THE JANUARY 25TH, 1999, EARTHQUAKE IN THE COFFEE GROWING REGION IN COLOMBIA: EFFECTIVENESS OF THE SEISMIC MITIGATION PROJECT OF PEREIRA AND NEIGHBORING TOWNS

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SUMMARY

This paper presents the preliminary observations and the lessons learned from the earthquake of January 25, 1999 regarding the effects produced in Pereira, Dosquebradas and Santa Rosa de Cabal, which are located within the affected area in the Department of Risaralda. The correlation with previous studies, the evaluation of the disaster response and the lessons from the damage assessment in the immediate post-disaster period are discussed.

In 1995, a Seismic Mitigation Project was established in the Department of Risaralda, and many activities have been carried out since. Among these, regional hazard assessment, geological, geophysical and geotechnical studies for preliminary microzonation maps, and vulnerability models. In addition, several strong motion instruments were installed. Damage evaluation forms and assessment strategies were developed before the earthquake took place. Although the losses may be proportionately greater in some of the smaller cities within the affected area, Pereira was the largest city, with more than 100,000 low-rise and high-rise buildings. Fieldwork included data collection from more than 10,000 buildings with damages ranging from minor damage to collapse.

The January 25 earthquake emphasized the need of coordination between the city, state and national emergency authorities, the importance of computers in supporting the activities, and the GIS databases not only for emergency response but also for recovery and reconstruction purposes.

INTRODUCTION

The current Colombian legislation addressing the disaster prevention and emergency response, such as the Decree-Law 919, 1989 and Law 99, 1993, in virtue of which the National System for Disaster Management and the Ministry of Environment were created, identify that evaluation of risks and the reduction in vulnerability as the most effective strategies to control the potential disasters. It demands the adoption of an effective action even though competent scientific knowledge about real dangers is still lacking. The national policies state that in order to improve the preventive action, it is essential to understand the natural hazards and the human society vulnerability, and formulate actions to mitigate their effects.

The new Colombian Earthquake Resistant Construction Code (Norm NSR-98), Law 400, 1997, in Section A.2.9-Studies of Microzoning, prescribes: "In the areas of intermediate and high seismic hazard, the state capitals and cities with more than 100,000 inhabitants, the municipal soil use regulations should detect and keep in mind the areas where the local conditions could affect the propagation of seismic waves through the layers of soil underlying constructions, by means of microzonation studies”.

Guided by current Colombian Government policies and in agreement with the norms previously mentioned, CARDER- the Autonomous Regional Corporation of Risaralda (entity entrusted with the environment care at state level), is in charge of the technical coordination for the Seismic Mitigation Project of Pereira,

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Dosquebradas and Santa Rosa de Cabal, with the support of the National Fund for Disasters, the State of Risaralda, the Municipalities, the National Institute of Research in Geoscience, Mining and Chemestry (Ingeominas) and the Pereira Public Services.

Through the identification and analysis of the set of variables involved in seismic phenomena as a whole and their consequences, the project aims to minimize human, social and economical losses in the cities with more than 100,000 inhabitants in the Department of Risaralda. It is planned to accomplish this by laying down the guidelines for the design and construction of earthquake-resistant buildings that will be constructed under local soils characteristics, by promoting to reinforce the existing structures, particularly urban constructions subject to vulnerability, by designing publicity campaigns for public education and information, by implementing measures for land use planning and by supporting the creation of prevention plans for attention of disasters.

The January 25 earthquake, is the strongest shallow event that has affected the cities within the Coffee Growing Region of Colombia throughout the existance years that do not exceed 150 years. The earthquake generated a great impact in five Departments including Risaralda, and must be analyzed from different topics related to the seismic risk mitigation.

REGIONAL SEISMIC HAZARD ASSESSMENT

The project has developed investigations in order to characterize the local and regional seismic activity through studies of structural and regional geology, neo-tectonics and historical seismic movements. In addition, two seismographs were installed in the Department of Risaralda, connected to the Seismological Observatory of the Southwest (OSSO- Univalle), to better locate the seismic activity in the region.

