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SEISMIC RISK EVALUATION IN MÉRIDA, VENEZUELA

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SUMMARY

A seismic risk assessment for the city of Mérida (Venezuela) is presented. The study mainly consists of three steps:

1. *Determination of seismic hazard*. The Boconó Fault Zone (BFZ) is established as the seismogenetic source for the metropolitan area of the city. A probabilistic analysis is carried out on the seismic catalogue (available recorded earthquakes) in order to calculate the return period (T = 170 years) corresponding to the maximum observed intensity (I = X EMS 92).
2. *Evaluation of vulnerability*. Buildings are classified according to their most relevant structural characteristics in 3 types (vulnerability classes). These 3 categories correspond to the groups described in EMS 92 and MSK 64 intensity scales. Urban area has been divided in 28 sectors taking into account homogeneity, physical barriers and accessibility. Each sector is divided in sub-sectors; most of the buildings in each sub-sector belong to the same vulnerability class.
3. *Assessment of seismic risk*. Damage scenarios are determined by obtaining the level of damage in each of the vulnerability classes for the events derived in the first step.

Preliminary results show that seismic risk is high.

1. INTRODUCTION

Catastrophic events have caused great damage in urban areas along history; earthquakes are among the more destructive. Along the 20th century cities have grown in surface and population without much control, consequently, elements at risk (persons and goods) have multiplied. In developing countries this expansion usually does not comply with urban and constructive codes and rules of practice, determining zones of high vulnerability. Sometimes, such suburbs are located in hazardous sites, hence risk is considerably high.

Venezuela is a clear example of this phenomenon. In mid 20th century, modernization and transformation of the country brought a sustained physical growth of the cities and allowed important developments in communication and civil infrastructures (hydroelectric plants, dams, roads, bridges, water plants, etc.). Conversely, no enough attention was paid to the countryside and many people from rural areas immigrated to capital cities. Unfortunately, this lead to the construction of large ”barrios” (unorganized settlements without public services or roads, in hazardous zones) around metropolitan areas. This situation was worsened by the natural growth of population and by the economical recession. Also, the administrative and political apparatus required more space; this, sometimes not complying with urban planning.

Mérida is located in the western part of Venezuela on the Andean range. It has approximately 200,000 inhabitants; some of them live in barrios. Moreover, there is a big university that generates an additional floating population of about 50,000 people. This city is the administrative capital of Mérida State, housing a number of government buildings.

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Seismic events have great impact on unprepared urban zones as described above, for example, the Caracas earthquake (July 1967) having 6.3 Richter magnitude, caused damage to a considerable number of buildings (around 2,600) of different types, the number of deaths officially was 245 and 1,500 persons were wounded. Most recently, the Cariaco earthquake in the eastern region of Venezuela, (July 1997) with a magnitude M_s = 6.8, and a maximum (EMS 92) intensity *I* = VII [Schwarz et al., 1998; Pérez, 1998], affecting the localities of Cariaco and Cumaná and several surrounding villages. In Cariaco, two RC school buildings were destroyed causing most of the human victims.

Information about historical seismicity in Mérida encompasses period from 1610 to present days. Available data from 1610 to 1950 consist of description of damage caused by earthquakes; after 1950 records exist for a number of inputs, from which its magnitude and epicentral coordinates have been calculated. The most destructive earthquake had intensity *I* = X (March 1812), severely damaging the cities of Mérida, Barquisimeto and Caracas, with more than 10,000 mortal casualties in the entire country. No other seismic event of this intensity occurred since then; it is used along this study as the maximum observed input. Different researchers have obtained various return periods for an earthquake of this intensity by probabilistic studies for the seismicity of the region. In [MOP, 1976] the return period is 135 years while in [Garciacaro, 1997] is 250 years. Two authors [Laffaille, 1996; Iannuzzi, 1997] performed separate studies about damage scenarios in Mérida using a deterministic approach for the determination of the expected inputs and using the MSK 64 intensity scale for vulnerability assessment. [Laffaille, 1996] obtained the risk by a probabilistic method, [Iannuzzi, 1997] implemented the risk information into a GIS.

