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SEISMIC RISK SCENARIOS FOR MÉRIDA, VENEZUELA

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ABSTRACT :

This paper presents a seismic risk assessment on the buildings of Mérida, Venezuela. It consists of a global hazard and vulnerability evaluation. The tectonic frameworks as well as the seismogenic zones are taken from other investigations. Zonified Probabilistic Seismic Hazard Analyses from other studies are used in the hazard model, selecting the performance based seismic design extreme events, i.e. frequent (Ms = 5.35; PGA = 0.15; *I* (EMS) = VI-VII), and very rare (Ms = 7.65; PGA = 0.45; *I* (EMS) = X) scenario events. The ground motion parameters are estimated by means of a specially attenuation law for western Venezuela. PGA's are used for a number of representative site response analyses. The obtained maximum amplification periods and the corresponding amplification factors are used to carry out a microzonation of the Mérida plateau. Possible induced effects such as liquefaction and landsliding are estimated by the HAZUS® Earthquake Loss Estimation Methodology. The vulnerability of the buildings is assessed through a Building Typology Matrix based method (RISK-UE LM1), where in the case of Mérida a specific Typology Matrix is obtained. This approach provides Damage Probability Matrices for each of the scenario events and typologies, where expected damage distribution may be estimated. The seismic vulnerability of the city is high. For the frequent event the mean damage grades are Grade 0 and Grade 1, on the other hand, for the very rare event mean damage grades are Grade 3 and Grade 4. GIS ArcView® software is used to display damage and risk scenarios.

KEYWORDS: Seismic risk scenarios, vulnerability assessment, hazard assessment, damage probability matrices.

1. MÉRIDA IN VENEZUELA

Venezuela is a country that although containing many geographical features, from deserts to jungle, and from extended plains to steep slope mountain ranges, most of the land is unused, and the urban population concentrates over less than the 25% of the total surface. Population concentration is produced over an arch comprised mostly of mountain chains crossing the country with a southwest-northeast orientation, in the western side, and with an east-west orientation in front of the central and eastern coasts in the Caribbean Sea. Total estimated population for Venezuela is around 20 million people, where almost 20% accounts for urban population in Caracas.

Mérida is the city capital of Mérida State in the Andean mountain range region in western Venezuela. The premises inside the Mérida's Metropolitan area (State Capital) contain the most important parishes of the state. Inside Mérida's plateau, twelve parishes (which belong to the Libertador Municipality) are identified and described as the most populated in the state, and are used in this research as the territorial units for the study zone. With a total population of 197,636 inhabitants, only four of the parishes contain rural population in a small percentage: the Arias, the El Llano, the Jacinto Plaza and the Lasso de La Vega parishes (INE, 2001).

Mérida City is settled over an elongated plateau inside a valley, within the Andean mountain range in Venezuela. This plateau is oriented SW-NE surrounded by two mountain chains: the Sierra Nevada (SE) and the Sierra de la Culata (NW). Two rivers flow through the tableland: the Chama and the Albarregas rivers. The latter (Albarregas river) in the NW divides the city in two portions with a shallow canyon in between 10 m and 40 m depth; and the Chama river at the SE side of the plateau with a deeper canyon with depths ranging from 50 m to 180 m. The Chama River's canyon determines the urban area's geographical limit over this flank (base of the Sierra Nevada mountain chain). Altitudes in the tableland range from around 1,100 m at the southeasterly bounds to 1,900 m at the northwesterly limits. The Sierra de la Culata mountain chain constitutes the NW geographical limit of the plateau. Convergence of these two mountain chains at the northeast side forms a smaller valley dedicated to agriculture called El Valle Grande. In the southwest, the plateau limits with the conjunction of the two rivers along the city in a place called La Punta where a small city lies (belonging to Mérida's metropolitan area). The tableland covers an approximate area of 60 km^2, with geographical coordinates: 8º32'34'' and 8º38'49'' of North Latitude in its southern and northern parts, and 71º7'20'', 71º5'42'' of West Longitude in its extreme lateral sides. General configuration is rectangular (in plan) and elongated in the SW-NE direction.

