Chapter 8

8 Seismic Damage Scenarios

8.1 Introduction

The seismic damage scenarios are tools for visualizing the predictions of the expected seismic damage distribution over an urban zone, with different characteristics depending on the purpose of the output information (scientific research, decision-making processes, public awareness, urban planning). Scenarios are built based on the information about the most probable seismic events to occur in the interest zone, called Scenario Events, which are expressed as a ground motion parameter (that identifies the level of ground shaking for each of the events), and the structural system quality of the buildings in the interest zone and its inherent sensibility to ground motion (seismic vulnerability of buildings).

In the case of this research, the scenario events are identified by Macroseismic Intensities that range from I = VI (when damage appears) to I = IX (maximum intensity obtained in probabilistic evaluation of seismicity). The evaluation of seismic damage is performed by means of the WP4-LM1 Methodology and the Damage Probability Matrices obtained for the different building typologies in the survey (Section 6.2.1), where these functions represent the different damage grades generated in a building vulnerability class when occurring a certain Macroseismic Intensity event.

The damage scenarios are presented as maps for each scenario event and each damage grade (from Damage Grade 0, or no damage, to Damage Grade 5 or destruction) containing the distribution of the cumulative damage grade by sector. Each map is complemented with a chart showing the distribution of damage grades by building typologies for all the buildings in the survey. Additional information about the damage grades distribution by parishes in the city is also presented, showing the percentages of damaged buildings with a certain damage grade respect to the total number of buildings in the parish.

8.2 Seismic Damage Evaluation

The WP4-LM1 Damage Probability Matrices obtained in Chapter 5 are used to evaluate seismic damage distribution in the city of Mérida. The database of the buildings is a table containing the sub-sectors (as rows of the table) where each of the columns in the row identifies one of the building typologies found in the survey, with the corresponding number of buildings belonging to that typology in the sub-sectors. Several operations are performed in this table using the Damage Probability Matrices in (Table 6.5), two different expressions of damage are obtained: the cumulative damage per sector (without class differentiation), and another estimation of damage that describes the number of buildings of a certain vulnerability class undergoing a certain damage grade (from Damage Grade 0 to Damage Grade 5) for a given intensity inside the sub-sector. The results are obtained in the fashion of a table, in order to use the data as a database linked to a map describing the sub-sectors. The operations performed to obtain the damage distributions for each of the sub-sectors consist in:

- Cumulative Damage per sector: this parameter describes the cumulated damage for a certain damage grade in a sub-sector (without discriminating the building classes) at certain intensity, and is the result of the matrix product:

$$TDGN_I = [SC] \times \lfloor DPM_{T,I} \rfloor \qquad \text{eq. 8.1}$$

Where, $TDGN_I$ is the Total number of buildings with Damage Grade N given an Intensity I, SC is the sector matrix containing, in each row, the number of buildings for the respective typologies in the sector, and $DPM_{T,I}$ is the Damage Probability Matrix for the typologies considered, given an Intensity I (see the example of Damage Probability Matrix for I = VI in Table 8.1).

Typology	Description	Damage Grades					
		DG0	DG1	DG2	DG3	DG4	DG5
R	*Rancho*	0.372	0.398	0.18	0.046	0.005	0
M2	*Adobe*	0.454	0.37	0.141	0.031	0.002	0
NENG-RC	*Non-engineered RC*	0.772	0.185	0.038	0.005	0	0
RC3.2	*RC Irregular frames*	0.928	0.063	0.009	0	0	0
RC3.1	*Regularly infilled walls*	0.965	0.032	0.003	0	0	0
RC5	*Precast Concrete Tilt-Up Walls*	0.968	0.029	0.003	0	0	0
S1	*Steel Moment Frames*	0.971	0.026	0.003	0	0	0

Table 8.1: Damage Probability Matrix for *I* = VI, for the seven typologies considered in the survey.

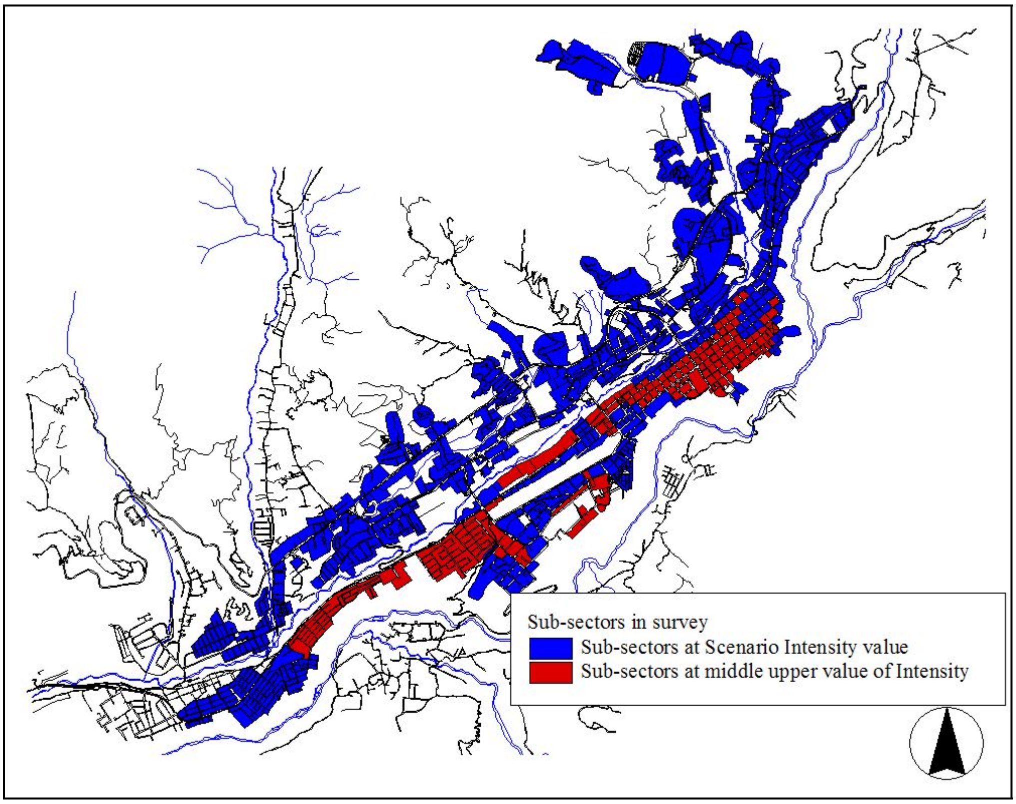
- Number of buildings of a vulnerability class with a certain damage grade: this parameter describes the number of buildings of a certain vulnerability class undergoing a damage grade for a given intensity, and is the result of the product between the discrete beta probability for the typology associated with damage grade k ($p_{k,I}$), at a given intensity I, and the number of buildings belonging to that vulnerability class in the sub-sector, having the form:

$$TyDN_I = p_{k,I}^{Ty} \times TyN_S \qquad \text{eq. 8.2}$$

Where, $TyDN_I$ is the number of vulnerability class buildings with a certain damage grade at intensity I, $p_{k,I}^{Ty}$ is the discrete beta probability for the typology undergoing a damage grade k, given an Intensity I, and, TyN_S is the Number of buildings of belonging to a certain a Typology in the sector.

The local intensities in the microzonation of the city's tableau are included in the estimation of damage distribution, where in the sub-sectors contained in local amplification zones with higher intensity degrees (Map 5.8) the damage distribution is estimated using the increased middle value of intensity. The consideration of local intensities in the microzonation allows identifying the sub-sectors of the survey where the intensity degree is increased, superimposing the local intensities microzonation map and the sub-sectors map, a total of 123 sub-sectors are found belonging to these zones with upper middle values of intensity, located southerly the Albarregas River. Thus, the values of the mean damage grades for the typologies inside these sub-sectors are estimated with this superior intensity value for all the scenario events considered (see Map 8.1).

As the results of data visualization for damage scenarios are maps containing information on the percentage or number of buildings with a certain damage grade by sector, and the percentage or number of buildings of a certain typology undergoing a certain damage grade by sector, the interpretation of the different damage states is important to estimate the possible impact in the sub-sectors.



Map 8.1: Sub-sectors in the survey with middle upper values of intensity for the scenarios.

The definition of the damage states is performed by means of the damage grades in the European Macroseismic Scale [EMS, 1998], which have similarities with the "standard performance levels" in Vision 2000 [SEAOC, 1995]. In Table 8.2 the definitions for these performance levels and the damage grades in the EMS-98 are shown, the relationship between these is based in the similitude of the expected damage occurring in the buildings. Damage Grade 5 does not appear in the performance levels as it corresponds to a building that has already collapsed entirely or is near total collapse, however, it is included in the descriptions of damage using the definition in the EMS-98. This scale only considers the damaged buildings (from Damage Grade 1 to Damage Grade 5), on the other hand, the WP4-LM1 Methodology applied considers the inferior Damage Grade 0 or undamaged buildings so to obtain a damage distribution considering the unaffected buildings (accounting for a 100% of the buildings in the survey within the damage forecast); consequently, the damage classification in the scenarios considers a six damage degree scale including the Damage Grade 0 or undamaged state for the buildings.

The use of the standard performance levels to identify the damage grades is a convenient strategy to describe the state of buildings after an earthquake, as the definitions are more pertinent to the post-earthquake evaluation procedures (where the buildings are classified by the risk they represent to the occupants), and the terms used belong to the performance-based seismic design philosophy. Alternatively, the damage scenarios may also be defined by the performance level. For example, a scenario showing the distribution of Damage Grade 1 occurring at an Intensity I = VII, may be defined as a Fully Operational Scenario for Intensity I = VII, showing the percentage of buildings in each sector undergoing such damage grade. Due to the characteristics of the data available, no detailed information on specific damage to buildings is possible, as the locations of the building's sites are not specified in the data, instead, the distribution of damaged buildings with a certain damage grade in the sector is the parameter used to describe the seismic damage.

8.3 Damage Scenarios for Intensity I = VI

General results are obtained as the percentage of buildings (from the total number of buildings in the survey) belonging to a typology undergoing a certain damage grade for the expected Intensity. In Figure 8.1, these results are shown for Intensity *I* = VI, the total percentage of damaged buildings is 20% from the buildings in the survey, from which around a 15% of the buildings undergo Damage Grade 1, a 4% of the buildings need to repaired at convenience of the users, remaining functional (Damage Grade 2), less than a 1% suffer Damage Grade 3 and a 0.01% undergo near collapse damage state (Damage Grade 4), the superior Damage Grade 5 does not affect the buildings in this scenario event.

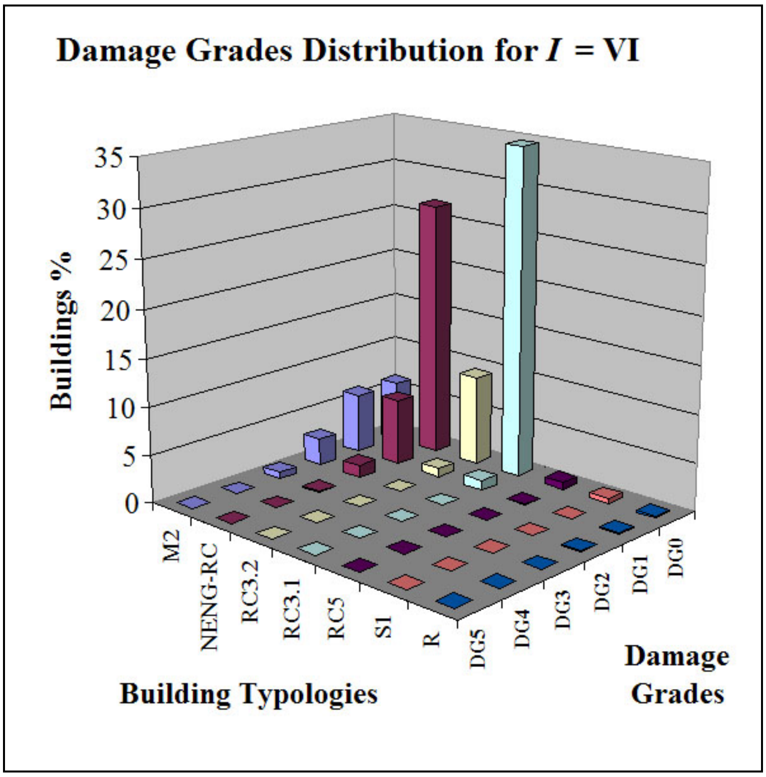


Figure 8.1: Damage grades distribution percentages by vulnerability classes for Intensity *I* = VI.

Vision 2000		EMS-1998		
Designation	Description	Designation	Description for Building Types	
			Reinforced Concrete	Masonry
Fully Operational	Only very minor damage has occurred. The building retains its original stiffness and strength. Nonstructural components operate, and the building is available for normal use. Repairs, if required, may be instituted at the convenience of the building users. The risk of life threatening injury during the earthquake is negligible.	Grade 1: Negligible to slight damage. (No structural damage)	Fine cracks in plaster over frame members and in partitions.	Hair line cracks in few walls; fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases only.
Functional	Only minor structural damage has occurred. The structure retains its original stiffness and strength. Nonstructural components are secured, and if utilities are available, most would function. Repairs may be instituted at the convenience of the building users. The risk of life threatening injury during the earthquake is very low.	Grade 2: Moderate damage. (Slight structural damage, moderate Nonstructural damage)	Hair line cracks in columns and beams; mortar falls from the joints of suspended wall panels; cracks in partition walls; fall of pieces of brittle cladding and plaster.	Cracks in many walls; fall of fairly large pieces of plaster; parts of chimneys fall down.
Life Safety	Significant structural and nonstructural damage has occurred. The building has lost a significant amount of its original stiffness, but retains some lateral strength and margin against collapse. Nonstructural components are secure but may not operate. The building may not be safe to occupy until repaired. The risk of life-threatening injury during the earthquake is low.	Grade 3: Substantial to heavy damage. (Moderate structural damage, heavy Nonstructural damages)	Cracks in columns with detachment of pieces of concrete, cracks in beams.	Large and extensive cracks in most walls; pan tiles or slates slip off, Chimneys are broken at the roof line; failure of individual nonstructural elements.
Near Collapse	A limiting damage state in which substantial damage has occurred. The building has lost most of its original stiffness and strength, and has little margin against collapse. Nonstructural components may become dislodged and present a falling hazard. Repair is probably not practical.	Grade 4: Very heavy damage. (Heavy structural damage, very heavy nonstructural damage)	Severe damage to the joints of the building skeleton with destruction of concrete and protrusion of reinforcing rods; partial collapse; tilting of columns.	Serious failure of walls: partial structural failure.
N/A	N/A	Grade 5: Destruction (Very heavy structural damage)	Total or near total collapse	Total or near total collapse

Table 8.2: Vision 2000 [SEAOC, 1995] "Standard Performance Levels" and European Macroseismic Scale damage grades [EMS, 1998].