The regional geology and the structural model of the Andean region in Colombia, are characterized by a great complexity which is due to the convergence of the Nazca, South American and Caribbean Plates, which have originated the formation of many important geological structures, with which it is possible to distinguish the seismic sources in a general manner.

Starting from the information tracking over the historical seismicity, 24 harmful events were identified in the period 1785 -1995, with intensities between VI and VII on the MSK scale. It was concluded that every 5.25 years at least an event with intensity greater than V occurs, and although most of the events in the region were generated in the Wadati Benioff zone, it was necessary to pay attention to the potential surface activity [Espinosa, 1996].

Within the Project influence zone, several segments of faults had been distinguished showing major evidences of tectonic activity; its estimation was accomplished based on the morphological expression, the continuity and diagnosis degree of the neo-tectonic features. Lengths of rupture were established within a maximum range of 20 km, resulting in calculations of maximum probable magnitudes between 5.9 and 6.9. In agreement with the regional tectonic context and the information gathered during the study, the activity rates are low (0.01-0.1 mm/year) to moderate (0.1-1 mm/year), and consequently, the recurrence intervals are wide, between 400 and 4,600 years. The distance of these accepted segments from the three cities of interest oscillates between 15 and 110 km [Guzmán J. et al., 1997].

The January 25 event occurred 48 Km South of Pereira, demonstrating that the fear of potential surface activity and estimates of magnitudes were correct. The location of the epicenter of the main shock and aftershocks reported by the National Seismological Network (RSNC- Ingeominas) and the Seismological Observatory of the Southwest (OSSO- Univalle) is near to the Silvia Pijao fault, which was identified during the neotectonic studies as a strike-slip fault with a left-lateral movement. This is coherent with the NEIC, ERI, USGS and Harvard CMT (Centroid Moment Tensor) solutions.

LOCAL SITE EFFECTS

With the purpose of studying the local site effects of the urban and suburban zones in the cities of Pereira, Dosquebradas and Santa Rosa de Cabal, the project carried out studies on: site surface geology, characterization and location of filling areas, geophysical studies, and microtremors. About one thousand soil borings associated with the construction of buildings were compiled to produce a preliminary geotechnic zonification of the area. Finally, geomorphological maps were prepared and five strong motion instruments were installed on different geological units. So far, more than eighty records have been obtained. Subsequently, additional soil borings were made to take samples for laboratoy and field dynamic testing. and seismic microzonation maps were proposed for the three mentioned cities.

Geological Description of the Area

The focus area of study boasts an extremely varied topography, ranging from small hills to very high slopes on the river banks. Volcanic ashes from the Ruiz-Tolima volcanic complex covers almost the entire area, whose thickness ranges from ten to thirty meters in depth. The thickness of these ash deposits diminishes near the river basins. The volcanic ashes are normally found over a high resistance stratum of conglomerate layers (pebbles and boulders in a sandy clay matrix, emerging from volcanic activity), except in some areas where they have settled on residual or alluvial strata, or colluvial deposits, whose volcanic ash thickness ranges from two to five meters.

In the urban area of Pereira, the topography is characterized by the presence of elongated hills in the East-West direction, separated by deep depressions, which encourages and facilitates the cut and fill practices. As the urban area expands, the development of man-made fill deposits has been continuous. These deposits consist of construction refuse and trash, earth movement surpluses and even domestic garbage; their purpose is to prepare the ground for the construction of housing. The fill zones cover approximately 30 to 40% of the deposits where the city of Pereira is located [James, 1995].

Microzonation

Based on the studies carried out in this project, a general map showing the seismic microzoning of Pereira, Dosquebradas and Santa Rosa de Cabal was elaborated. The map defines and limits the areas exhibiting similar seismic behavior and establishes different design spectra for each type of soil. In addition, the amplification factors dependent upon local geometric and topographical feasures are established. These should be used in designing buildings in accordance with the foregoing geometric and topographical features of the location site of each project.