2. SEISMIC HAZARD IN MÉRIDA

Seismicity in Mérida is important; it is categorized as a high seismicity zone in the Venezuelan seismic code (COVENIN, 2001). The most important seismogenic source for western Venezuela is the Boconó Fault Zone (BFZ) a 600 km long and 100 km wide NE oriented tectonic stripe, with about 80% of the seismicity occurring in the region since 1983 and important historical earthquakes (Pérez et. Al, 1997), such as the 1812 March 23 and the 1894 April 28 earthquakes. The first with an inferred Intensity *I* (MMI) = IX affecting mostly Mérida city as the macroseismic epicenter (Altez, 2006), and the second with a maximum assigned intensity *I* (MMI) = X-XI (MOP, 1976). Several studies identify the BFZ as the most important seismogenic source in western Venezuela (Laffaille, 1996; Garciacaro, 1997; Pérez et. Al, 1997; Bendito, 2000).

2.1. Scenario Earthquakes

The Performance Based Seismic Design (PBSD) approach establishes four design earthquakes, based in the expected performance levels of the structures, within these, two scenario earthquakes are selected for this study, the frequent and the very rare events. The ground motion parameters used are those from (Bendito, 2000), where the PSHA performed renders hazard curves for each of the seismogenic sources, and a deaggregation of accelerations is performed obtaining isoacceleration curves for northwestern Venezuela based in the four performance states in the PBSD. As the ground motion parameter for the scenarios (Table 2.1) is the

Macroseismic Intensity from the European Macroseismic Scale (EMS) (Grünthal, 1998), the maximum expected accelerations are treated with an attenuation law for western Venezuela (Arggawal, 1981).

Table 2.1 Scenario earthquakes

Earthquake	Return Period	Ms	PGA (g)	I (EMS)
Frequent	43 years	5.35	0.15	VI-VII
Very Rare	970 years	7.65	0.45	X

2.2. Geological Local Effects

Mérida is settled in a tectonic valley (graben) limited by the La Culata Sierra (NW) and the Sierra Nevada (SE). The valley is constituted by Alluvial deposits in cone-terrace shape (Pleistocene era), fluvial spreading and terraces. Slope in the terrain ranges from 0 to 15 grades in the central part of the valley. Two rivers cross the tableland: the Chama and the Albarregas rivers. The first separates the Pleistocene terrace (over which the city is settled) from the Nevada Sierra through a canyon with maximal depths of 180 m. The Albarregas River with a slope from 2 to 3 grades is controlled by faults. Slopes on the river borders depend on canyon depths and range in general from 20 to more than 40 grades. The soil composition is an extensive sedimentation of lime, sand, gravel and variable size of pebbles, which came from the sides of the Sierras in the boundaries of the valley. The average geotechnical conditions of soil and sub-soil comprises a three-layered deposit that describes the general constitution of Mérida's tableau (Table 2.2). A site response analysis is performed by the use of Equivalent-linear Earthquake site Response Analysis software (EERA) (Bardet et. al., 2000), over a set of two geotechnical columns representing average conditions at each side of the Albarregas River. Acceleration time histories are obtained by the use of Target Acceleration Spectra Compatible Time Histories software -TARSCTH- (Papageorgiu et. al., 2001). Amplification factors (AF) are obtained based in a series of synthetic earthquakes compatible with the elastic response spectra in the Venezuelan seismic code. Results for AF show a difference in acceleration values, greater for the southerly Albarregas River soils. This difference is used to estimate a microzoning of the tableau, expressed in macroseismic intensity by means of a conversion law (Goretti and Dolce, 2004) which states that seismic amplification expressed in terms of a ground motion parameter, such as PGA, may also be expressed in terms of an increment in the macroseismic intensity, the conversion law has the form:

$$F_a = Y/Y_{REF} = 10^{\,0.22(I-IREF)} = 10^{\,0.22\Delta I} \tag{2.1}$$

Where Y and Y_{REF} are, the amplified ground motion parameter and the reference ground motion parameter, and ΔI is the increment of the macroseismic intensity. The application of this law renders that at southerly Albarregas River, several deposits amplify up to a middle intensity degree as shown in Figure 2.1. This local amplification is taken into account to produce damage scenarios.