The least affected typologies are those less vulnerable (typologies RC5 and S1), where RC5 buildings undergo Damage Grade 1 in a quantity representing the 0.01% of the buildings in the survey, and S1 buildings result undamaged. The most damaged typologies are M2 and NENG-RC, accounting for a 10% and an 8% of all buildings, where Damage Grade 1 is predominant with percentages around 6% and 7%, respectively. Damage Grade 2 accounts for a 3% of the buildings for typology M2, a 1.3% for typology NENG-RC and less than a 0.1% for the Rancho typology. Damage Grade 3 only occurs in buildings belonging to the Rancho (R), M2 and NENG-RC typologies, accounting for a 0.01%, a 0.7% and a 0.1%, respectively. Damage Grade 4 affects only buildings belonging to typology M2 representing a 0.01% of the buildings in the survey.

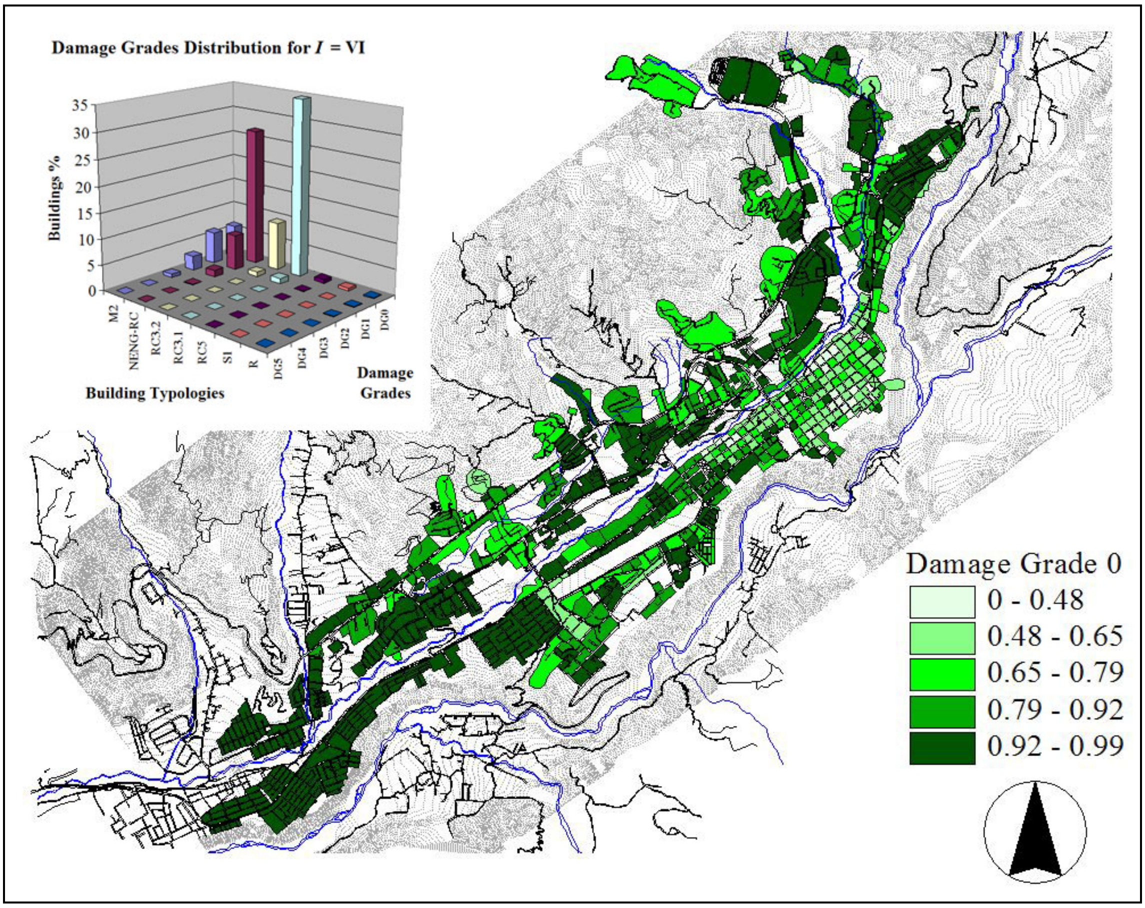
Typology	R	M2	NENG-RC	RC3.2	RC3.1	RC5	S1	Totals
Damage Grade	%	%	%	%	%	%	%	%
Grade 0	0.17	6.29	26.81	9.41	34.61	0.75	0.52	78.56
Grade 1	0.19	6.28	6.94	0.86	1.04	0.01	0	15.32
Grade 2	0.07	2.88	1.34	0.01	0.04	0	0	4.34
Grade 3	0.01	0.67	0.09	0	0	0	0	0.77
Grade4	0	0.01	0	0	0	0	0	0.01
Grade5	0	0	0	0	0	0	0	0
TOTAL	0.44	16.13	35.18	10.28	35.69	0.76	0.52	99

Table 8.3: Damage grades distribution by typologies for *I* = VI.

8.3.1 Undamaged buildings for I = VI

The maps for the scenario events and the respective damage grades distribution expresses the percentages as fractions of the unit; in this fashion a 0.99 of the sector represents a 99% of the buildings in the sector.

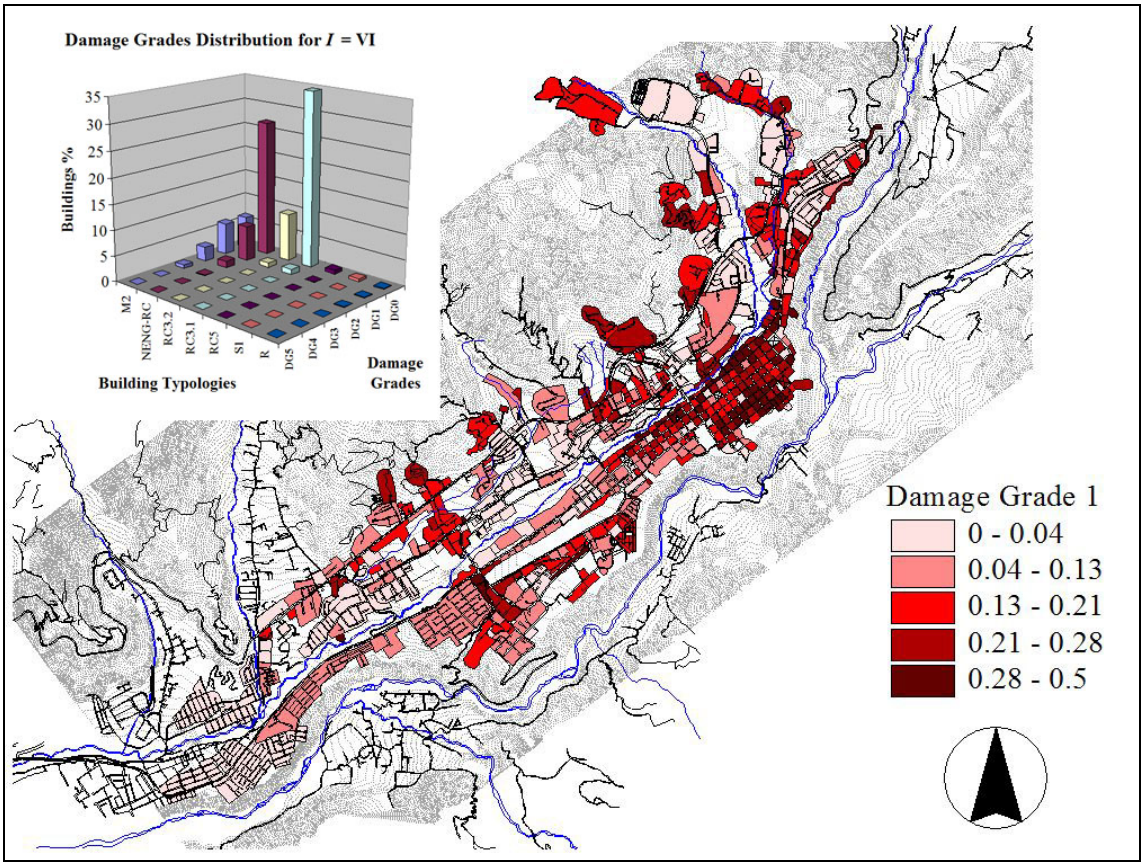
For the scenario event *I* = VI, around an 80% of the buildings in the survey result undamaged, where the greater concentrations of Damage Grade 0 or no damage are observed located mostly at southwesterly and northeasterly the city, and over the northern side of the Albarregas River. These dark-green colored sub-sectors, contain greater percentages of buildings (more than an 80% of the buildings in the sub-sectors) belonging to the RC3.1 building typology (see Map 6.5) which represent around a 35% of all the buildings in the survey (see chart in Map 8.2).



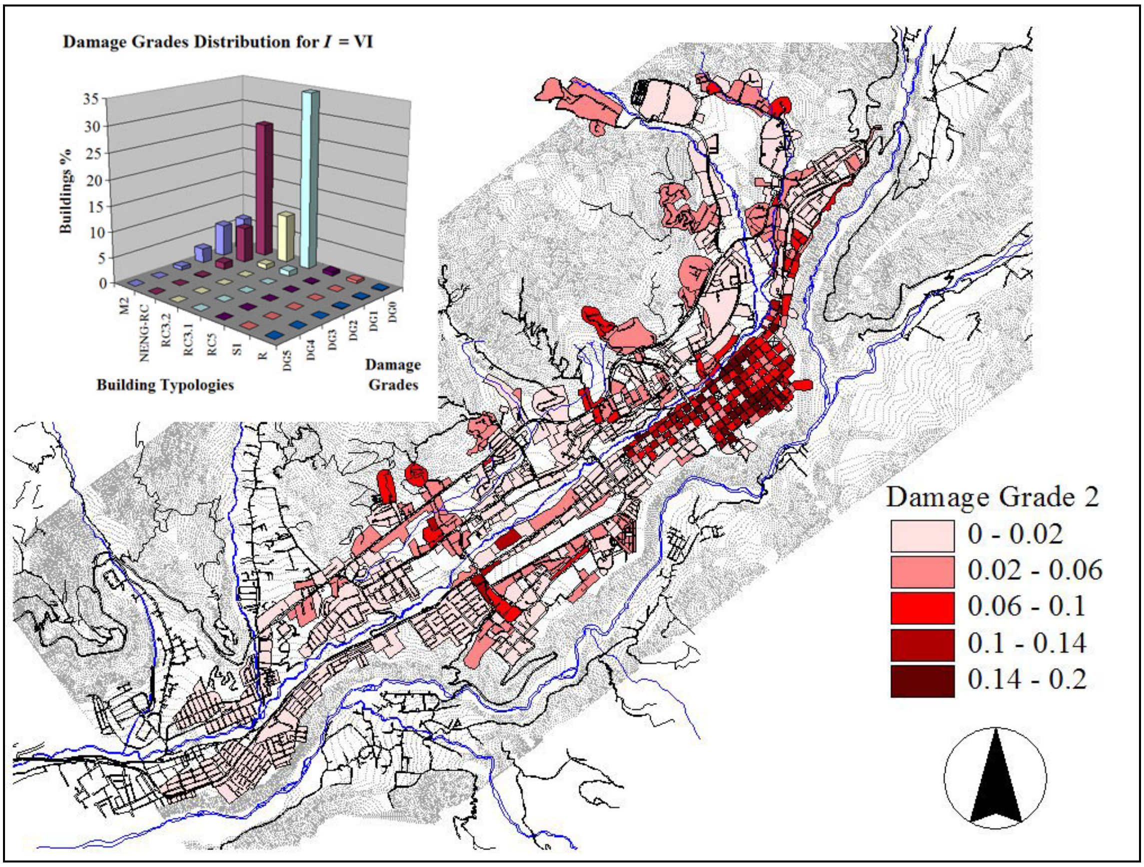
Map 8.2: Undamaged buildings in the survey for Intensity *I* = VI.

8.3.2 Damage Grade 1 (Fully Operational Performance Level) Distribution

The results for damage grade 1 distribution for Intensity *I* = VI are shown in Map 8., the distribution is expressed as the percentage of damaged buildings with a Damage Grade respect to the total number of buildings in the respective sub-sectors (as a fraction of the unit); it may be verified how fully operational performance level is concentrated in zones containing high vulnerability typologies (R, M2 and NENG-RC), al locations downtown the city where slight damage accounts for around a 13% and up to a 50% of the buildings in the sub-sectors (mostly belonging to the M2 typology), and over the settlements identified as Barrios where this damage grade occurs over the 13% and up to a 28% of the buildings in the sub-sectors (mostly belonging to the NENG-RC building typology and also with some cases of Rancho typology). In the chart of Map 8., distribution of damage grades by vulnerability classes is shown for the scenario intensity, it is verified how the greater percentage of all the buildings undergoing Damage Grade 1 (around a 15% of all the buildings in the survey) belong to the NENG-RC typology with a 7% of buildings, and to the M2 typology with a 6%.