For the case of the city of Pereira, the city was divided into seven zones [Universidad de los Andes, 1999]:

Zone 1 - Volcanic ashes from 2 m to 10 m.
Zone 2- Volcanic ashes from10 m to 20 m.
Zone 3- Volcanic ashes from 20 m to 25 m.
Zone 4 - Volcanic ashes from 25m to 35 m.
Zone 5 - Volcanic ashes 5m + alluvial deposits.
Zone 6 – Man made land fills
Zone 7 - Volcanic ashes 8m + residual deposits

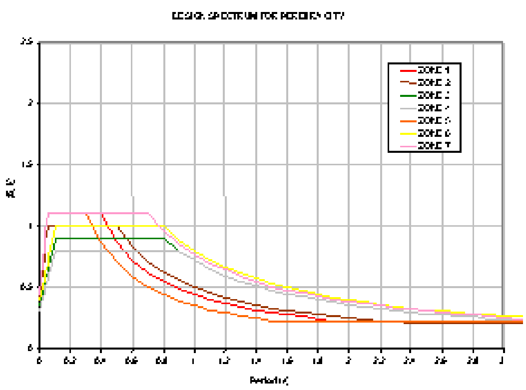

Figure 1: Design Spectrum for Pereira city

Accelerographic Instrumentation

Since the installation in 1996 of the local accelerometer network in Pereira, Dosquebradas and Santa Rosa de Cabal, the most significant event registered corresponds to the earthquake that took place in the department of Quindío. High ground movement amplifications ranging from 2 to 5.8 were observed, which is directly related to the presence of a thick covering of eolian deposits of volcanic ashes and man made fills that were combined with the amplification factors on account of the geometry and topography of the ground (fill areas, hills and slopes). In Pereira, only the zones 6 and 3 had an instrument installed, but the one on zone 3 was out of service for maintainance (See Table 1 and Figure 2).

Table 1: Description of the Accelerometer Stations

STATION	GEOLOGY	TOPOGRAPHY AND OBSERVATIONS	PEAK GROUND ACCELERATION (cm/seg^2)		
			N-S	Vertical	E-W
Bocatoma	Geological Basement with stiff rocks of relative high density	Gently slopes in the lower level of the Otún river valley	49.8	25.5	77.7
Santa Rosa de Cabal Hospital*	Volcanic Ashes up to 18 meters in thickness with conglomerate lens	Almost flat.	259.3	63.3	181.3
La Rosa Dosquebradas*	Lake and fluvial deposits up to 70 meters in thickness, clay and silt materials with different levels of gravel strata.	Flat	188.5	73.6	180.6
Mazpereira * ZONE 6	Man made fills, up to 15 meters in thickness, poor geotechnical conditions	Basin gently slope	290.7	99.1	253.2
Castañares ** ZONE 6	Man made fills, up to 6 meters in thickness	Almost flat. Probable interaction between soils and buildings	145.8	97.4	210.3
Filo** ***	Conglomerate deposits of good stiffness.	Irregular depression. Probable topographic effects	---	---	---
UTP** ZONE 3	Volcanic ashes, up to 23 meters. Overlaid conglomerate strata of good stiffness.	Almost flat	---	---	---

* Carder Stations, ** Ingeominas Stations

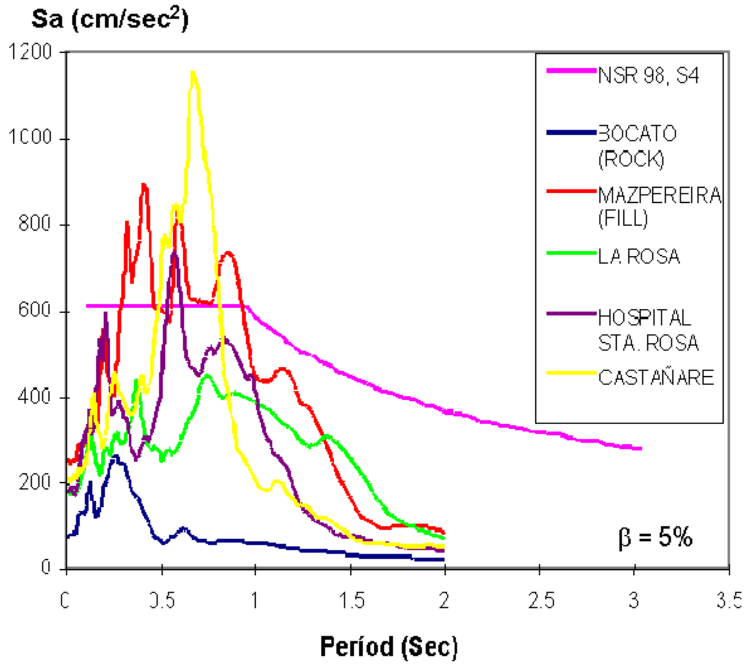

Figure 2: Response Spectra January 25th 1999 earthquake (E-W components)