Table 2.2 Representative geotechnical soil columns (MOP, 1976)

Soil Type	Layer	Composition	Unit Weight (KN/m^3)	Shear Wave Velocity (m/s)
Northerly Albarregas River	Surface	Sandy Clay with Gravel	18.85	200 to 800
	Intermediate	Silty Sand with Gravel	19.64	800 to 1,700
	Deep	Boulders, Pebbles and Gravel	22.06	Over 2,000
Southerly Albarregas River	Surface	Clayey Sand with Gravel	19.64	200 to 800
	Intermediate	Silty Sand with Gravel	20.43	800 to 1,700
	Deep	Boulders, Pebbles and Gravel	22.01	Over 2,000

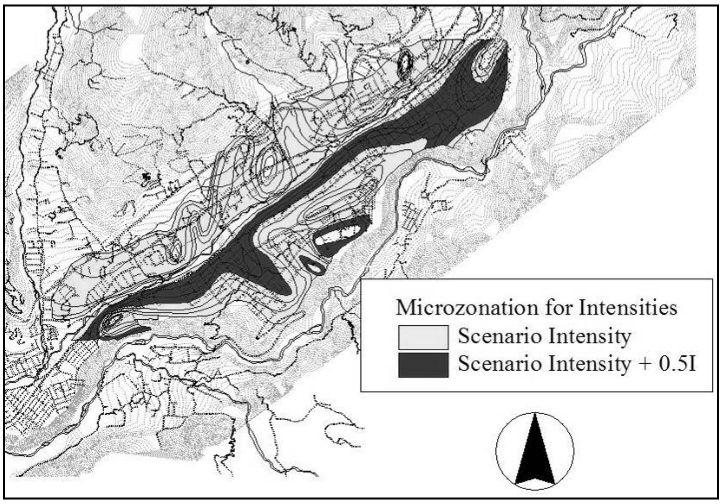


Figure 2.1 Increments of intensity degree for the tableau

2.3. Other Induced Effects

Other induced local effects, such as liquefaction and landslide, are estimated through the use of the HAZUS®99 Earthquake Loss Estimation Methodology (HAZUS-99-SR2, 2002).

2.3.1 Liquefaction Susceptibility

The application of the HAZUS approach is performed using the geologic and geomorphologic maps for Mérida from the Venezuelan Ministry of Mines and Oil (Ministerio de Minas e Hidrocarburos, 1974). Map resulting from Probability of Liquefaction analysis in Mérida's plateau, is shown in Figure 2.2a. Soils with Low Susceptibility occupy an area of 2,520 Ha, corresponding to an 87.54% of total surface considered; on the other hand, Moderate susceptibility covers 359 Ha, with a 12.46% of soil deposits in the study area (Castillo, 2006).

2.3.2 Landslide Susceptibility

Using the slope classification map of the terrain and the geologic group of the deposits, landslide susceptibility is assessed finding very susceptible deposits in the northern flank of the deeper Chama River Canyon where steep slopes are verified (in between 30 and greater than 40 degrees). In Figure 2.2b this important zone is shown.