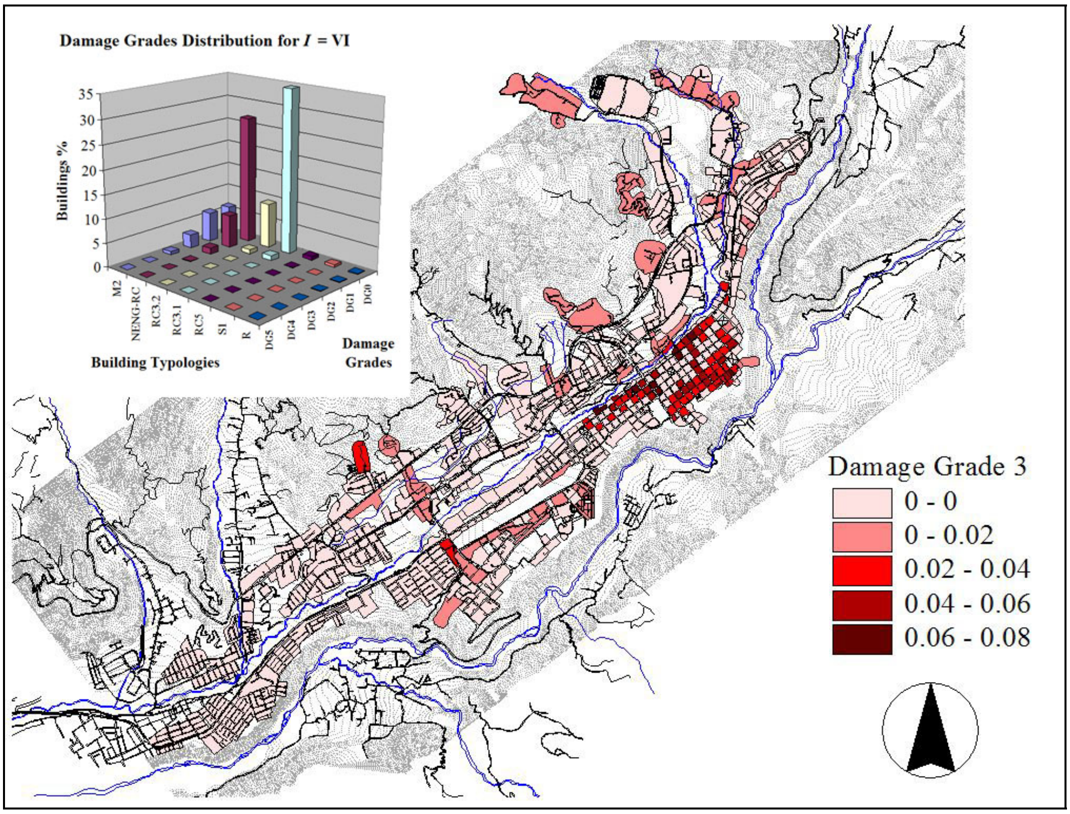
Map 8.3: Damage Grade 1 distribution scenario (Fully Operational) for Intensity I = VI.



Map 8.4: Damage Grade 2 distribution scenario (Functional) for Intensity *I* = VI.

8.3.3 Damage Grade 2 (Functional Performance Level) Distribution

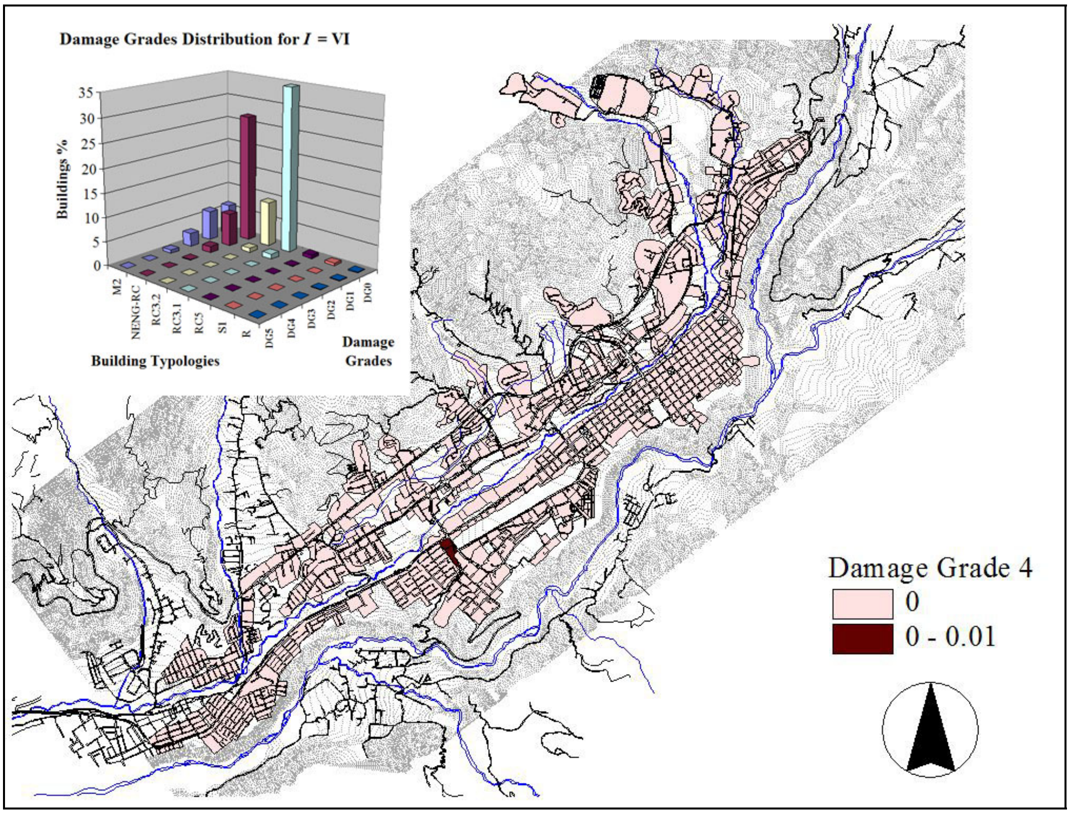
In Map 8.4, the damage distribution is expressed in the same fashion as for Damage Grade 1, once again, the premise of damage appearing where greater concentrations of higher vulnerability typologies (M2 and NENG-RC) is present as seen in the chart of the map, but with a lower percentage of the total number of buildings in the survey (around a 4%) between the two classes, where typology M2 accounts for 3% of all the buildings and NENG-RC for 1%. Damage Grade 2 concentrations of around 2% and up to 10% occur mostly in the settlements called “Barrios”, and concentrations between 10% and up to 20% occur mostly in downtown Mérida, where the oldest group of buildings are predominant in the sub-sectors.



Map 8.5: Damage Grade 3 distribution scenario (Life Safety) for Intensity *I* = VI.

8.3.4 Damage Grade 3 (Life Safety Performance Level)

This damage grade is mostly concentrated in sub-sectors located downtown Mérida (between 4% and 8 % of the buildings in the sub-sectors, in Map 8.5), where the greater percentages of buildings belonging to the M2 typology are observed (see Map 6.2 and Table 8.3), the Barrios are affected with up to a 2% of buildings undergoing this damage grade, where the predominant typology NENG-RC accounts, in general for less than a 1% of the buildings in the survey undergoing Damage Grade 3 (Table 8.3). Also the Rancho typology is affected by this damage grade, but the percentages are very low, as the building typology accounts for a small number of the buildings in the survey (around a 0.5% of the buildings).



Map 8.6: Damage Grade 4 distribution scenario (Near Collapse) for Intensity *I* = VI.

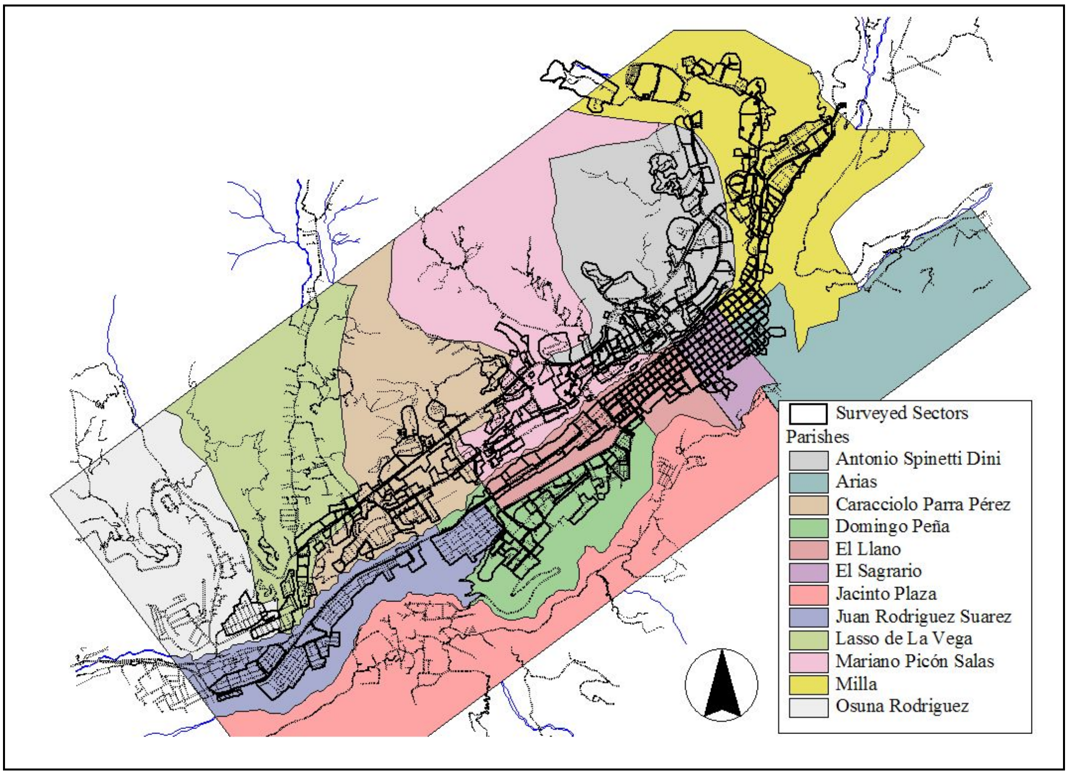
8.3.5 Damage Grade 4 (Near Collapse Performance Level)

Only one sub-sector, containing buildings belonging to the M2 and the NENG-RC typologies, exclusively, is affected by this damage grade, in Map 8.6 this sub-sector is shown, where the percentage of damaged buildings with this damage grade accounts for around a 1% of the buildings inside the sub-sector.

8.3.6 Damage Grades Distribution by Parishes for Intensity *I* = VI

The political division of the city consists of twelve Parishes, where the building's survey covers eleven out of these twelve parishes. for all the scenario events, the Jacinto Plaza parish (Southerly the city) is not considered in the distribution due to the fact that the survey does not include sectors within it; the Lasso de La Vega and Osuna Rodríguez parishes (western parishes) are shown in the distribution, although the contents in building's typologies percentages are not representative of the parishes, as the surveyed sectors cover only a small portion of the parish (Map 8.7), i.e. not enough number buildings inside these parishes are surveyed.

The percentage of buildings in the parishes, belonging to a typology with respect to the total number of buildings in the survey is shown in Figure 8.2; where the most populated parishes (in buildings) are the Antonio Spinetti Dini, the Domingo Peña and the Milla parishes, with around a 52% of all the buildings in the survey, and also containing the greater percentages of NENG-RC typology buildings, where these percentages easily doubles any of the nearest percentage of the other typologies in the parish. Other parishes show a different predominance of typologies, such as the Caracciolo Parra Pérez, the Juan Rodríguez Suárez, the Lasso de la Vega, the Mariano Picón Salas and the Osuna Rodríguez parishes, where the predominant typology is the RC3.1 typology (RC frame with regularly infilled walls buildings). The building typology RC3.2 (RC irregular frames) predominates in the El Llano parish, while in the Arias and El Sagrario parishes the predominating typology is the M2 typology (Adobe block walls).



Map 8.7: Surveyed Sub-sectors and Parishes in Mérida.

The percentages for the different typologies, with respect to the total number of buildings in each parish, are shown in Figure 8.3, where the predominance of different typologies in the different parishes is clearly observed. The greater percentages of the M2 typology in the Arias (around a 40% of the buildings) and the El Sagrario (around a 50% of the buildings) parishes, evidences the presence of the older buildings in the city inside the oldest parishes, containing most of the cultural heritage buildings in Mérida. The Spinetti Dini, the Domingo Peña and the Milla parishes evidence the presence of most of the Barrios inside its premises, due to the predominance of the NENG-RC typology, which accounts for around a 60% of the buildings in the Antonio Spinetti Dini and the Domingo Peña parishes, and for around a 50% of the buildings in the Milla parish. The RC3.1 typology (RC frames with regularly infilled walls) is observed as predominant (with percentages up to almost a 100% of the buildings) for the rest of the parishes, except for the El Llano parish where the predominant typology is the RC3.2 building typology (RC irregular frames), with around a 35% of the buildings in the parish belonging to that typology.

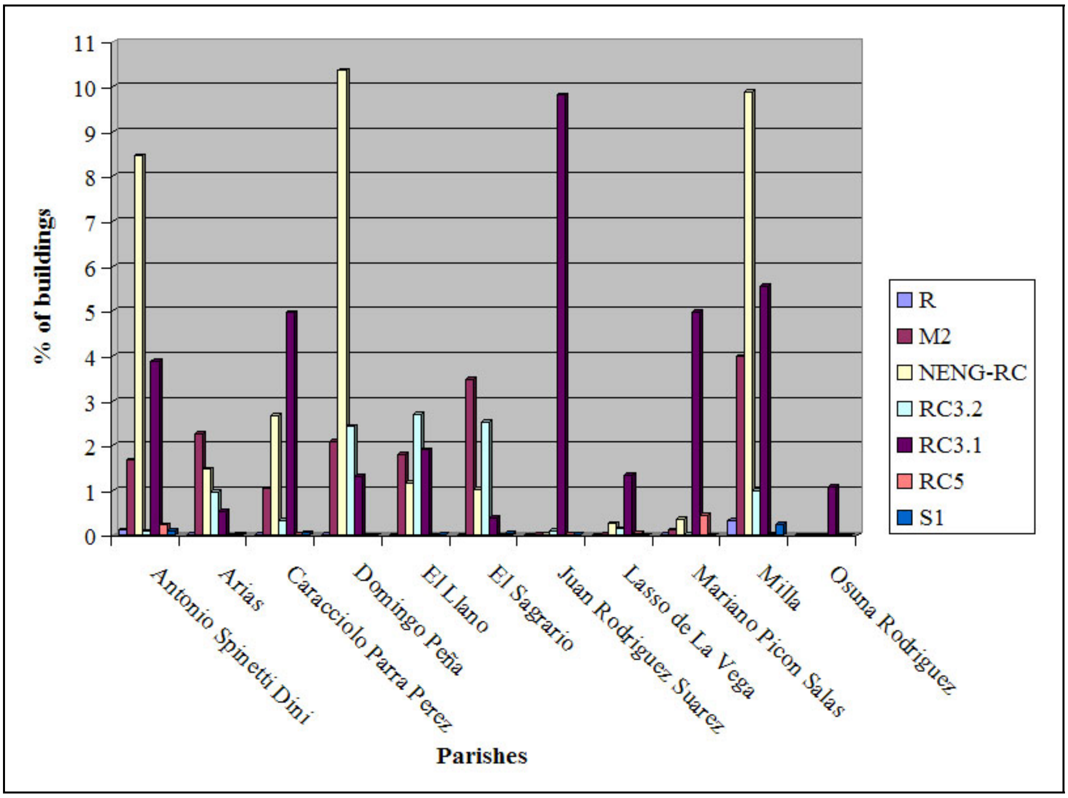


Figure 8.2: Typologies distribution in the parishes, with respect to all the buildings in the survey.