The objective of this paper is to perform a numerical study about the seismic risk of Mérida. The research approach consists of three consecutive steps:

- *Determination of seismic hazard*. The Boconó Fault Zone (BFZ) is found as the main seismogenetic source for the metropolitan area. The maximum observed intensity (*I* = X EMS 92) and its return period (*T* = 170 years) is calculated by a probabilistic analysis using Gumbel 1 distribution for the intensities (obtained from available magnitudes by attenuation laws).

- *Evaluation of vulnerability*. Starting from the previous work by [Laffaille, 1996], buildings are classified according to their most relevant structural characteristics in 3 types (from most to least vulnerable to earthquakes). These 3 classes correspond to the groups described in EMS 92 [Grünthal, 1993] and MSK 64 [Medvedev and Sponheuer, 1969] intensity scales. As in [Laffaille, 1996] urban area is divided in 28 sectors taking into account homogeneity, physical barriers and accessibility. Each sector is divided in sub-sectors; normally constructions in each sub-sector belong to the same vulnerability class.

- *Assessment of seismic risk*. The damage scenarios corresponding to the expected intensities are determined as the quantitative level of damage in each of the 3 vulnerability classes. Obtained results will be implemented into a GIS (envisaged research).

Research corresponding to each of these three stages are described, respectively, in the three following sections.

2. SEISMIC HAZARD IN MÉRIDA

Mérida is the capital city of the state after its name, located in the Venezuelan Andes, on the western region of the country. It is the most important political, administrative and educational center for the Andean Region. Its location in one of the most earthquake prone Venezuelan regions justifies this study, as well as does the planning that ought to be performed to prepare the city for a seismic event. The Boconó Fault Zone (BFZ) has been identified as the most important seismic source in western Venezuela and southwestern Caribbean regions. The 600 km. long and 100 km. wide fault zone (BFZ, with NE orientation) crosses through all the Andean Mountain Range in Venezuela, determining the subduction boundaries of the Caribbean plate beneath the South American one. The motion is prominently NE oriented with a right-lateral strike slip focal mechanism on its principal trace, and NE oriented striking reverse faulting in the Andean piedmonts [Pérez et al., 1997].

Geographically, the city is settled on a plateau (11 km long, 4 km. wide) oriented NW-NE and located between two mountain chains, the Sierra Nevada on the SE side and the Sierra de La Culata on the NW side. Two rivers flow trough the city, the Albarregas and the Chama River, located respectively in the northern and southern sides of the tableland. At the southern part of the plateau, both flows joint in La Punta (satellite town of Mérida). A 3D representation of the urban zone is presented at Figure 1.