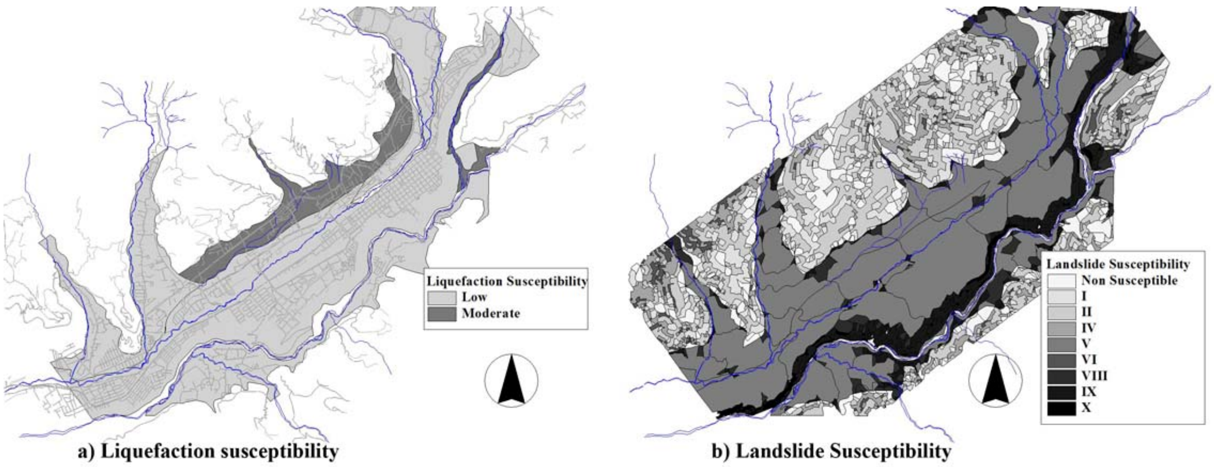


Figure 2.2 Other induced effects: a) Liquefaction susceptibility, b) Landslide susceptibility

These results point towards an increment of seismic risk, particularly due to landsliding susceptibility, as many buildings are settled in the limits of the tableau and over both river canyons (the Albarregas and the Chama Rivers), mostly belonging to typologies with high seismic vulnerability (Castillo, 2006).

3. SEISMIC VULNERABILITY OF BUILDINGS

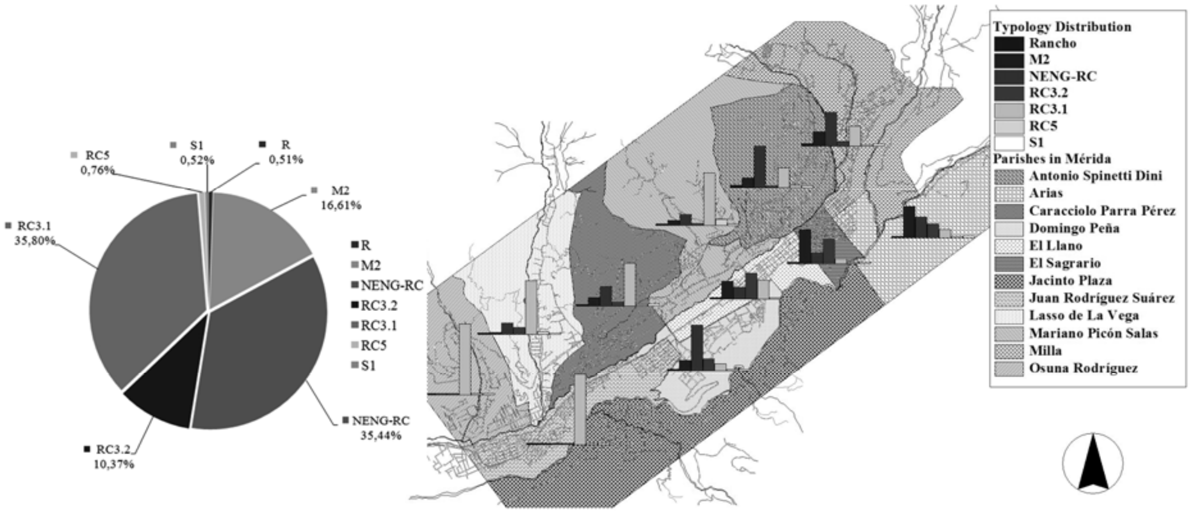
The assessment of seismic vulnerability is performed using the RISK-UE LM1 approach (Milutinovic and Trendafiloski, 2003), where vulnerability is sought within a standard Building Typology Matrix (BTM). A total of 16,147 buildings are assessed in the survey, considering a sectorization of the city in 42 sectors, based in building type contents (homogeneity in building classes) and in the physical barriers and accessibility, such as rivers, bridges and roads. Preliminarily, seven building typologies are found as representative, five that may be directly identified from the BTM of LM1 approach and two not complying completely the BTM descriptions (Table 3.1). However, the RISK-UE LM1 methodology allows to adequate the vulnerability index if the building typology is not identified directly from the BTM, procedure that has been performed using the instructions in the aforementioned methodology.