The damage grades distribution for the parishes as the percentage of the total number of buildings in each parish is shown in Figure 8.4, the least damaged parishes are those with Damage Grade 0 with percentages over 90% of the buildings, such as the Juan Rodríguez Suárez, the Lasso de La Vega, the Mariano Picón Salas and the Osuna Rodríguez parishes. The most damaged parishes are the Arias and the El Sagrario parishes, where Damage Grade 1 accounts (in both parishes) for around a 25% of the buildings, Damage Grade 2 for around a 10%, and Damage Grade 3 for near a 3% of the buildings in the parishes. The Antonio Spinetti Dini, Domingo Peña, El Llano and Milla parishes account for percentage between 15% and 20% of buildings undergoing Damage Grade 1, and around a 5% of the buildings in the parishes suffer Damage Grade 2; Damage Grade 3 accounts for percentages between 1% and 3% of the buildings in the parishes.

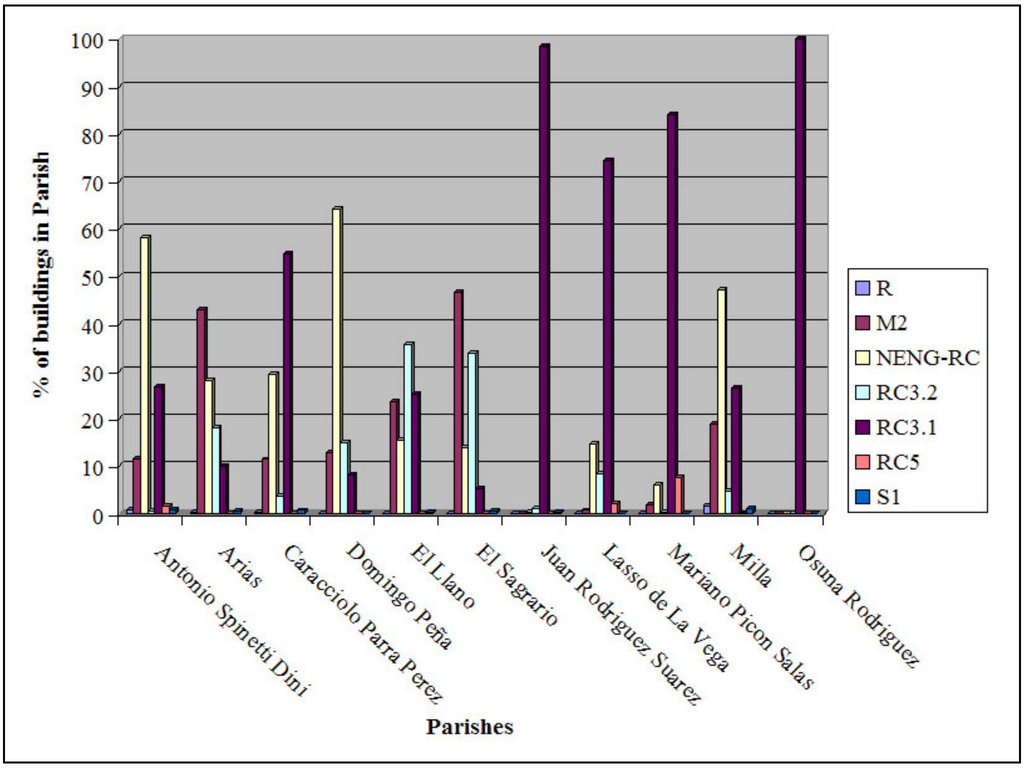


Figure 8.3: Typologies distribution within the parishes.

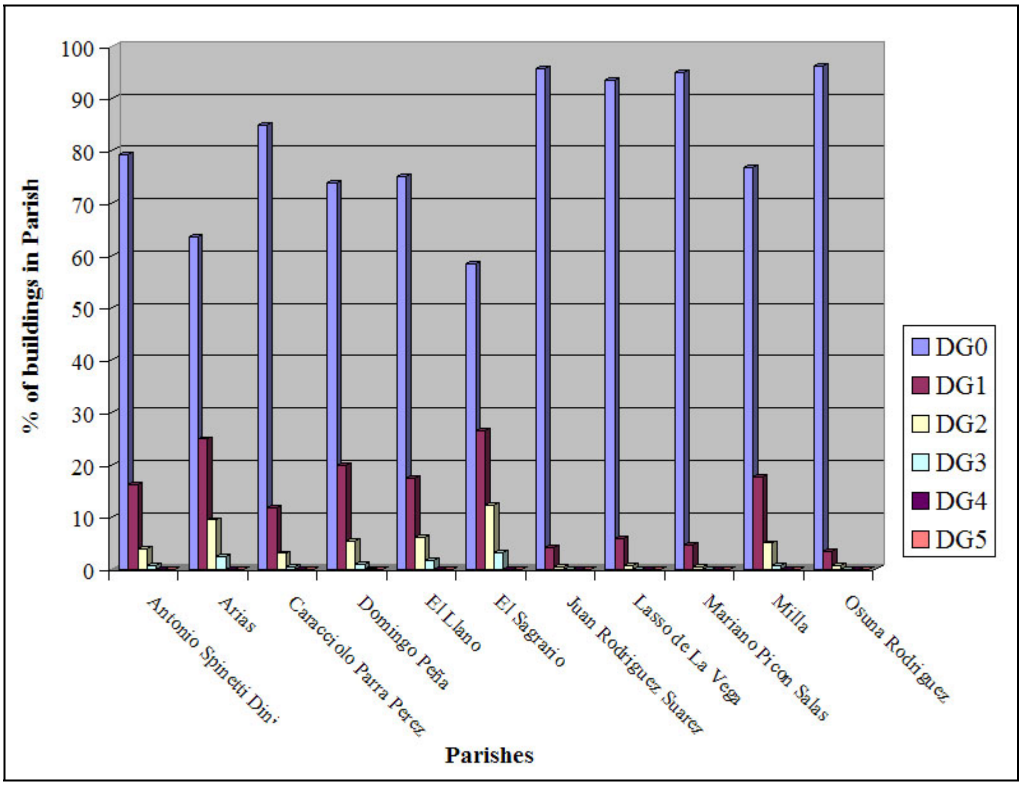


Figure 8.4: Damage Grades distribution by Parishes for Intensity *I* = VI.

8.4 Damage Scenarios for Intensity I = VII

The results of damage for all the buildings in the survey are shown in Figure 8.5 discriminated by typologies, where a 56% of the buildings remain undamaged and 44% of all buildings are damaged at different damage grades. Damage Grade 1 (Fully Operational performance level) accounts for a 24% of the buildings, the following Damage Grade 2 (Functional performance level) affects a 12% of the buildings in the survey and a 4.5% undergoes Damage Grade 3 (Life Safety performance level), Damage Grade 4 (Near Collapse performance level) affects less than a 1% of the buildings and the superior Damage Grade 5 (Collapse) does not affect any building in the survey for this scenario event.

Discriminating the damage by building typologies (see Table 8.4), the most affected typology is the NENG-RC, representing a 21% of the buildings in the survey undergoing different damage grades (from Damage Grade 1 to Grade 4), followed by the buildings belonging to the M2 typology which represent a 15% of the buildings in the survey undergoing damage grades 1 to 4. Typology RC3.1 buildings affected by damage (with damage grades 1 to 3) represent a 3.44% of the buildings in the survey followed by the RC3.2 typology buildings, with a percentage slightly lower than a 3% of the buildings in the survey. The rest of the typologies represent less than a 1% of damaged buildings in the survey each one (R typology with a 0.39% and R5 typology with a 0.05%), except for the S1 typology, where no damage is observed.

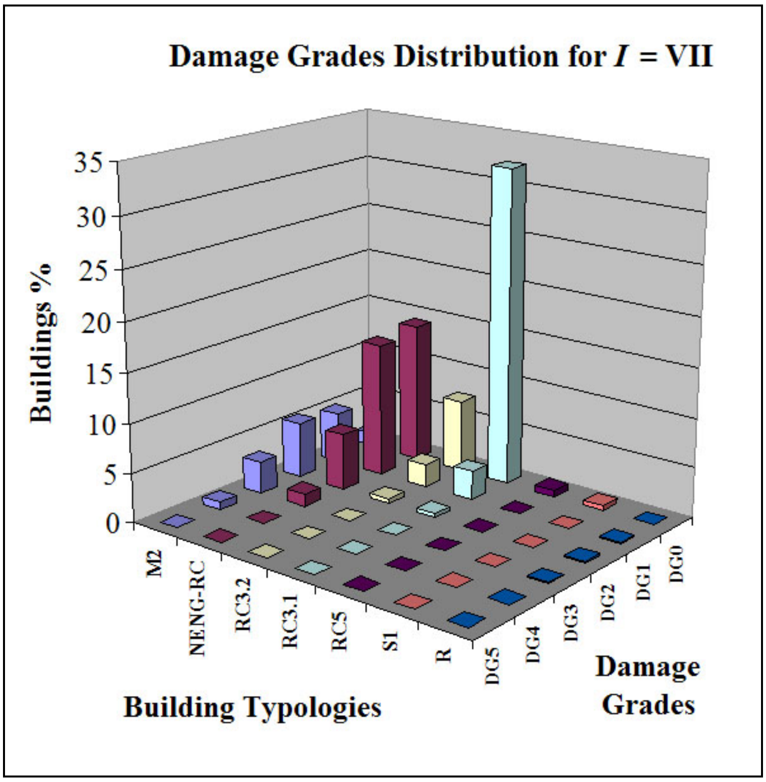


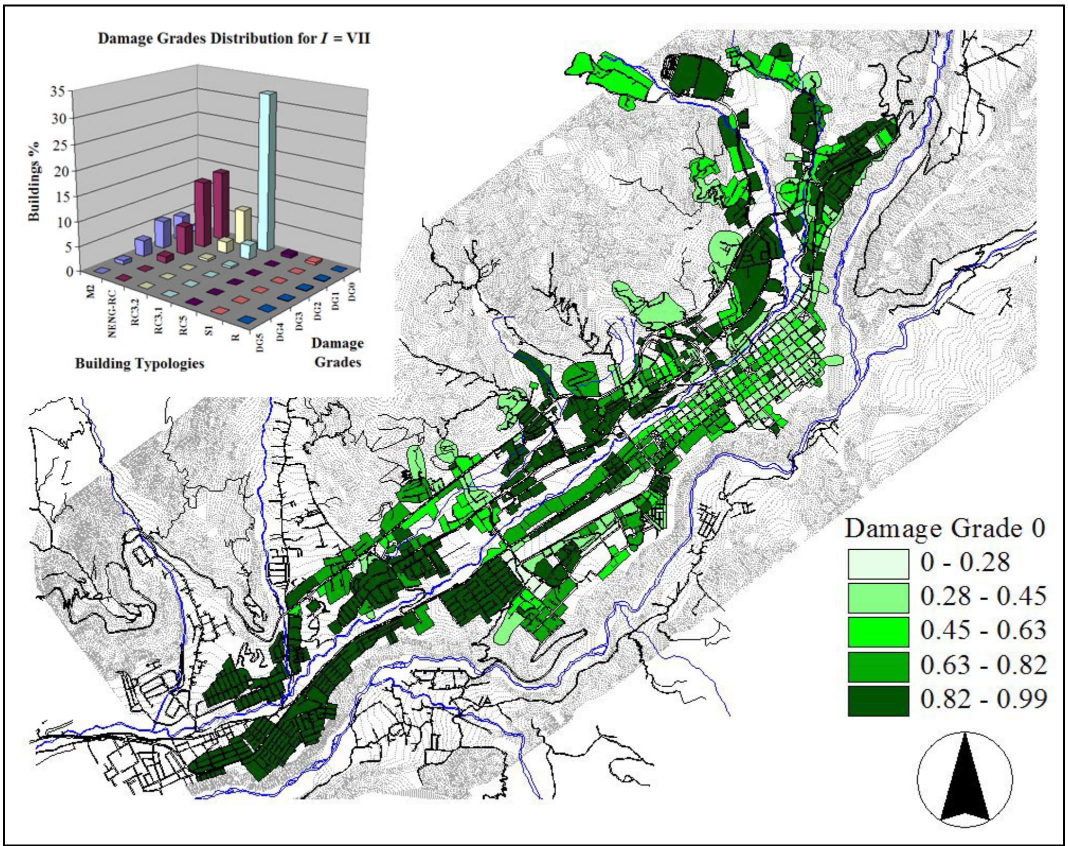
Figure 8.5: Damage grades distribution by vulnerability classes for Intensity *I* = VII.

Typology	R	M2	NENG-RC	RC3.2	RC3.1	RC5	S1	Totals
Damage Grade	%	%	%	%	%	%	%	%
Grade 0	0.02	1.36	14.23	7.4	32.21	0.7	0.52	56.44
Grade 1	0.15	5.11	13.57	2.32	3.03	0.05	0	24.23
Grade 2	0.16	5.62	5.78	0.46	0.4	0	0	12.42
Grade 3	0.07	3.16	1.28	0	0.01	0	0	4.52
Grade4	0.01	0.78	0.06	0	0	0	0	0.85
Grade5	0	0	0	0	0	0	0	0
TOTAL	0.41	16.03	34.92	10.18	35.65	0.75	0.52	98.46

Table 8.4: Damage grades distribution by typologies for *I* = VII.

