, and vertically. Readings from different stations differ widely.

CHARACTERIZATION OF SOILS

Medellín covers an area of only 110 km². However, its geotechnical, geological, and geomorphological diversity is overwhelmig. To characterize the different soils a data base with data from 940 perforations was prepared. Aggresive field work and laboratory testing was undertaken to complement the available data. From all this information geological sections were prepared and integrated with a Geographical Information System. The result was a tridimensional geological-geotechnical model of the valley with cross section every 150 m, approximately.

Both static and dynamic soil properties were measured and added to the data base. Wave speed propagation, stiffnes moduli, and damping properties were also measured. All of this information was organized and saved onto the data base, obtaining a huge body of fresh knowledge on local soils that was simply not known before. Local soil properties are very different from deposits reported elsewhere in the literature.

6. Seismic microzonation of the City of Medellín

To analyze the records from the 22 accelerographic station on the valley, empiric transfer functions were calculated, as well as the ratio of response spectra (RRS). Since, the records available up-to-date in Medellín correspond to low intensity earthquakes, theoretical modeling was necessary to estimate design response. To calibrate the theoretical models a unidimensional analysis was used.

Also, a detailed analysis of the tridimensional stratigraphic model was undertaken, with a mesh of 50 m x 50 m.

Based on the seismic response identified on each station and on the findings of the statigraphic model, zones with similar seismic behavior were tentatively defined. The zones were further classified according to geological, geotechnical and geomorphological characteristics.

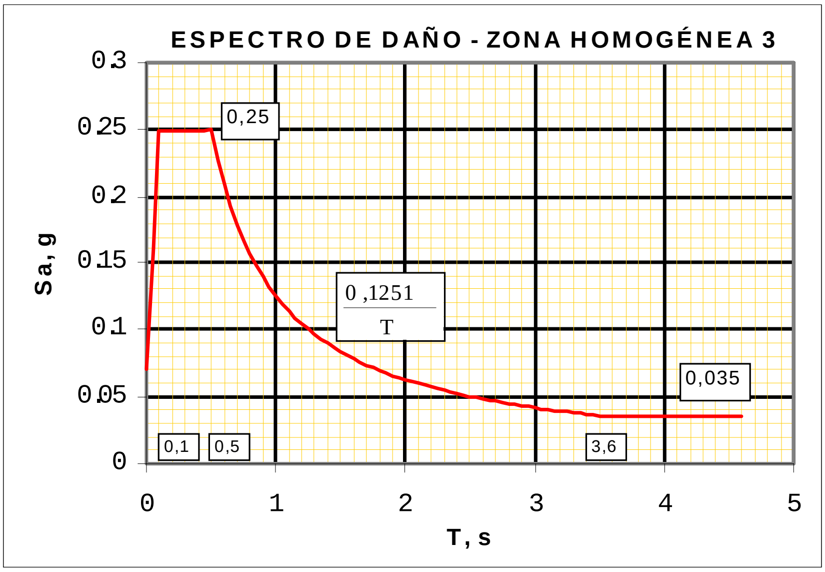
For each zone a spectral shape was defined for both the service (damage control level) and design earthquakes. The former was constructed with a damping factor of 2%, while the latter had a damping factor of 5%. In order to define each spectral shape, spectral response was calclated for representative stratigraphic sequences, considering the ranges of variation with depth of layer thickness, as well as the variation of dynamic properties depending on the level of deformation. Nonlinear effects in soils were also considered.

The spectral shape of each zone was obtained constructing an elastic design spectrum as an envelope of the calculated responses for the different stratigraphic sections. The height of the design spectrum was determined as 90% of the total height of the estimated spectrum on the surface, specially for short periods. To cover possible mistakes in period calculations, a 20% prolongation of the end of the flat part of the spectrum was introduced. The decreasing portion of the spectrum was calculated usinf a formula of the type FvAa/T, where Fv is a site factor, Aa is the acceleration on rock for the subject earthquake, and T is the period of vibration of the structure.

This study resulted in 14 homogeneous zones. For each zone, a design spectrum was constructed. Figure 7 shows an example of such a spectrum for zone 3.

Also, a damage control level spectrum was defined

Figure 7 shows the resultant 14 zones..



CONCLUSIONS

A role model for interinstituional and interdiscplinary colaborative effort, this project transformed the City of Medellín into the second best instrumented city of Latin America, after Mexico.

The studies realized on the soils of the valley confirmed the astonishing variety of soils found within the small area of Medellín and the wide variation of their characteristics.