Table 3.1 Building Typology Matrix for Mérida City (Castillo, 2006)

EMS-98 Vulnerability Class and Building Type	Building Typology Matrix for Mérida		
	Typology	Description	Vulnerability Index
N/A, considered as A (Modified Vulnerability Index)	***R***	*Rancho*	**0.9**
A- Adobe block walls, Rubble stone (field stone)	***M2***	*Adobe*	**0.84**
B- RC moment resisting frame designed for gravity loads only (no seismic features) or confined masonry (Modified Vulnerability Index)	***NENG-RC***	*Based on Concrete Moment Frames*	**0.69**
E- Steel moment-resisting frame with brick masonry partitions	***S1***	*Steel Moment Frames*	**0.363**
D- RC frame designed with seismic features.	***RC3.1***	*Regularly infilled walls*	**0.402**
C- RC Flat slab structure.	***RC3.2***	*Irregular frames*	**0.522**
E- RC Shear wall structure, cast in-situ.	***RC5***	*Precast Concrete Tilt-Up Walls*	**0.384**

3.1. Vulnerability Classes Assessment and Distribution

The modification of the vulnerability index for the Rancho (R) and the Non-Engineered RC frames (NENG-RC) buildings is performed in two different ways. For the Rancho typology the most vulnerable index is considered as the typology is identified as very vulnerable. For the NENG-RC typology a detailed analysis is performed by the Italian Vulnerability Index Method using the "Second Level Assessment Form" (GNDT, 2001), over a representative settlement in Mérida city where this typology is predominant (Castillo, 2006). This last typology is widely spread in urban premises in Venezuela, where most of the cities contain informal settlements (mostly low income population), called "barrios", with high population density and where most of the buildings are both non-engineered and self-constructed housing. The general distribution of building typologies (Table 3.1) is shown in Figure 3.1a, where the predominant typologies in the city are the RC3.1 (RC frame buildings designed with seismic features) and the NENG-RC typologies, with a 35.8% and a 35.44%, respectively. However, the most vulnerable typologies (R, M2 and NENG-RC) represent around a half of all the buildings in the survey. The high concentration of the NENG-RC type inside informal settlements configure zones with high seismic risk in the city, as the vulnerability is high and the settlements mostly occupy zones with steep terrains and consequently with high seismic hazard (susceptible to landsliding). As it may be seen in Figure 3.1b, several parishes account for high concentrations of vulnerable buildings, such as the Arias, El Sagrario, Milla, Antonio Spinetti Dini and the Domingo Peña parishes, where typologies M2 and NENG-RC buildings are predominant; the first two parishes configure most of the city's downtown in which M2 typology represents the oldest buildings in the city (earthen buildings) and the rest of the three parishes contain the largest informal settlements in Mérida. It is noticeable how the RC3.1 typology is predominant over five other parishes in the southern portion of the city corresponding to the second half of the 20th century growth.