Earthquake Damage by Zone

Based on the results of the post-seismic evaluation of the earthquake of february 8, 1995 and the earthquake of January 25, 1999 (See basic parameters in Table 2), the affected buildings in a small Pereira sector, which cover about 1/3 of the city, were classified as per microzoning areas. This area represents only zones 1, 3, 5 and 6.

Table 2: Basic parameters of the last earhquakes

Date	February 8th 1995	Janaury 25th 1999
Magntiude Ml	6.4	6.2
Depth	75 Km	15 Km
Epicentral distance to Pereira	120 Km	48 Km
Rock acceleration	0.04 g (estimated)	0.08 g

Table 3. Distribution of damages in zones 1, 3, 5 and 6, for the 1995 and 1999 earthquakes

Zones	Existing buildings		Affected buildings 1995		Affected buildings 1999		Affected/ Existing 1995	Affected/ Existing 1999
	#	%	#	%	#	%	(%)	(%)
Zone 1	1827	14.67	20	3.04	82	4.15	1.09	4.49
Zone 3	5213	41.86	390	59.27	1118	56.61	7.48	21.45
Zone 5	2168	17.41	13	1.98	74	3.75	0.60	3.41
Zone 6	3246	26.06	235	35.71	701	35.49	7.24	21.60
TOTAL	12454	100.00	658	100.00	1975	100.00	5.28	15.85

Table 3 shows that the porcentual distribution of damages in the different zones is very similar although the number of damages is three times greater for the 1999 earthquake. In Zones 3 and 6, volcanic ashes and fills, there is a proportionally larger number of affected buildings, which could be understood on account of the amplification effects that were registered in those zones.

Table 4. Distribution of damages as per the number of floors in zones 1, 3, 5 and 6, for the 1999 earthquake

Number of floors	Zone 1			Zone 3			Zone 5			Zone 6		
	E	A	A/E	E	A	A/E	E	A	A/E	E	A	A/E
1	735	23	3.13	1708	263	15.40	1293	42	3.25	1303	184	14.12
2 to 3	1057	46	4.35	2961	553	18.68	869	30	3.45	382	382	22.00
4 to 6	35	13	37.14	429	230	53.61	6	1	33.33	174	114	65.52
7 to 9	0	0	0	57	31	54.39	0	1	0	22	10	45.45
>10	0	0	0	58	41	70.69	0	0	0	11	11	100.00
TOTAL	1827	82	4.48	5213	1118	21.44	2168	74	3.41	3246	701	21.60

E =Existing buildings, A =Affected buildings

In Table 4, it is possible to observe a high number of four to six story buildings with damages in all zones, which could be the result of the predominant period of the 1999 earthquake in the city. Althoug the number of affected houses between one to three floors is high, the proportion of these is low in relation to the number of existing houses.

In zones 3 and 6, where the highest number of affected buildings is presented, it is important to observe the high vulnerability of the tall buildings, which could be the result of the low control of the story drift and the high amplification factors in those zones.

JANUARY 25th EARTHQUAKE DAMAGE EVALUATION

Immediately after the earthquake occured, groups of professionals (engineers, architects and geologists) from various municipal and regional institutions joined together of their own free will. Their objective was to compile an inventory of the damages caused to the buildings as quickly as possible, so they could understand the extent of the catastrophe and thus to take decisions over the habitable status of said buildings.

Once this information had been compiled, it was classified by colors to illustrate the scale of the damage and the danger this represented to the people who lived in the buildings, to the neighboring buildings and to the pedestrians and vehicular traffic. The classification scale employed is described hereinafter:

RED: For buildings which suffered total collapse or serious strucutural damage. In addition, these buildings represent a great danger to the dwellers and/or the surrounding buildings due to stability problems or to the occurrence of aftershocks. Property that had to be demolished partially or totally was also included in this category.