8.4.1 Undamaged Buildings for *I* = VII

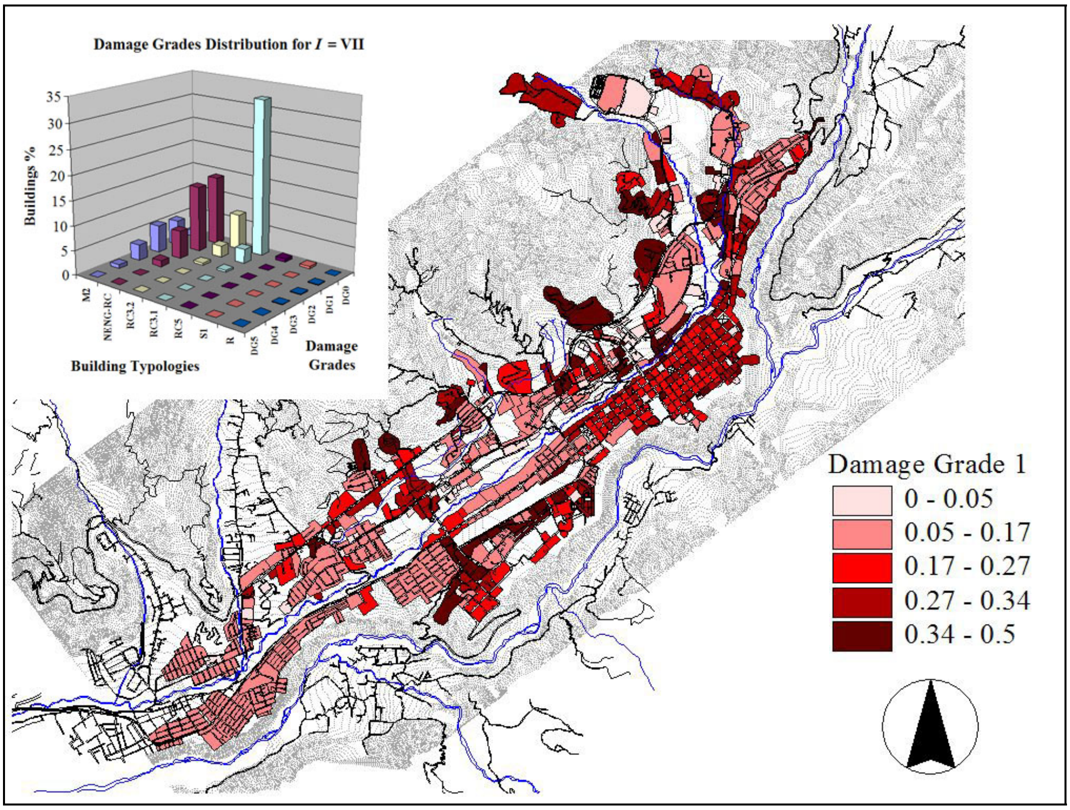
The percentage of undamaged buildings in the survey (around a 56%) is mostly concentrated in sub-sectors containing buildings belonging to the RC3.1 typology (which accounts for a 32% of all the undamaged buildings), which concentrate from an 82% and up to a 99% of undamaged buildings inside the sub-sectors (Map 8.8), configuring safer zones of the city where damage is unlikely to occur. For the rest of the sub-sectors, undamaged buildings percentages decrease (around a 50% and lower than a 28%) as the vulnerable typologies presence increase (R, M2 and NENG-RC typologies).



Map 8.8: Undamaged buildings in the survey for *I* = VII.

8.4.2 Damage Grade 1 (Fully Operational Performance Level) Distribution

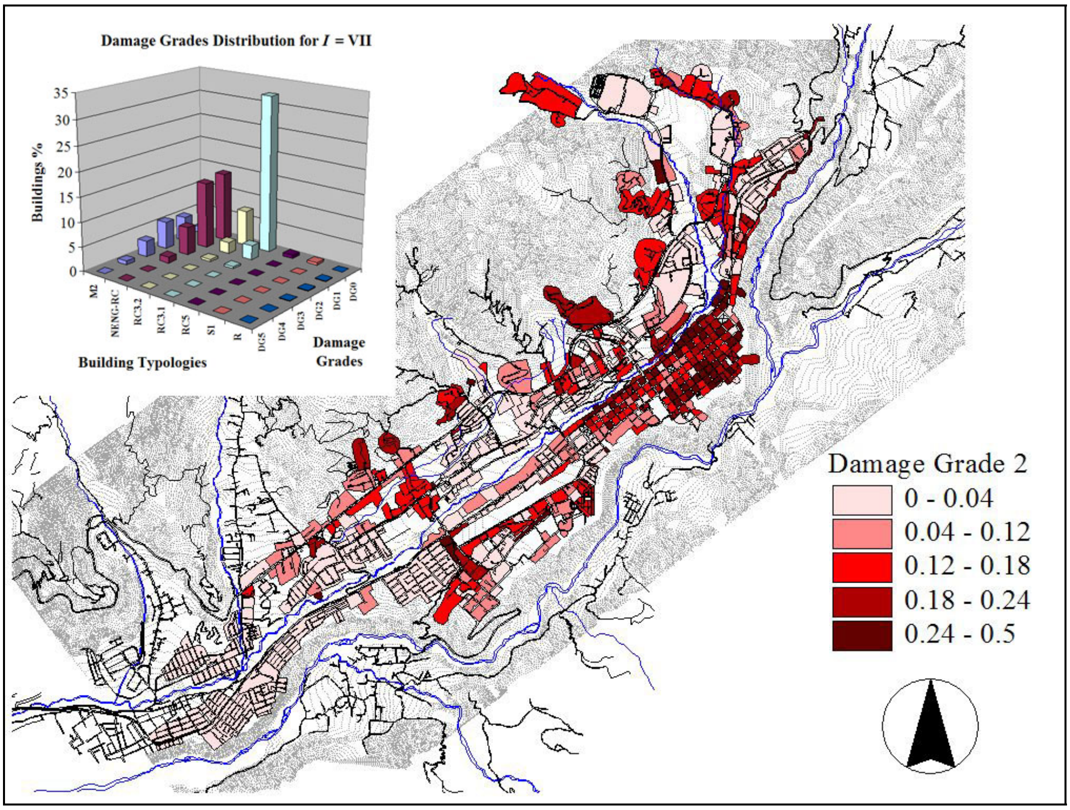
Distribution of this damage grade is shown in Map 8.9, which also contains a chart with the damage grades distribution by the typologies (upper left corner of the map). The Fully Operational Performance level is distributed over a 24% of the total buildings in the survey, where buildings belonging to the NENG-RC typology account for around a 14% of the buildings with the greater concentrations of this damage grade (from a 34% and up to a 50%) occurring mostly at the Barrios, also the Rancho typology is present in the Barrios, but the lower percentages of this typology inside the sub-sectors results in a small contribution to the general damage grade percentage, as the Rancho typology buildings undergoing Damage Grade 1 account for a 0.15% of the buildings in the survey. In downtown Mérida, the percentages of damaged buildings with Damage Grade 1 are mostly between a 17% and a 27% of the buildings inside the sub-sectors, where the building typologies M2 and RC3.2 are predominant. The sub-sectors with percentages of damaged buildings with this damage grade between 5% and 17% are mostly populated by buildings belonging to the RC3.1 typology (see Map 6.5).



Map 8.9: Damage Grade 1 (Fully Operational Performance Level) for Intensity I = VII.

8.4.3 Damage Grade 2 (Functional Performance Level) Distribution

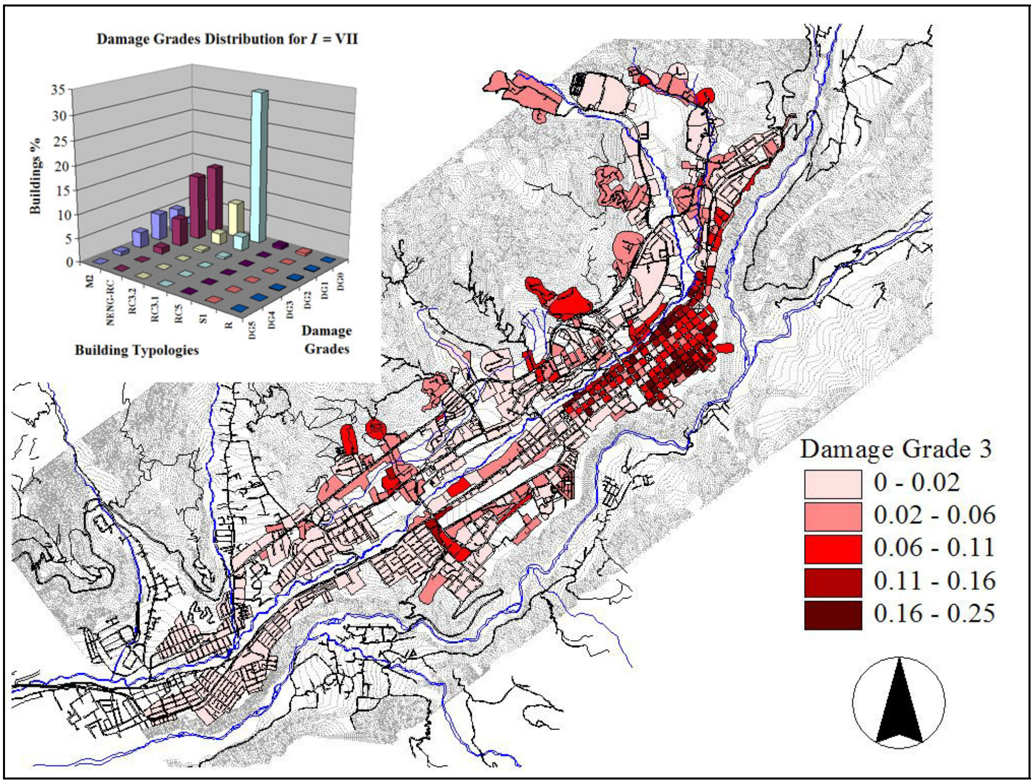
Damage Grade 2 distribution is shown in Map 8.10, the chart in the map indicates that the damage is concentrated over the typologies M2 and NENG-RC with a 5.63% and a 5.78% of the buildings, respectively. The distribution by sub-sectors shows that the occurrence of Damage Grade 2 is concentrated, with the highest percentages, in downtown Mérida (with percentages ranging between 18% and 50% of the buildings inside the sub-sectors), and in the settlements called "Barrios" (with ranges of percentage from a 12% to an 18% of buildings in the sub-sectors). These sub-sectors with higher concentrations of Damage Grade 2 are those containing greater percentages of the aforementioned typologies. The contribution of the rest of typologies to the percentage of damaged buildings is less than a 0.5% for the Rancho, RC3.1 and RC3.2 typologies, the least vulnerable typologies RC5 and S1 are not affected by this damage grade (see Table 8.4).



Map 8.10: Damage Grade 2 distribution scenario (Functional) for Intensity *I* = VII.

8.4.4 Damage Grade 3 (Life Safety Performance Level) Distribution

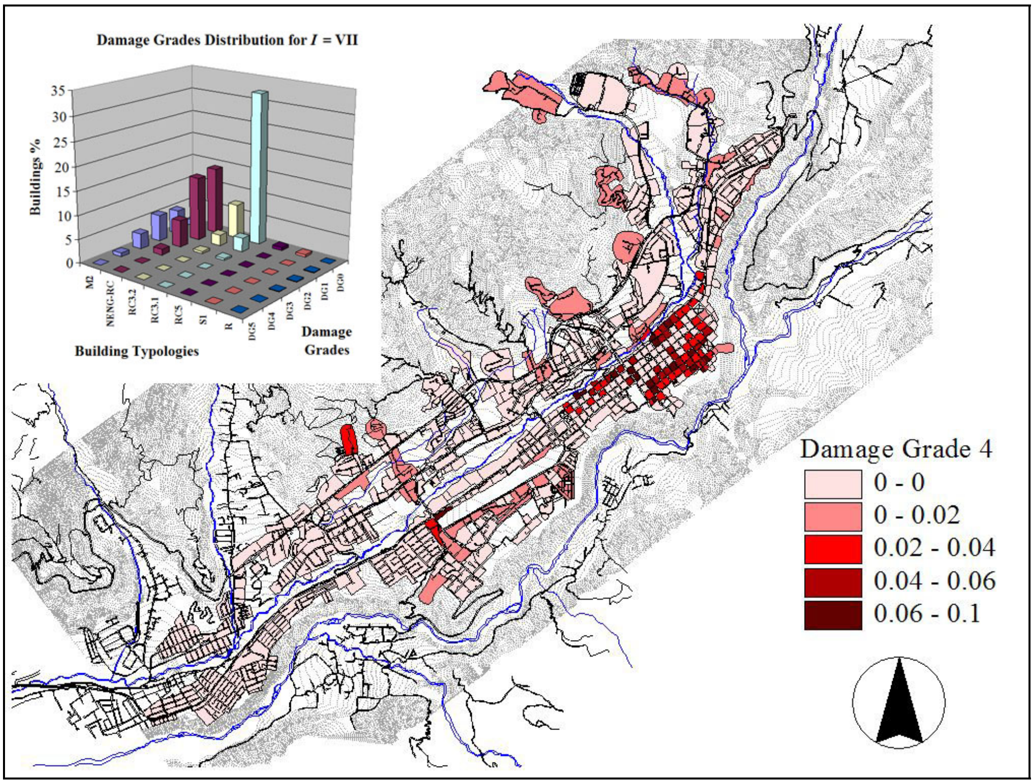
The distribution of Damage Grade 3 inside the sub-sectors is shown in Map 8.11, the typologies affected by this damage grade are typologies M2 and NENG-RC, which account for a 4.5% of all the buildings in the survey, where M2 typology represents a 3.2% of the buildings and NENG-RC a 1.28% of the buildings in the survey (see Table 8.4). Higher concentrations of damage are observed in downtown Mérida, where the greater percentages of typology M2 buildings are present. In these sub-sectors, the Life Safety Performance Level accounts for a 16% and up to a 25% of the buildings in the sub-sectors, where the buildings represent mostly the oldest buildings in the city (most of the cultural heritage architecture in Mérida). In some Barrios the percentage of damaged buildings with this damage grade account for around a 10% of the buildings in the sub-sectors.



Map 8.11: Damage Grade 3 distribution scenario (Life Safety) for Intensity *I* = VII.

8.4.5 Damage Grade 4 (Near Collapse Performance Level) Distribution

The Near Collapse Performance Level (Damage Grade 4) distribution is shown in Map 8.12, it is expected that around an 0.85 % of all the buildings in the survey undergo this damage grade; from the percentages in Table 8.4, it is verified that these buildings belong mostly to typology M2 (with a 0.78% of the buildings), followed by the NENG-RC typology accounting for a 0.06% of the buildings and by the Rancho typology with a 0.01% of the buildings undergoing this damage grade. The rest of the typologies are not affected by this damage grade. The Near Collapse performance level is mostly concentrated in downtown Mérida, with percentages ranging from a 6% to a 10% of buildings in the sub-sectors.