a) Type distribution in Mérida **b) Type distribution in parishes**

Figure 3.1 Building types distribution in Mérida: a) General Distribution, b) Distribution in parishes

4. SEISMIC RISK SCENARIOS

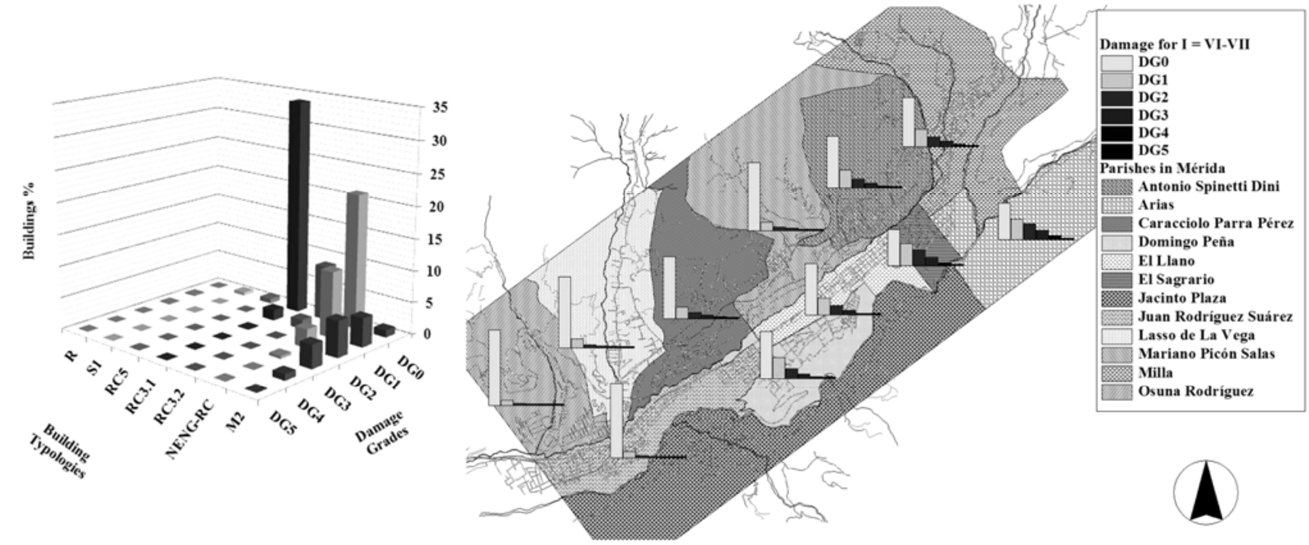
The RISK-UE LM1 approach allows damage forecast by means of Damage Probability Matrices (BTM), based in relating for each typology the probable Damage Grades (from Damage Grade 0 to Damage Grade 5) that may undergo the buildings when exerted to a certain macroseismic intensity of the EMS. The calculations are performed in accordance with the instructions in (Milutinovic and Trendafiloski, 2001) so to build the DPM's and forecast damage for the two selected scenarios.

4.1. Frequent Scenario

The frequent scenario, with an intensity *I* (EMS) = VI-VII and a return period (RP) of 43 years, produces small damage in the city as the intensity is half a degree over the damaging threshold of the scale. The mean Damage Grades are Damage Grade 0 (DG0: no damage) and Damage Grade 1 (DG1: slight damage) with 65% and 18% of total buildings, respectively (Figure 4.1a). Upper damage grades 2 and 3 occur locally, where the most vulnerable typologies (M2 and NENG-RC) are predominant (the Arias, El Sagrario, Milla, Antonio Spinetti Dini and the Domingo Peña parishes). Buildings undergoing Damage Grade 4 are those of the M2 typology, with a small percentage (around 1% of total buildings), the superior Damage Grade 5 is not expected to occur.