ORANGE: For buildings that suffered light structural damage or substantial architectural damage, subject to potential danger in case of aftershocks. However, they can be repaired without too much difficulty and returned to their pre-earthquake state once insecure elements or elements that may block evacuation routes had been removed.

YELLOW: For buildings that suffered moderate damages. For repairing them, there is enough available time in order to implement the necessary security measures. In addition, these repairs do not cause any harm to the buildings dwellers or to the nearby property.

GREEN: For buildings that suffered light architectural damages which can be easily repaired and do not compromise the safety of their dwellers.

Those buildings representing a serious risk (red) were checked a second time by structural engineers, in agreement to the established guidelines previously mentioned. The technical report on the status of the structures includes recommendations concerning the procedures that should be followed, such as: evacuation, need for supporting structures, partial or total demolition.

These reports were submitted for the consideration of the Technical Committee for Evaluation and Demolition, named by municipal agreement. This committee was responsible for taking the final decisions and subsequently expedite resolutions in accordance with the established legal procedures. During the inspection visits to the damaged structures, geological and geotechnical evaluations were also carried out for which an appraisement questionare was designed.

To complement the previous actions, a computer database was established in order to process the information effectively. Besides, it was associated with a geographical information system to locate rapidly the buildings according to the extent of the damage and to identify the most critical areas. This information served a great support for the tasks of providing help to the affected people and to provide certificates for the people could solve insurance claims, securing loans, subsidies, etc. Furthermore, it allowed the authorities to decide upon strategies for the planning and reconstruction, and provided information regarding the vulnerability models already mentioned.

Post –Seismic Evaluation Lessons

The guidelines previously established to carry out the evaluations were used in the 1995 earthquake and afterwards they have been revised and improved. However, no training courses were given to the professionals in charge of applying these guidelines to ensure that the evaluation criteria were homogeneous. Consequently, there was great disparity of judgement between the professionals evaluating the damage and the volunteers, who lacking experience, made difficult the evaluation task.

The visits to evaluate the status of the buildings were poorly planned and the volunteers often failed to cover all the houses in the assigned sector of the city, and only visited those homes of people who had requested help by telephone or in person. Therefore, it was necessary to send again volunteers to the same sector in many occasions. Besides, the lack of a central database regarding home addresses meant that the visits were often repeated.

Although many neighboring towns received the form designated by the Project for Mitigation of Seismic Risk in Pereira, Dosquebradas and Santa Rosa de Cabal, each town council managed the procedures and statistics differently, and consequently non homogenous information was available for the whole affected zone.

The lack of coordination among the different entities and between the National and Regional offices meant that many accomplished surveys had different scopes and objectives. This resulted in a lack of credibility from the public, who were reluctant to grant access to the buildings.

Information regarding individual apartment and their dwellers was needed to obtain loans and subsidies. However, the information in the post-seismic evaluation forms was made collectively for the entire building. Initially, it was necessary to make estimates based on the number of floors each building had in order to calculate statistics concerning the number of affected families. This was due to the fact that information stating the number of apartments in each building was not available.

It was necessary to develop a new methodology to correct some of the faults mentioned, above all, the normalized evaluation of all properties and the owners identification. Five months have now passed since the event occurred and this work is currently being carried out on behalf of the Ministry for Development in agreement with the organization in charge of managing the cadastre (Instituto Geográfico Agustin Codazzi). All the available data was collected from the different organizations having information about the damages caused, in order to standardize it and subsequently recheck it in the field, this time using a detailed, standardized form as a guide. In this form is registered the damage degree to the building, essential information about the owners (like mortgage status or insurance policies, financial assistance provided by credit organizations, etc.). In order to process those properties which have not been included in previous surveys, a general form was designed to verify whether the buildings were damaged or not. In the cases of damaged buildings not covered before, a more detail evaluation form was used.