Map 8.12: Damage Grade 4 distribution scenario (Near Collapse) for Intensity *I* = VII.

8.4.6 Damage Grades Distribution by Parishes for Intensity *I* = VII

The damage grades distribution by parishes is shown in Figure 8.6, the percentages correspond to the number of buildings inside the parish undergoing a certain damage grade. The most affected parishes are the Arias and the El Sagrario Parishes, which are within downtown Mérida, accounting for more than 63% of buildings undergoing damage. The Arias parish presents a 3% of buildings undergoing Damage Grade 4, and the El Sagrario parish a 3.5% for the same damage grade. The least affected is the Juan Rodríguez Suárez, parish, where the percentage of damaged buildings is around 13%. The discrimination of the damage for each of the parishes is as follows:

1. Antonio Spinetti Dini: A 53% of the buildings result undamaged. Damage occurs at Damage Grades 1 to 4, no cases of Damage Grade 5 are present. Around a 29% of buildings in the parish suffer Damage Grade 1 and a 13% suffer Damage Grade 2. A percentage of 4% undergo Damage Grade 3 which means that these buildings need to be repaired and may not be occupied until repairs are performed. The Damage Grade 4 (Near Collapse Performance Level) accounts for a 0.63% of all the buildings in the parish, where repairs may not be practical.
2. Arias: Damage Grade 0 or no damage accounts for a 37% of the buildings in the parish. Damage Grade 1 occurs in a 29% of the buildings and Damage Grade 2 presents a percentage of 21%. Damage Grade 3 accounts for a 10% of buildings, which may not be occupied until repairs are performed. Very heavy damage (Damage Grade 4) occurs in around a 3% of buildings in the parish, where the buildings represent a hazard to occupants and repairs may not be practical.
3. Caracciolo Parra: Undamaged buildings account for a 67% of the buildings in the parish. The lower damage grades 1 and 2 represent a 21% and a 9% of the buildings, respectively. Damage Grade 3 accounts for a 3% of buildings which need repairs and may not be occupied until the repairs are performed. The buildings with Damage Grade 4 or Near Collapse Performance Level represent a 0.41% of buildings in the parish.
4. Domingo Peña: The Damage Grade 0 or no damage represents a 44% of the buildings in the parish. The lower state of damage (Damage Grade 1) accounts for a 33% of the buildings in the parish. Damage Grade 2 is accounted for a17% of buildings which need to be repaired representing no hazard to the occupants. Buildings with a Life Safety Performance Level (Damage Grade 3) range up to a 5.5% of the buildings which need repairs and may have to be unoccupied for this purpose. Around a 1% of the buildings in the parish are near collapse, and represent a hazard to occupants (Damage Grade 4).
5. El Llano: More than a half of the buildings inside the parish remain undamaged (54% of buildings). Damage Grades 1 and 2 occur in a 38% of the buildings in the parish, specifying for each Damage Grade, the contents are: a 24% of buildings undergoing Damage Grade 1, and a 14% of the buildings undergoing Damage Grade 2, which may be repaired at convenience of the occupants. Around a 6% of the buildings suffer Damage Grade 3, which need to be repaired unoccupied. The Damage Grade 4 (Near Collapse) accounts for a 1.5 % of the buildings in the parish.
6. El Sagrario: Over a third part of all the buildings (34%) in the parish remain undamaged. Damage Grades 1 and 2 are predominant in this parish, with a 27% and a 22% of the buildings, respectively; this leads towards expecting repairs over 49% of buildings, where around the half of this percentage of buildings need to be repaired at convenience of the occupants. Damage Grade 3 represents a 13% of buildings, which

need to be repaired without occupants. Near Collapse Performance Level is observed in a 3.5% of the buildings undergoing Damage Grade 4.

7. Juan Rodríguez Suárez: The undamaged buildings in this parish range up to an 87% of the buildings. Only Damage Grades 1, 2, and 3 are expected to occur in this parish, with an 11%, a 2%, and a 0.12% of the buildings, respectively. Only a 2% of buildings may need to be repaired at the convenience of the occupants and a 0.12% need to be repaired without occupancy. Damage grades 4 and 5 are not observed as affecting any of the buildings in the parish.
8. Lasso de La Vega: The undamaged buildings in the parish account for an 82% of the buildings. Only Damage Grades 1, 2, and 3 are expected to occur in this parish, with a 13%, a 4%, and a 0.7% of the buildings, respectively. Damage grades 4 and 5 are not observed in this parish.
9. Mariano Picón Salas: An 87 % of the buildings in the parish remain undamaged. Only Damage Grades 1, 2, and 3 are expected to occur in this parish, with a 10%, a 2.4%, and a 0.4% of the buildings, respectively. The superior damage grades 4 and 5 do not occur in this parish.
10. Milla: Around a half of the buildings in the parish (51%) remain undamaged, damage grades from 1 to 4 occur in the rest of the buildings distributed as: a 28% of the buildings suffer Damage Grade 1, around a 15% is affected by Damage Grade 2, a 5% undergo Damage Grade 3, and a 0.67% is affected by Damage Grade 4.
11. Osuna Rodríguez: The percentage of undamaged buildings accounts for a 91% of the buildings in the parish, where only damage grades 1 and 2 occur with an 8% and a 1%, of the buildings in the parish, respectively.

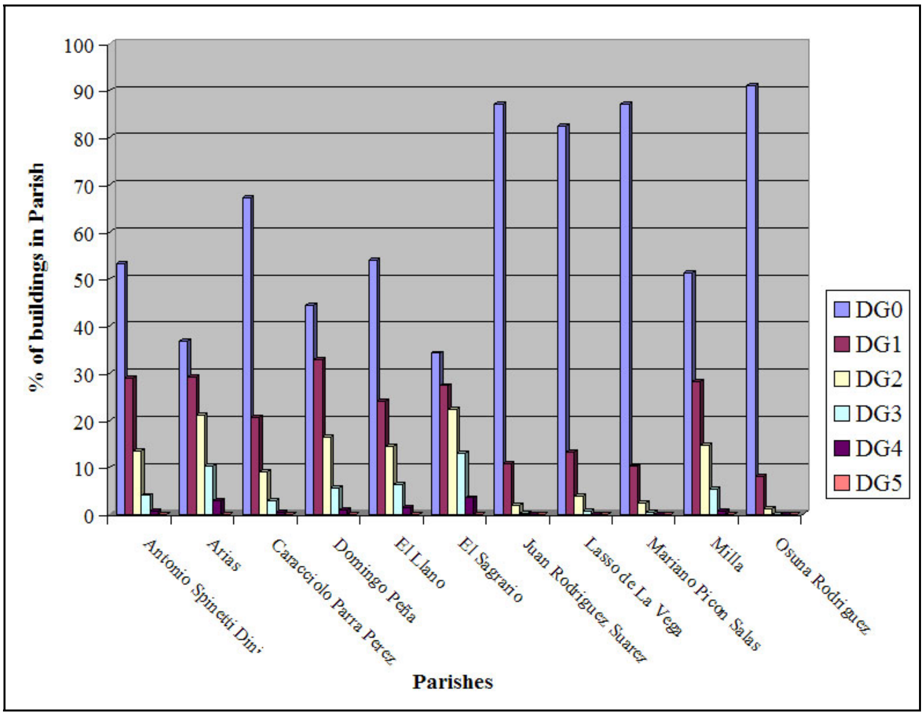


Figure 8.6: Damage Grades distribution by Parishes for Intensity *I* = VII

8.5 Damage Scenarios for Intensity I = VIII

The damaged buildings percentage by typologies with respect to all the buildings in the survey is shown in Figure 8.7, where around a 67% of all buildings, undergo damage at different damage grades (Table 8.5). The buildings belonging to the seven typologies in the survey result damaged with different damage grades. Damage Grade 1 (Fully Operational) is generated in around a 26% of buildings and Damage Grade 2 (Functional) accounts for around a 20% of buildings. Superior damage grades are generated in about a 19% of the buildings, where a 13% undergo Damage Grade 3 (Life Safety Performance Level), a 5.5% suffer Damage Grade 4 (Near Collapse) and less than a 1% is affected with Damage Grade 5 (Collapse).

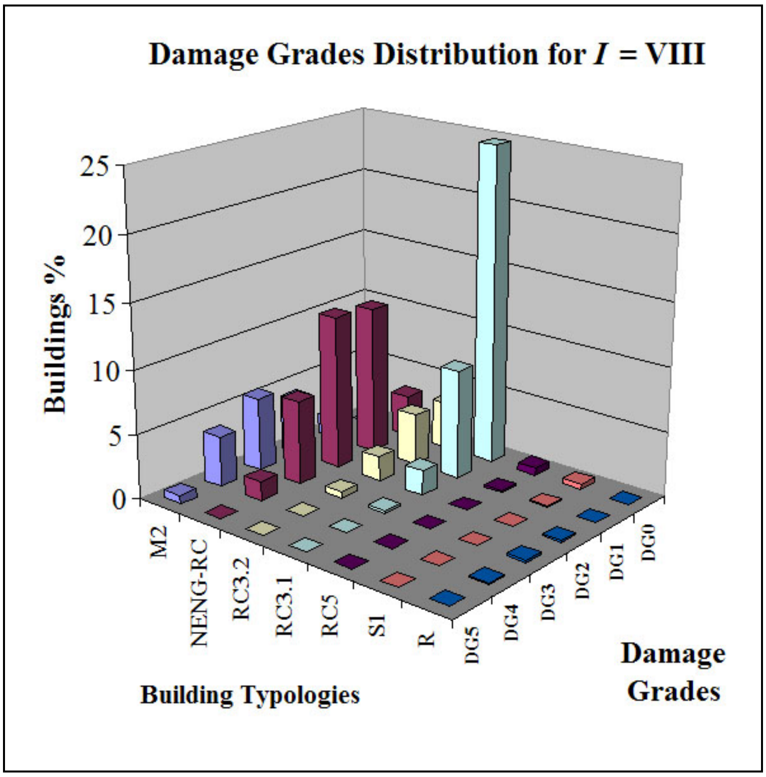


Figure 8.7: Damage grades distribution by vulnerability classes for Intensity *I* = VIII.

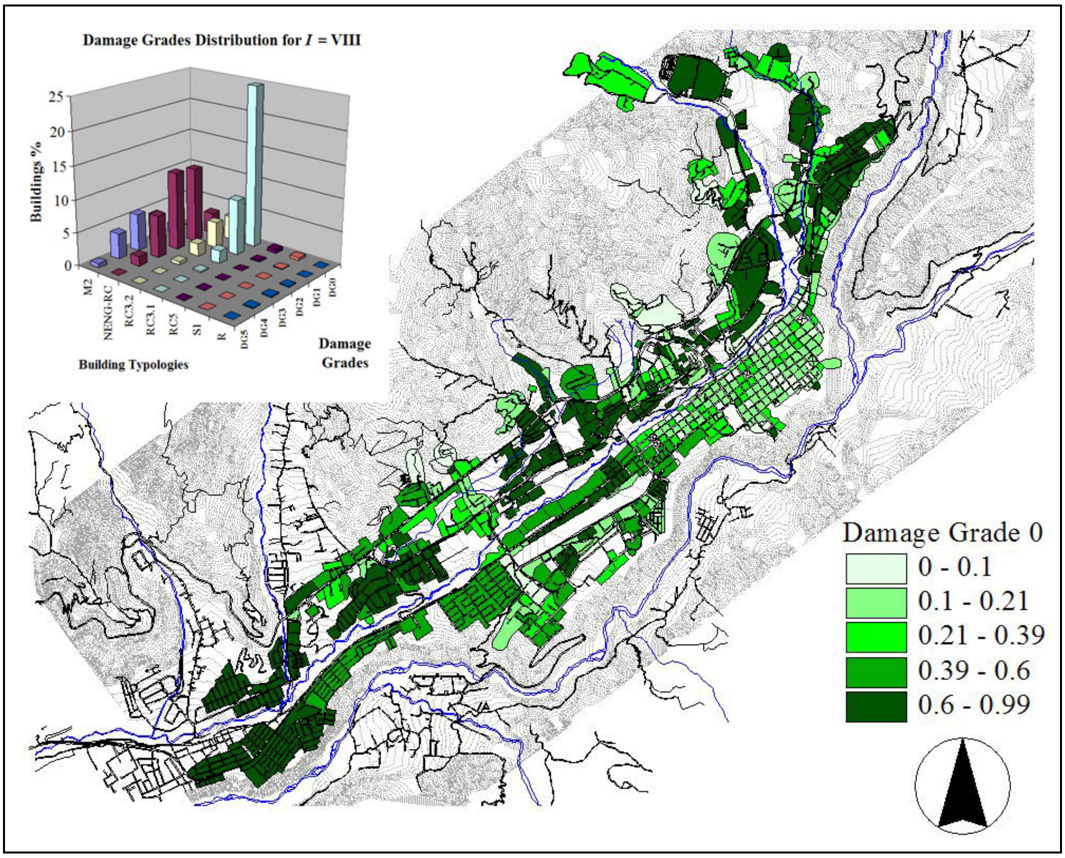
The buildings belonging to the NENG-RC typology account for the greater percentages of damage, as it is one of the most common building typologies in the survey, with damaged buildings representing a 31.5% of all the buildings (with damage grades from 1 to 5), followed by buildings belonging to the M2 typology with a 16% of buildings (with damage grades from 1 to 5). Typology RC3.1 buildings account for an 11% of all buildings in the survey undergoing damage grades 1 to 3. The rest of the typologies represent around a 7% of the buildings in the survey, where RC3.2 buildings account for a 6.4% (with damage grades from 1 to 3), typology R buildings undergoes damage grades 2 to 5 accounting for a 0.4%, the buildings belonging to typology RC5 for a 0.2% of all buildings in the survey (with damage grades from 1 to 3), and typology S1 only affected by Damage Grade 1 and representing less than a 0.1%.

Typology	R	M2	NENG-RC	RC3.2	RC3.1	RC5	S1	Totals
Damage Grade	%	%	%	%	%	%	%	%
Grade 0	0	0.02	3.27	3.63	24.79	0.59	0.44	32.74
Grade 1	0.03	1.62	11.53	3.99	8.52	0.15	0.08	25.92
Grade 2	0.14	4.39	11.94	1.89	1.95	0.02	0	20.33
Grade 3	0.17	5.67	6.51	0.48	0.2	0	0	13.03
Grade4	0.09	3.92	1.51	0	0	0	0	5.52
Grade5	0	0.62	0.02	0	0	0	0	0.64
TOTAL	0.43	16.24	34.78	9.99	35.46	0.76	0.52	98.18

Table 8.5: Damage grades distribution by vulnerability classes for *I* = VIII.