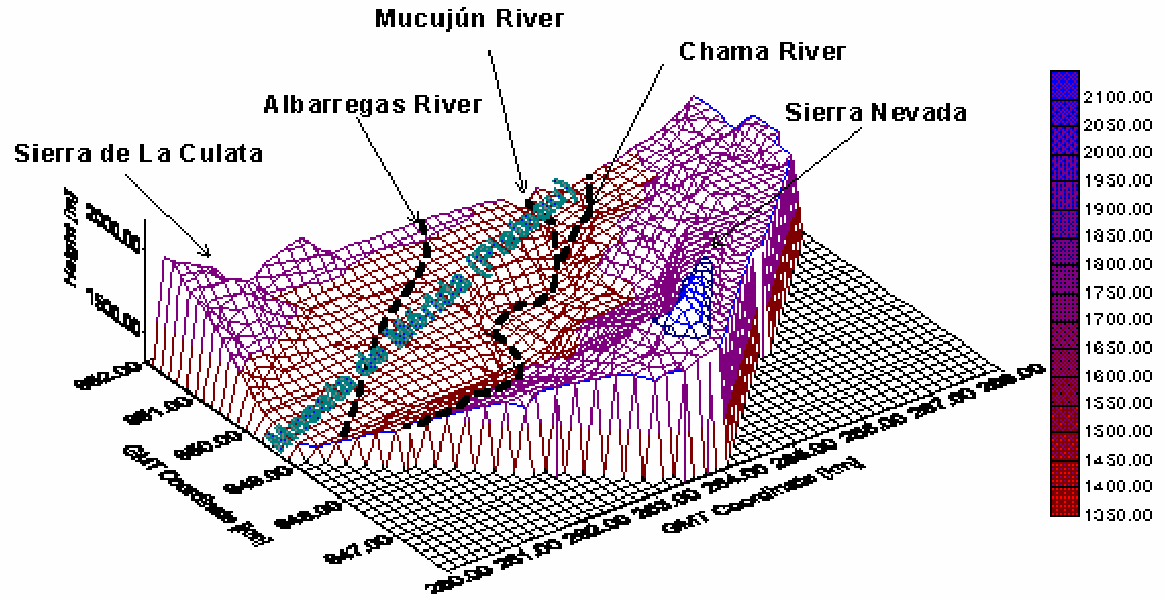

Figure 1: Topographic 3D image of Mérida zone

Seismic recurrence probabilistic studies are carried out from the known seismicity of the region. Available data is classified in two series: historical (1610 - 1950) and instrumental (1950 – present). Historical information consists of damage description. Instrumental information consists of seismic records from which the magnitude and epicentral coordinates of the observed earthquakes have been calculated. Probabilistic studies performed in this paper consider only recorded data from the seismic catalog over a period of 30 years (1950 – 1980) for the BFZ; 76 earthquakes are selected.

Probabilistic analysis uses the Gumbel 1 distribution [Gumbel, 1967] for maximum intensity values. Intensities are calculated from known magnitudes by means of the following attenuation laws:

$$I(R) = 2.98 + 1.5M - 1.70\ln R \qquad (1)$$

$$I(R) = 0.51 + 1.5M - 1.12\ln R \qquad (2)$$

$$I(R) = 7.90 + 1.45M - 13.03\ln R \qquad (3)$$

where I is the intensity, M is the magnitude and R is the epicentral distance [km]. Model (1) is due to [Arggawal, 1981], (2) to [Gershanik & Gajardo, 1981] and (3) to [MOP, 1976]. Values from equations (1) and (3) are greater than XII for some inputs (this might due to the fact that such relations have been derived for other sites than Venezuela), hence (2) is selected.

A linear fit for ln(-lnG(I)) (where $G(I)$ is the Gumbel Number corresponding to intensity I) vs. intensity I is performed (Figure 2). Two different straight regression lines are obtained for, respectively, intensities smaller than and bigger or equal than VI. Parameters λ and β are, respectively, the origin ordinate and the slope of the fit 2 (right, red) regression straight line: λ = 3.04 and β = - 0.625. For each intensity, return periods T [years] are calculated as the inverse of the annual probability of occurrence G_n:

$$T(I) = \frac{1}{G_n(I)}, \quad G_n(I) = \lambda\, e^{\beta I} \qquad (4)$$

Obtained return periods for Intensities $VI \le I \le XII$ are shown in Table 1.