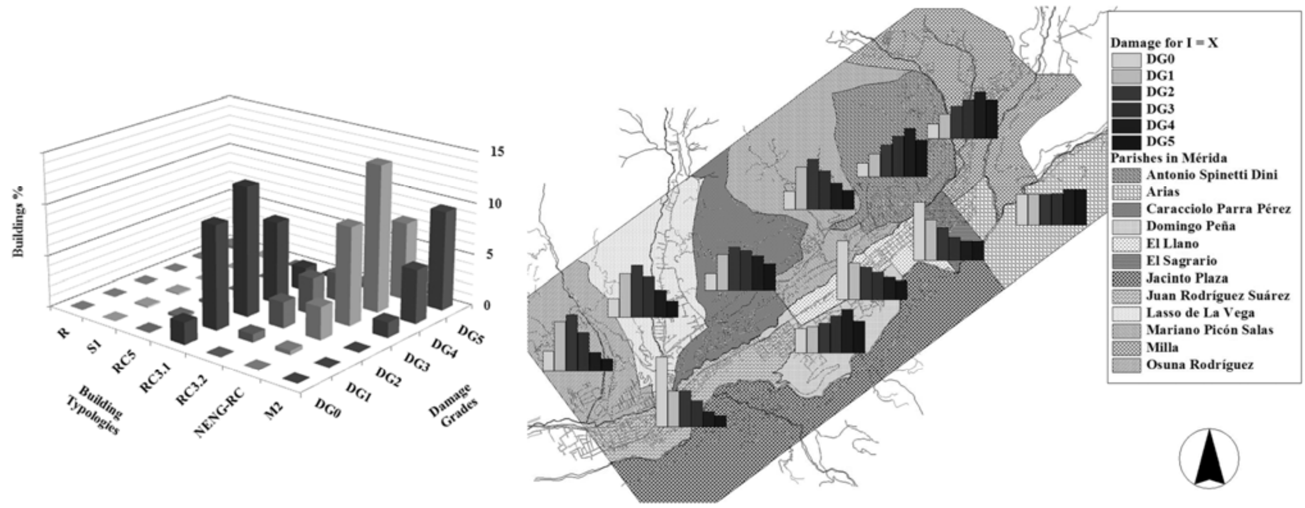
4.2. Very Rare Scenario

The very rare event (*I* (EMS) = X, and a return period of 970 years) damages great quantity of buildings at upper damage grades (DG4: very heavy damage, heavy structural damage and very heavy non-structural damage; and DG5: destruction, very heavy structural damage), with slightly more than one third of all the buildings in the survey undergoing such damage grades (Figure 4.2a). The mean damage grades for this event are damage grades 3 and 4, with around a 19% of all buildings each. Occurrence of upper damage grades 4 and 5 are predominant in the Antonio Spinetti Dini, the Arias, the Domingo Peña and the Milla parishes, with percentages of around 25% of all buildings in the parish for DG4 and around 10% for DG5 (Figure 4.2b).



a) General Damage Grades (DG) distribution **b) Damage Grades (DG) distributions in parishes**

Figure 4.2 Damage Grades distribution for *I* = VI-VII: a) General Distribution, b) Distribution in parishes



a) General Damage Grades (DG) distribution **b) Damage Grades (DG) distributions in parishes**

Figure 4.2 Damage Grades distribution for *I* = X: a) General Distribution, b) Distribution in parishes

5. CONCLUSIONS

- Local amplifications are expectable in the southern side of the Albarregas River.
- Local earthquake induced effects, such as liquefaction and landsliding are likely to occur in the city's premises, increasing seismic risk.
- High concentrations of vulnerable buildings are detected in the city's downtown and inside informal settlements, built over hazardous terrains with landsliding susceptibility.
- More than a third of all the buildings in the survey undergo damage grades 4 and 5.

- Several parishes are expected to suffer superior damage grades (DG4 and DG5) in their buildings, accounting for important percentages of the buildings.
- Seismic risk in Mérida is high, both for the high seismicity qualification and the high contents of vulnerable buildings in the city.

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