8.5.1 Undamaged buildings for I = VIII

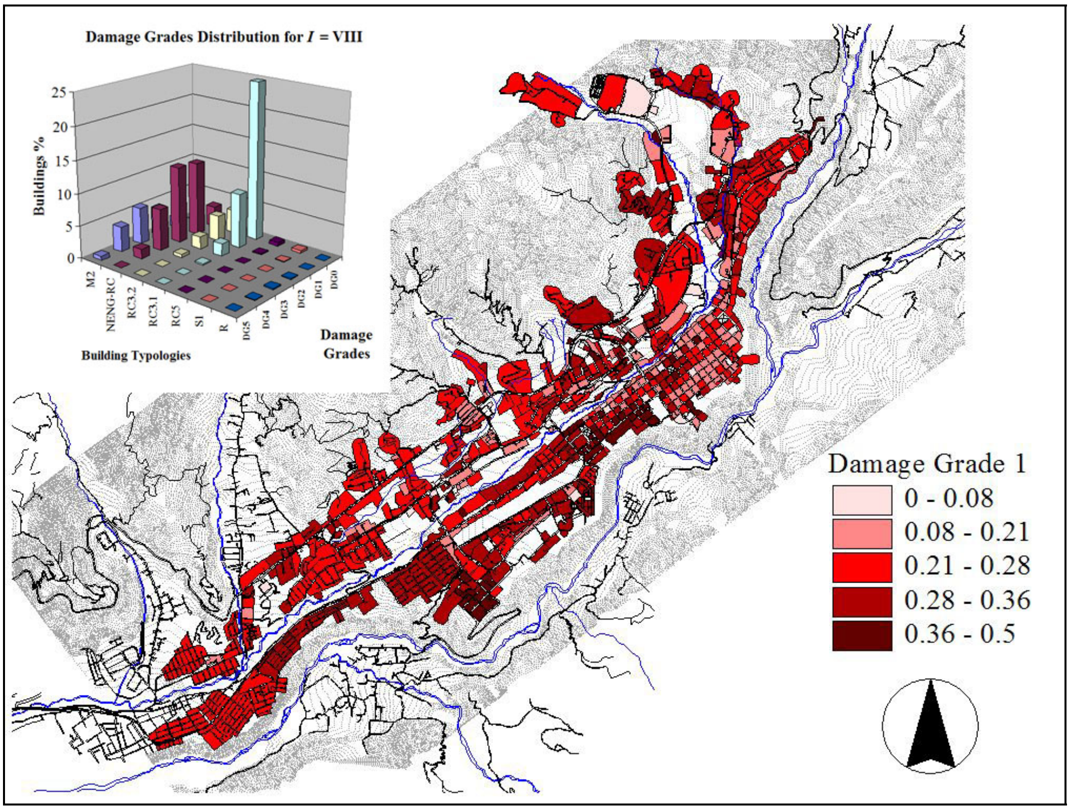
The percentage of undamaged buildings in the survey is around a 33% of all buildings (Table 8.5), mostly concentrated in sub-sectors where the RC3.1 typology is predominant (accounting for a 25% of the undamaged buildings). In Map 8.13, the distribution of Damage Grade 0 or no damage is shown for the sub-sectors in the survey, where the greater concentrations of this damage grade (60% to 90%) are mostly located at the northeastern and southwestern zones of the city, and also at the northern-center side of the Albarregas River. Percentages as low as the 1% and up to a 21% are observed mostly downtown Mérida and in the locations called “Barrios”, where the predominant building typologies are M2 and NENG-RC, respectively.



Map 8.13: Undamaged buildings for Intensity *I* = VIII.

8.5.2 Damage Grade 1 (Fully Operational Performance Level) Distribution

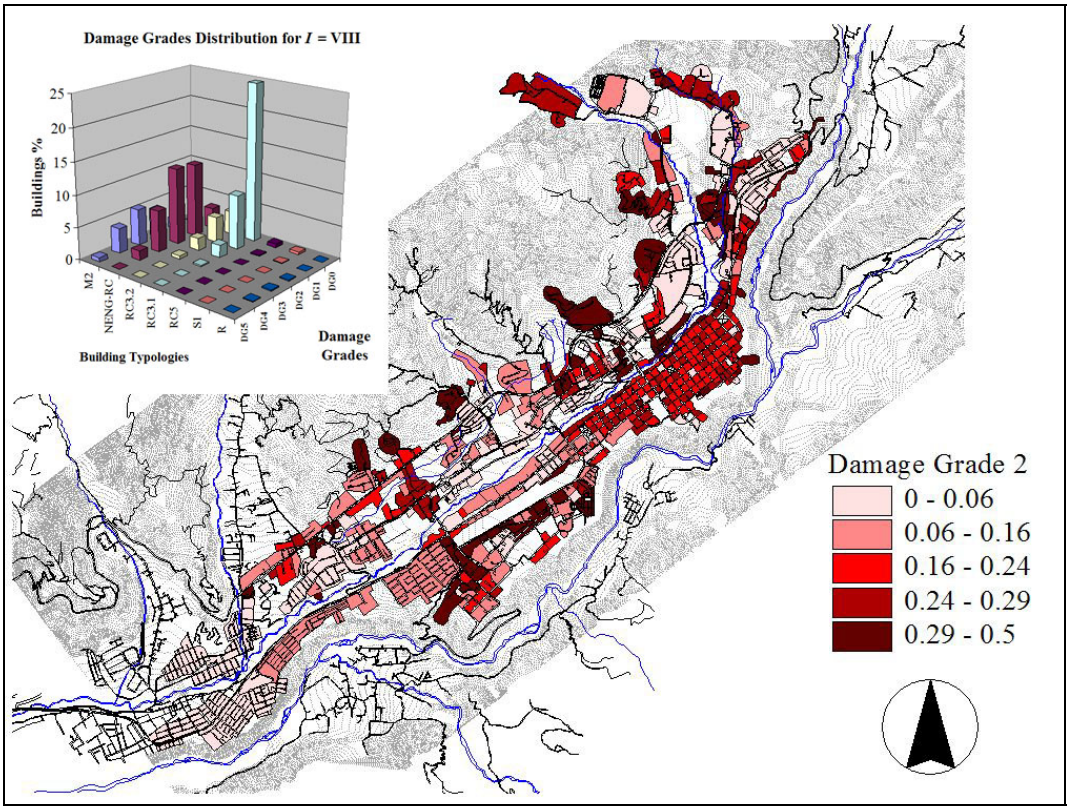
For the scenario Intensity *I* = VIII the Damage Grade 1 distribution by sub-sectors is shown in Map 8.14, the percentage of buildings in the survey undergoing this damage grade is around a 26%, affecting all typologies in the survey, where the greater percentages of this damage grade occur in buildings belonging to typologies NENG-RC (with an 11.5% of the buildings) and RC3.1 (with an 8.5% of the buildings); the damage grade concentration is then observed (from 21% and up to a 50% of buildings) in sub-sectors that contain mostly these typologies.



Map 8.14: Damage Grade 1 distribution scenario (Fully Operational) for Intensity *I* = VIII.

8.5.3 Damage Grade 2 (Functional Performance Level) Distribution

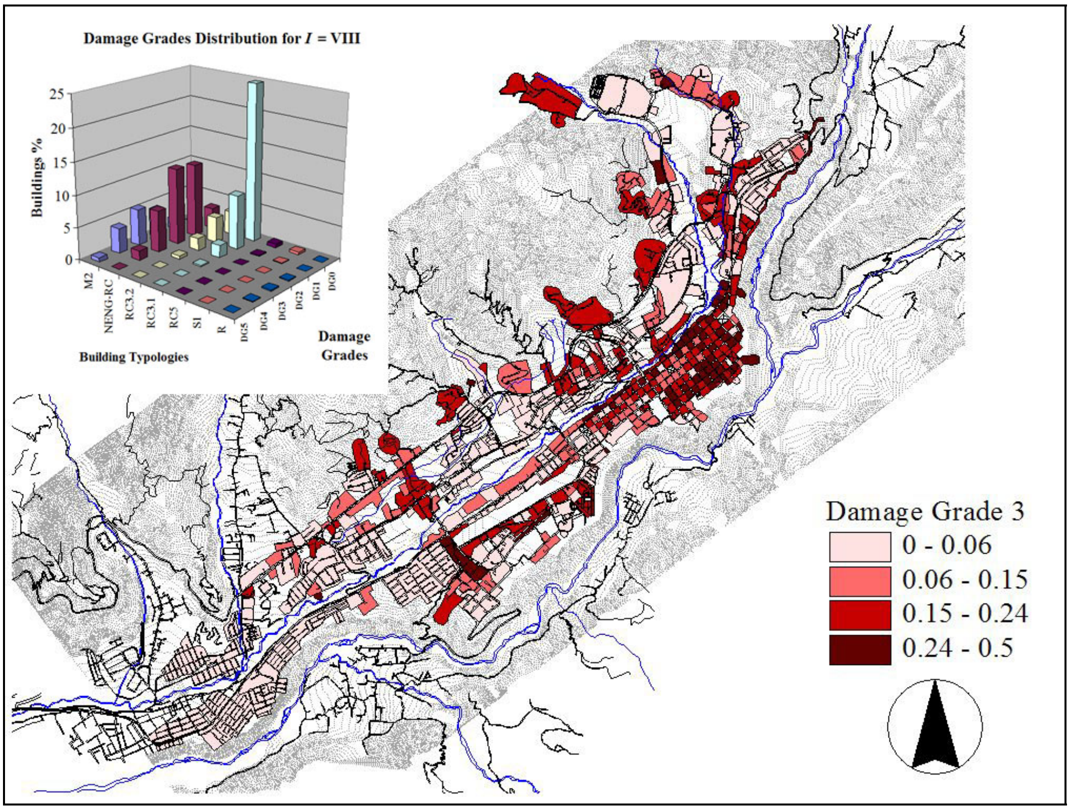
The Damage Grade 2 distribution by sub-sectors is shown in Map 8.15, the total damage grade percentage is around 20% affecting all the typologies in the survey, except typology S1 (which results undamaged at this damage grade). The percentages for each typology undergoing this damage grade are: around a 0.1% for the Rancho typology buildings, around a 4% for the M2 typology buildings, around a 12% for NENG-RC, around a 2% for the RC3.2 and RC3.1 typology buildings and a 0.02% for typology RC5 buildings (see Table 8.5). The greater concentrations of this damage grade (29% to 50% of the buildings in the sub-sectors), are produced in locations where buildings belonging to the NENG-RC typology are the most common (identified as Barrios).



Map 8.15: Damage Grade 2 distribution scenario (Functional) for Intensity *I* = VIII.

8.5.4 Damage Grade 3 (Life Safety Performance Level) Distribution

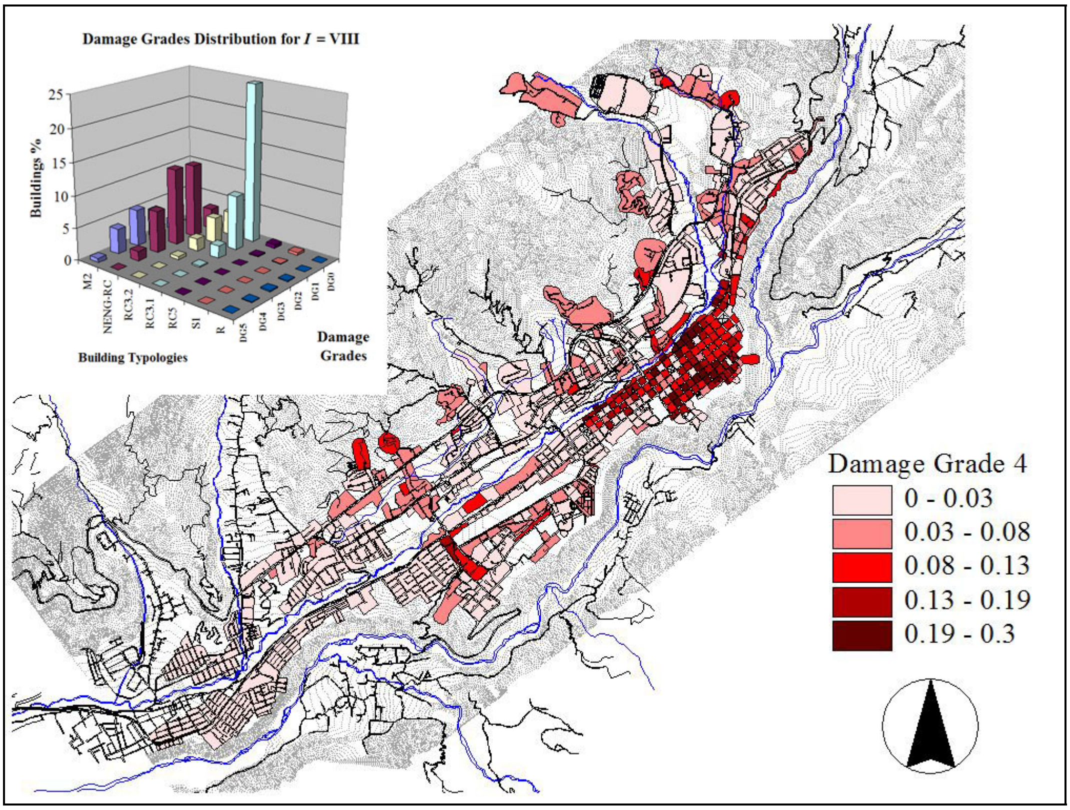
The percentage of buildings with Damage Grade 3 account for a 13% of all the buildings in the survey affecting buildings belonging to the R, M2, NENG-RC, RC3.2 and RC3.1 typologies, with percentages of 0.2% of the buildings in the survey for the Rancho typology, 5.7% for the M2, 6.5% for the NENG-RC.0.5% for the RC3.2, and 0.2% for the RC3.1 typology (Table 8.5). As the most affected typologies are the M2 and the NEN-RC typologies, greater concentrations of the damage grade by sub-sector, up to a 24% and up to a 50% of the buildings, are produced mostly in the “Barrios” and downtown Mérida, respectively.