PHYSICAL VULNERABILITY

A system was developed for the building classification involving most of the constructions in the cities of Pereira, Dosquebradas and Santa Rosa de Cabal. Variables such as the number of floors, type of structure, use, age and social level were kept in mind. The inventory preparation took advantage of the available information from several institutions (Office of Planning, official land records), and was completed with block-to-block field work and aerial photography surveys.

The computer simulation models permit the calculation of economic and human losses caused by earthquakes [Jaramillo, 1999]. They take into account a large amount of variables over which, it is believed, the probable resistance of structures and the characteristics of seismic movement depend upon. Therefore, the amplitude and frequency of seismic movements on the bedrock stratum and the dynamic properties of the soil deposits on each zone are considered in order to define actual motions at the local site in question. Variables such as the socio-economic level, the building number of floors, age, use and roof type are considered to calculate the probable resistance to the seismic movement.

The appraisals of construction damages and human losses in Pereira, Dosquebradas and Santa Rosa de Cabal caused by 1995 and 1999 earthquake were analyzed, because this information is considered a bench mark for calibrating hypothetical scenarios. It was compared with the outcomes of the simulation of both earthquakes for the same Pereira sector analyzed before, showing very similar results regarding the cost of the total losses which have an approximation of 85% for the 95 earthquake and 98% for the 99 earthquake (See Table 5).

Table 5: Comparison among the value of the existing infraestructure with losses calculated from post-seismic evaluations and simulated losses from computer model

Use	Total Cost Existing buildings		Real Losses Quake 1995			Simulated Losses Quake 1995		Real Losses Quake 1999			Simulated Losses Quake 1999	
	U.S $	%	U.S $	%	R/E*	U.S $	%	U.S $	%	R/E*	U.S $	%
Residential	1,850,814,788	89.1	33,865,009	80.40	1.83	33,250,000	93.48	106,881,702	80.71	5.78	122,560,000	92.74
Commercial	182,317,622	8.79	7,581,670	18.00	4.16	1,821,230	5.12	23,916,228	18.06	13.12	7,754,400	5.87
Industrial	20,870,706	1.01	137,469	0.33	0.66	158,900	0.45	309,816	0.23	1.48	591,229	0.45
Educational	21,292,048	1.03	534,995	1.27	2.51	340,200	0.96	1,317,110	0.99	6.19	1,253,680	0.95
TOTAL	2,075,295,164	100	42,119,143	100		35,570,330	100	132,424,856	100		132,159,309	100

*R/E Relation between the real losses and the total cost of existing buildings

CONCLUSIONS

The characteristics of the earthquake that took place on January 25, 1999, ratified some of the results obtained in the investigations carried out so far, allowing to formulate, based on them, recommendations and policies for the use of the land in the three cities. The above, with the purpose of advancing in a rational way the development of the constructions, through designs for the special local effects which could produce the worse probable earthquake. In this way, it is possible to minimize the future effects of seismic events, especially the losses of human lives, the number of people affected by the natural phenomenon as well as the economic losses. Only after many years of using the earhtquake-resistance desing specifications, the global vulnerabilty at municipal level will diminish until reaching acceptable levels for the society.

In the regulation considerations have been included on the following aspects: soil studies that should be made according to the characteristics of each seismic zone, regulation of the design spectra for each zone, restriction to some construction typologies, obligatoriness to separate new buildings, etc.

The post-seismic evaluation provided indispensable information for the calibration of vulnerability models, which help to generate hypothetical scenarios for a range of seismic activity, including of a greater magnitude than that experienced, and the activity located near the towns under analysis. In conclusion, the use of information in the inventory of building structures, census data, microzonation maps and geographical information systems can assist the emergency response organization to effectively predict potential high damage areas, which will allow to create emergency action plans in accordance with the local circumstances.

Among the actions which should be taken within the investigations it is necesary to improve the seismological instrumentation within the region and to expand the reach of seismotectonic studies to have a better idea of the seismic activity potential. In addition, a precise knowledge concerning the amplification effects of the topography and the deposits geometry is still uncertain. It is propossed to expand the strong movement network, to make additional boring holes and develop detailed two and three- dimensional analyses which permit to define empirical transfer functions in each of the zones.

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