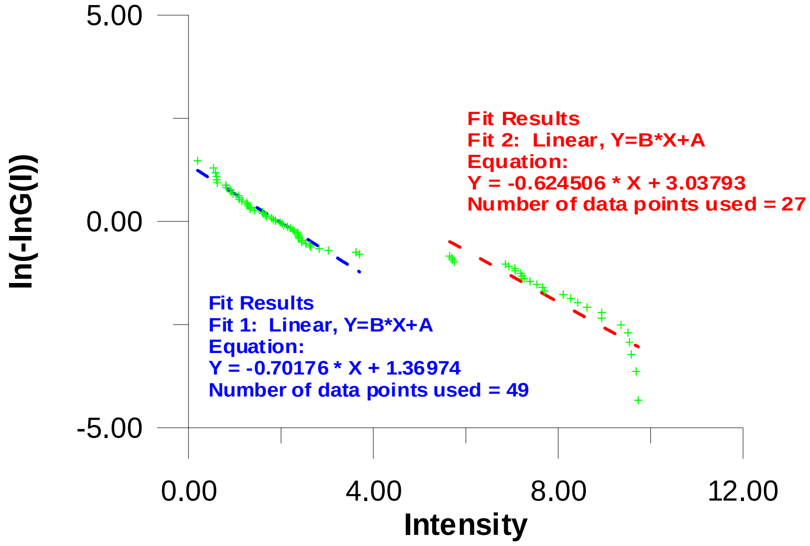

Figure 2: Linear fit of Gumbel distribution

Table 1: Return periods

I	*G(I)*	*T(I)* [years]
VI	0.071659216	13.9549392
VII	0.038375597	26.0582264
VIII	0.020551250	48.6588407
IX	0.011005793	90.8612405
X	0.005893923	169.666291
XI	0.003156367	316.819912
XII	0.001690327	591.601646

Since the more destructive observed earthquake has intensity *I* = X, results from Table 1 show that its return period is about 170 years.

No local effects are considered in this paper; i.e. the same input is assumed in all locations inside the urban area. The site effects due to local soil conditions will be accounted for in further studies (research currently in progress). Soil has mostly sedimentary origin. Average water table depth is about 3 m.

3. SEISMIC VULNERABILITY IN MÉRIDA

Buildings are classified in vulnerability classes according to their most relevant structural characteristics starting from the previous work by [Laffaille, 1996]. Such author considers 6 types (from most to least vulnerable to earthquakes): *Rancho – A* (self-construction, rubble stone, adobe, earthen), *B* (unreinforced brick, precarious timber), *C7* (reinforced concrete two way slabs), *C6* (reinforced concrete one way slabs with unreinforced concrete brick walls), *C5* (steel frame with unreinforced brick walls) and *C3* (reinforced concrete one way slabs with reinforced concrete brick walls). In this paper two different classifications have been considered corresponding to, respectively, the intensity scales described in EMS 92 [Grünthal, 1993] and MSK 64 [Medvedev and Sponheuer, 1969]. Although EMS 92 considers classes ranging from *A* to *F*, in Mérida almost all the buildings belong only to groups *A*, *B* and *C*. Assumed equivalencies of these categories with those proposed by [Laffaille, 1996] are described in Table 2.

As in [Laffaille, 1996] the Mérida metropolitan area is divided in 28 sectors taking into account homogeneity (similarity between predominant buildings), physical barriers (mostly the two rivers) and accessibility (bridges, roads). Each sector is divided in sub-sectors; normally constructions in each sub-sector belong to the same vulnerability class (according to the considered classifications). Information collected by such author consists mostly of giving the number of buildings in categories *Rancho – A*, *B*, *C7*, *C6*, *C5* and *C3* that are inside any sub-sector. The total number of analyzed constructions is 14,565. Percentages of buildings in each of the three considered cases are shown in Figure 3 for EMS 92 and MSK 64 intensity scales.