Soil sections with stiffness and damping characteristics of low plasticity soil are predominant in Medellín, in accordance with values proposed by Dobry and Vucetic.

In addition, the degradation of these materials occurs on the superficial strata which are the ones with low shear wave speeds. This behavior produces insignificant decreases on the stiffness moduli of these soils, therefore resulting on low damping. These conditions, together with relatively high stiffness values to begin with, result in significant amplifications of the rock acceleration, for a well defined range of periods.

The results obtained with this study confirm the need of measuring the actual rsponse of the soils with accelrographs.

The characteristics of the dynamic behavior of soils in Medellín, and the accelerographic data recorded in the city, show that, in general, Medellín soils are competent, with periods on the shorter end of the spectrum. This in itself constitutes a great difference with the stipulated recommendations of the Colombian Building Code, NSR-98.

Maximum round accelerations vary between 0,18 g and 0,38 g.

The results of the Seismic Microzonation of Medellín demonstrate the importance of local effects on the seismic safety of buildings, and the validity of actual and reliable instrumentation which allows the calibration of theoretical models with real records of earthquakes.

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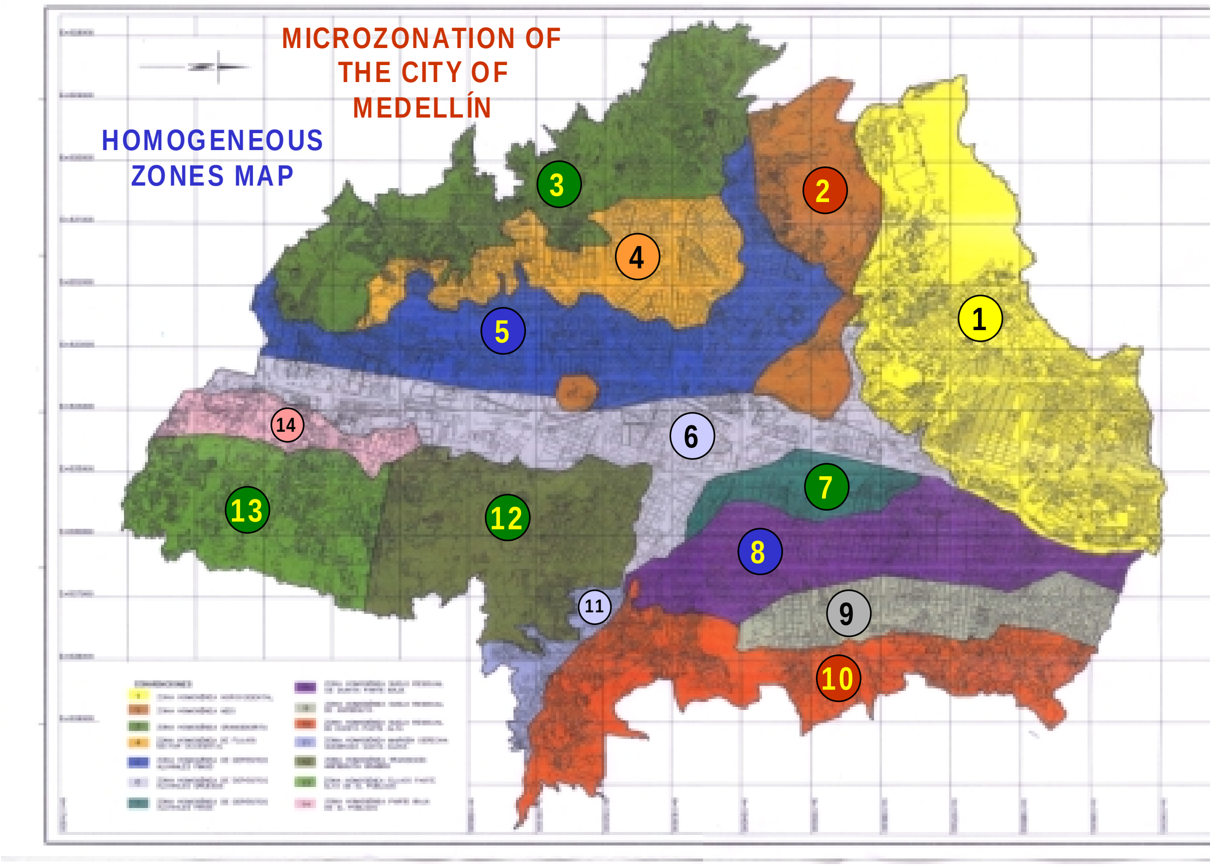

Figure 7. Microzonation of Medellín into 14 zones.