Table 2: Equivalence between vulnerability classes

Laffaille, 1996	EMS 92	Laffaille, 1996	MSK 64
Rancho - A	*A*	*Rancho - A*	*A*
B, C7, C6, C5	*B*	*B*	*B*
C3	*C*	*C7, C6, C5, C3*	*C*

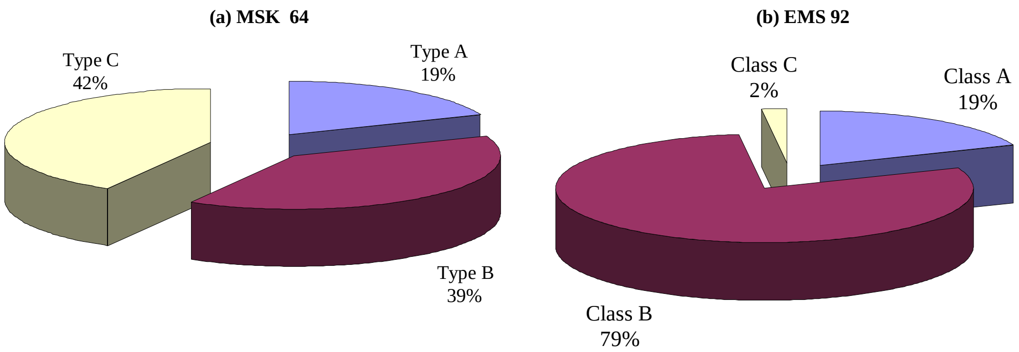

Figure 3: Classification of buildings according to (a) MSK 64 and (b) EMS scales

Graphs from Figure 3 show that in MSK 64 scale the percentage of least vulnerable buildings is dramatically greater than in EMS 92 one. This discrepancy requires further research.

Essential buildings (hospitals, government offices, telecommunication facilities, civil protection headquarters, police and fire stations, among others) have not been differentiated from other uses. Such research is currently being carried out.

4. SEISMIC RISK FOR MÉRIDA

Damage scenarios for the different intensities listed in Table 1 are created from results obtained in the two previous sections. For input intensity VI no significant damages are detected and intensities XI and XII are unfeasible; hence, only intensities ranging from VII to X are considered.

For each intensity and vulnerability class (*A*, *B* or *C*) both EMS 92 and MSK 64 scales specify the percentage of buildings undergoing certain grade of damage. Three levels of percentages of damaged buildings are considered: most, many, few; five damage grades are contemplated: negligible to slight, moderate, substantial to heavy, very heavy and destruction. Both variables are quantified on this study. Numerical values assigned to the percentages of damaged buildings are shown in Table 3. Such percentages have been obtained from indications contained in EMS 92 and MSK 64 intensity scales. Numerical values assigned to the damage grades are the following (damage indices for a particular building): 0.013 (negligible to slight), 0.047 (moderate), 0.137 (substantial to heavy), 0.8 (very heavy) and 1 (destruction). These assumptions follow those considered in [Laffaille, 1996]; only the two last numbers have been modified (such author considered 0.37 and 0.98, respectively).

Obtained results consist of predicted damages for each sub-sector, each intensity (from VII to X) and for EMS 92 and MSK 64 intensity scales. Predicted damage is quantified as a global *damage index* (ranging from 0 to 1) that accounts for the “total amount of damage”. For each scale, intensity and vulnerability class such index is preliminary defined as the sum of the products of the percentages of damaged buildings times the damage grade. For each sub-sector and intensity the damage index is calculated as the sum of the products of the damage indices of each vulnerability class times their percentages.

Table 3: Percentages of damaged buildings

Intensity scale	Most	Many	Few
EMS 92	90%	50%	10%
MSK 64	75%	50%	5%

Figure 4 depicts a comparison of the damage indices at each sector for seismic input with intensity X according to EMS 92 and MSK 64 scales. Results from Figure 4 show significant differences between damages in some sectors predicted according to EMS 92 and MSK 64 scales.

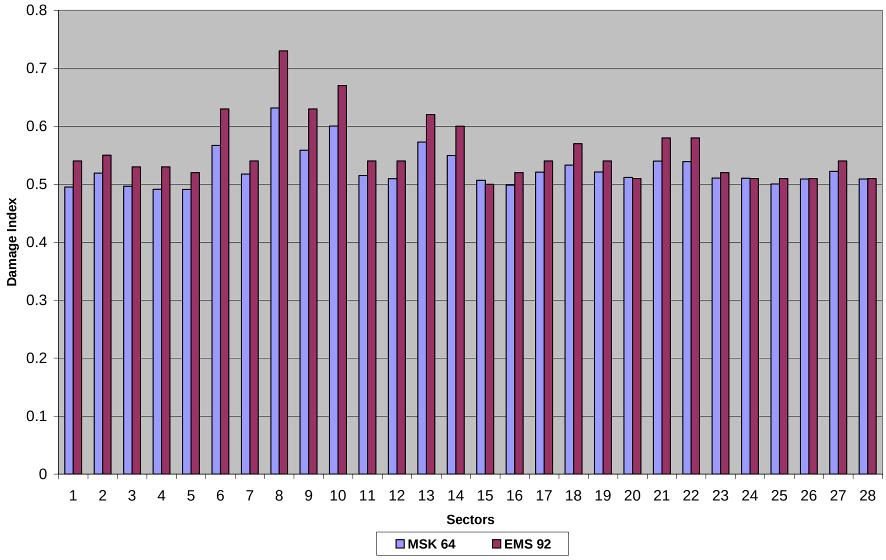

Figure 4: Comparison of damage indices. Input intensity X

Figure 5 reveals the damage indices at each sector for inputs with intensities VII, VIII, IX and X according to EMS 92 scale. Results from Figure 5 show that substantial damage corresponds to intensities VIII - X.

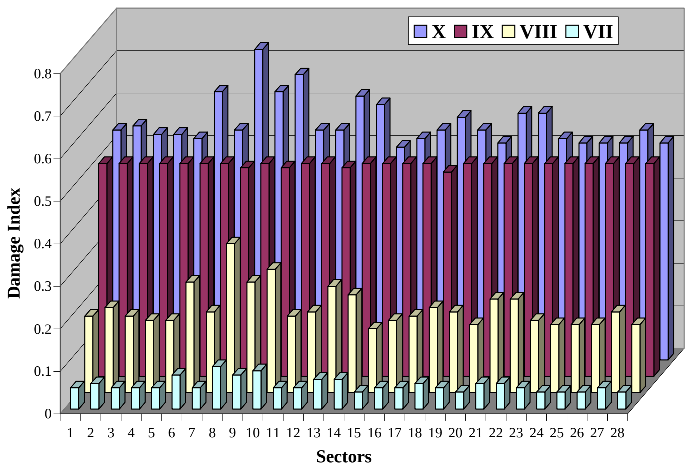

Figure 5: Damage indices. EMS 92 scale

Figure 6 and 7 show damage scenarios for inputs with intensity VIII and X (EMS 92 scale), respectively.

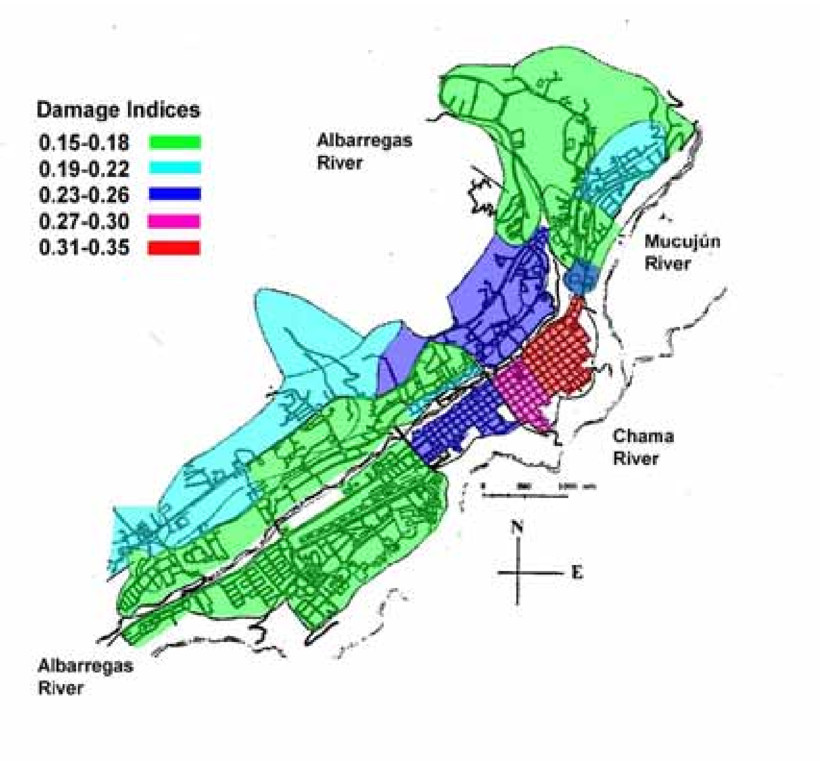

Figure 6: Damage scenario for intensity VIII. EMS 92 scale

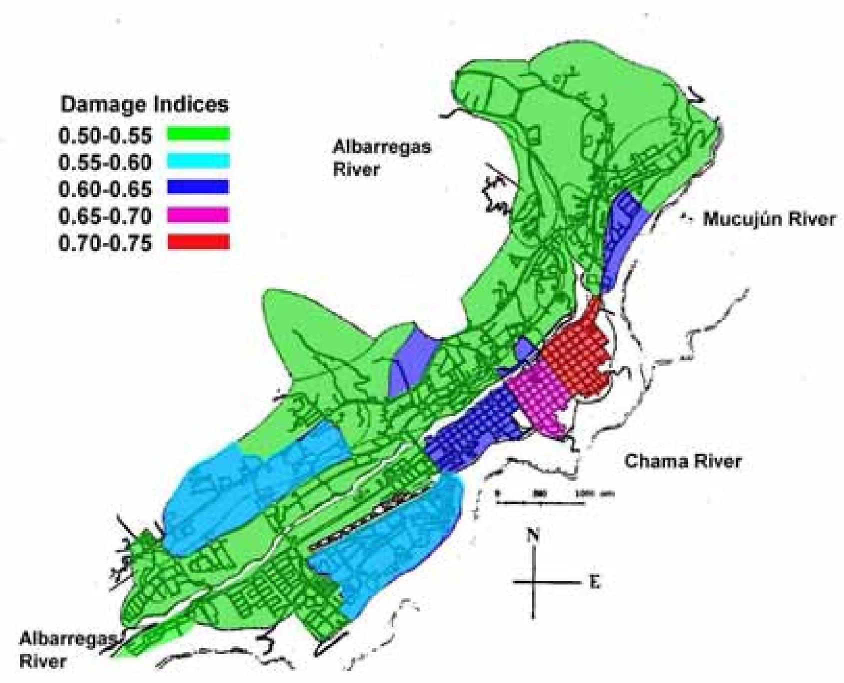

Figure 7: Damage scenario for intensity X. EMS 92 scale

Results from Figures 5 and 7 show that for intensity X, predicted damages in the most affected sectors are almost "very heavy". These areas are also the most populated and contain many important buildings such as government offices, banks, theatres, high schools, schools, shops, museums, etc. Figure 6 shows similar damage distribution.

5. CONCLUSIONS

A numerical seismic risk assessment for the city of Mérida (Venezuela) has been carried out. Research approach has consisted of obtaining the seismic hazard by a probabilistic analysis from the available seismic information, evaluating the vulnerability of the existing buildings and obtaining damage scenarios for the expected seismic intensities.

Preliminary results show that seismic risk is elevated and affects highly populated and essential zones.

Research currently in progress involves accounting for local site effects, performing new vulnerability analysis (smoothing contrasts between classifications in different intensity scales and considering building use) and implementing damage results in a GIS.

6. ACKNOWLEDGEMENTS

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