Map 8.16: Damage Grade 3 distribution scenario (Life Safety) for Intensity *I* = VIII.

8.5.5 Damage Grade 4 (Near Collapse Performance Level) Distribution

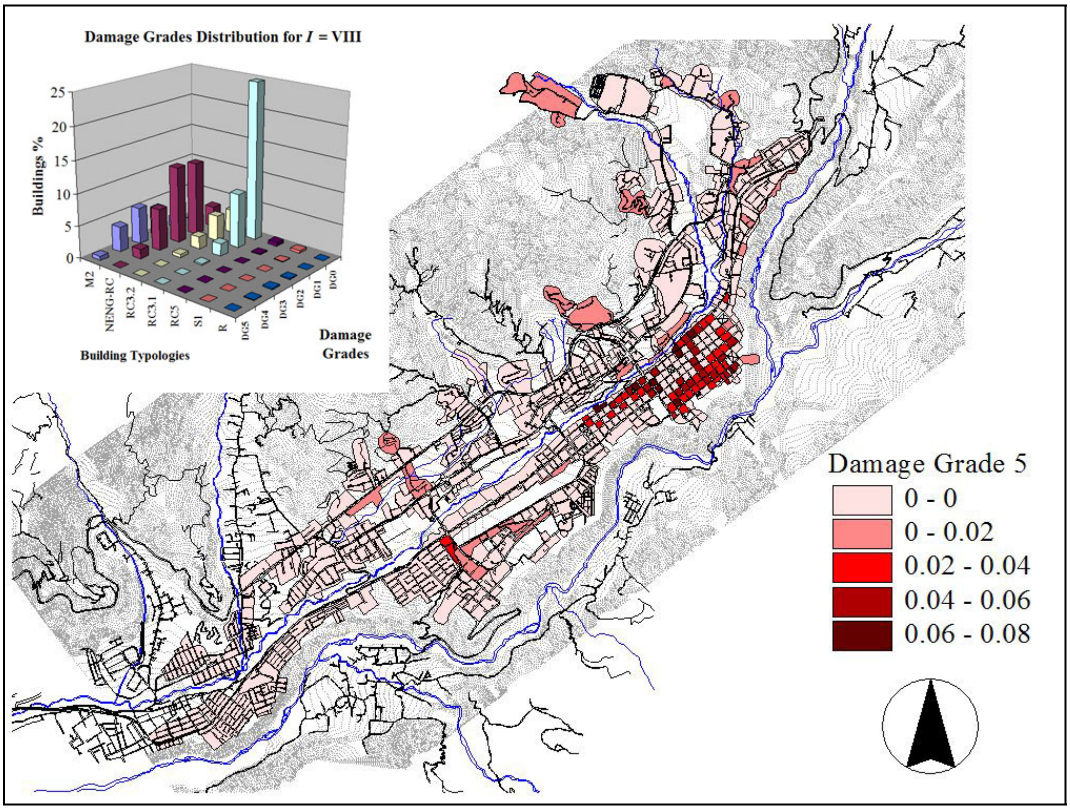
Damage Grade 4 accounts for a 5.5% of all the buildings in the survey, the buildings undergoing this damage grade belong to typologies R, M2 and NENG-RC, with percentages of 0.1%, 4% and 1.5% of all the buildings, respectively (see chart in Map 8.17 and Table 8.5). Damage grade is concentrated mostly in downtown Mérida, with percentages up to a 50% of damaged buildings in the sub-sectors, where the higher percentages respond to the greater contents of typology M2 buildings within these.



Map 8.17: Damage Grade 4 distribution scenario (Near Collapse) for Intensity *I* = VIII.

8.5.6 Damage Grade 5 (Collapse) Distribution

This damage grade affects only M2 and NENG-RC buildings with around a 0.6% of all the buildings in the survey (see Table 8.5), the higher concentrations of collapse are produced in downtown Mérida, with percentages up to an 8% of collapsed buildings in the sub-sectors (Map 8.18). The buildings affected by this damage grade in downtown Mérida, are mostly old buildings (back to the 19^{th} century or the early 20^{th} century), where some have a historic value to the city (cultural heritage).



Map 8.18: Damage Grade 5 distribution (Total Collapse) for Intensity *I* = VIII.

8.5.7 Damage Grades Distribution by Parishes for Intensity *I* = VIII

In Figure 8.8, the damage grades distribution by parishes is shown as the percentage of buildings in the parish undergoing a certain damage grade. The most affected parishes by damage at different damage grades, are ordered by increasing percentage of damaged buildings, and are: the El Llano parish (71% of the buildings), the Antonio Spinetti Dini parish (72% of the buildings), the Milla parish (73% of the buildings), the Domingo Peña parish (82% of the buildings), the Arias parish (84% of the buildings), and the El Sagrario parish (with an 86% of the buildings damaged). In the rest of the parishes the damaged buildings percentage range from 28% to 55% of the buildings in the parishes.

The most affected parishes by damage grade 3 to 5 are the Arias and the El Sagrario parishes, which account for a 36% and a 40% of damaged buildings with these damaged grades, respectively. The occurrence of Damage Grade 5 (collapse) affects mostly the Arias, the El Llano, and the El Sagrario parishes with percentages of 2%, 1.5% and 3% of the buildings in the parishes, respectively. The discrimination of the damage grades distribution by parishes is as follows:

1. Antonio Spinetti Dini: The undamaged buildings in the parish account for a 28% of the buildings. Damage Grade 1 affects a 28% of the buildings in the parish, and Damage Grade 2 (Functional Performance Level) accounts for a 25% of the buildings in the parish. Damage Grade 3 (Life Safety Performance Level) is expected to occur in 15% of the buildings. Around a 5% of buildings undergo Damage Grade 4 (Near Collapse Performance Level), and a 0.3% of buildings in the parish collapse (Damage Grade 5).
2. Arias: The percentage of buildings unaffected by the scenario event accounts for a 16% of the buildings in the parish. Slight damage (Damage Grade 1) occurs in around a 23% of the buildings, a 25% undergoes Damage Grade 2 with repairable damage at convenience of the users, and Damage Grade 3 accounts for a 22% of the buildings in the parish, which need to be repaired most probably without occupancy of the buildings. Damage Grade 4 accounts for a 12% of the buildings in which repairs may probably not be practical, and, a 2% of buildings in the parish collapse.
3. Caracciolo Parra Pérez: Undamaged buildings represent around a 45% of the buildings in the parish. Around a 25% of buildings in the parish suffer Damage Grade 1, around an 18% undergoes repairable damage (Damage Grade 2), and a 10% is expected to suffer Damage Grade 3 and most probably need to be unoccupied until repairs are practiced. A percentage of buildings around a 3% suffer Damage Grade 4 (Near Collapse Performance Level), and, around a 0.2% of buildings in the parish collapse.
4. Domingo Peña: An 18 % of the buildings in the parish remain undamaged. Around a 29% of the buildings in the parish undergo Damage Grade 1, a 28% Damage Grade 2 and an 18% Damage Grade 3. Damage Grade 4 (Near Collapse Performance Level) occurs in a 6% of buildings, and, around a 0.6% of buildings suffers Damage Grade 5 (collapse).
5. El Llano: Undamaged buildings account for a 29% of the buildings in the parish. Around a 28% of buildings in the parish undergo Damage Grade 1, repairable damage is present in a 20% of buildings with Damage Grade 2, and a 14% of buildings undergo Damage Grade 3. A percentage of buildings around 8% may not be repairable suffering Damage Grade 4, and a 1.5% of buildings collapse (Damage Grade 5).
6. El Sagrario: Around a 14% of all the buildings in the parish remain undamaged. Damage Grade 1 accounts for a 22% of the buildings. Damage Grades 2 and 3 are predominant in this parish, with a 23% and a 22.4% of the buildings, respectively; this leads towards expecting repairs over 45% of buildings, where around the half of this percentage of buildings need to be repaired without occupants. Damage Grade 4 (Near collapse performance level) represents a 15% of buildings, and Damage Grade 5 affects a 3% of the buildings in the parish.
7. Juan Rodríguez Suárez: The undamaged buildings in the parish represents around the 64% of the buildings. The predominant damage grade in the parish is Damage Grade 1 with around a 27% of the buildings, Damage Grade 2 accounts for around an 8%, Damage Grade 3 for a 1.4%, and Damage Grade 4 accounts for less than a 1% of the buildings. No buildings with collapse damage state (Damage Grade 5) are present in the parish.
8. Lasso de La Vega: The 60% of the buildings in the parish remain undamaged. Around a 25% undergo Damage Grade 1, and an 11% Damage Grade 2. A percentage of 3.4% is damaged at Damage Grade 3 and around a 0.7% undergoes Damage Grade 4 (Near Collapse).
9. Mariano Picón Salas: Undamaged buildings account for a 67% of the buildings in the parish. A percentage of 23% suffer slight damage (Damage Grade1) and a 7% of the

buildings in the parish suffer moderate damage (Damage Grade 2). Damage Grade 3 is present in around a 2% of the buildings, and Damage Grade 4 accounts for around a 0.4% of the buildings in the parish. No collapsed buildings are observed in the distribution.

10. Milla: Around a 27% of the buildings in the parish remain undamaged. Damage Grade 1 accounts for a 26.5% of the buildings in the parish and Damage Grade 2 for around a 24%. The Life safety performance level (Damage Grade 3) accounts for around a 16% and Damage Grade 4 (Near Collapse) for a 6% of the buildings in the parish. Damage Grade 5 (Collapse) accounts for a 0.5% of the buildings.
11. Osuna Rodríguez: A 72% of the buildings in the parish remain undamaged. Damage grades 1 to 3 are expected to occur in this parish, with a 22% of buildings for Damage Grade 1, a 5% for Damage Grade 2 and around a 0.5% for Damage Grade 3. The superior damage grades 4 and 5 are not expected to occur in this parish.

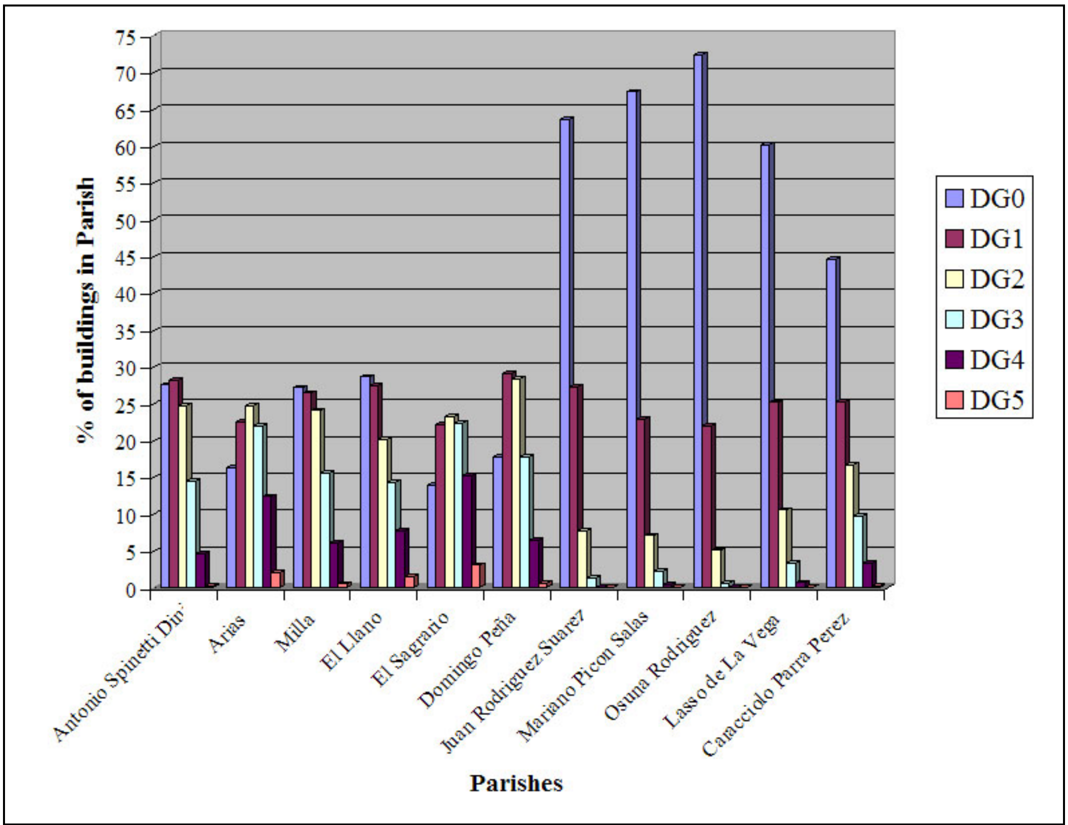


Figure 8.8: Damage Grades distribution by parishes for Intensity *I* = VIII.

8.6 Damage Scenarios for Intensity I = IX

The distribution of damage, by damage grades and vulnerability classes as percentages of the all the number of buildings in the survey, is shown in Figure 8.9. The resulting damage for all the buildings is around an 85% of all the buildings in the survey damaged with different damage grades. The lower Damage Grades 1 and 2 account for around a 21% and a 22% of the buildings, respectively. Superior damage grades account for around a 42% of all buildings, where Damage Grade 3 (Life Safety Performance Level) affects a 21%, Damage Grade 4 (Near Collapse) a 15%, and Damage Grade 5 (Collapse) is present in a 5.6% of the buildings in the survey. The results indicate that around a 21% of all the buildings may undergo collapse in two different fashions: a 15% of buildings suffer very heavy damage (partial collapse) that may not be repairable, and the rest may undergo total or near total collapse.

The greater percentage of damage is accumulated in buildings belonging to the NENG-RC typology, representing around a 35% of all buildings (with predominant damage grades 2 and 3), followed by the RC3.1 typology buildings accounting for a 24% of all buildings, with predominant damage grade 1 and 2 (Table 8.6). The M2 typology buildings accounts for a 16% of all buildings (with predominant damage grades 4 and 5). The rest of the typologies account for a 10.5% of the buildings damaged, where: the Rancho typology buildings represents a 0.45% of buildings (with predominant damage grades 4 and 5), the RC3.2 typology buildings around a 9% (with predominant damage grades 1 and 2), the RC5 typology buildings a 0.5% of all buildings in the survey (with predominant damage grades 1 and 2), and, the S1 typology buildings a0.2% of the buildings in the survey (with predominant damage grades 1 and 2).

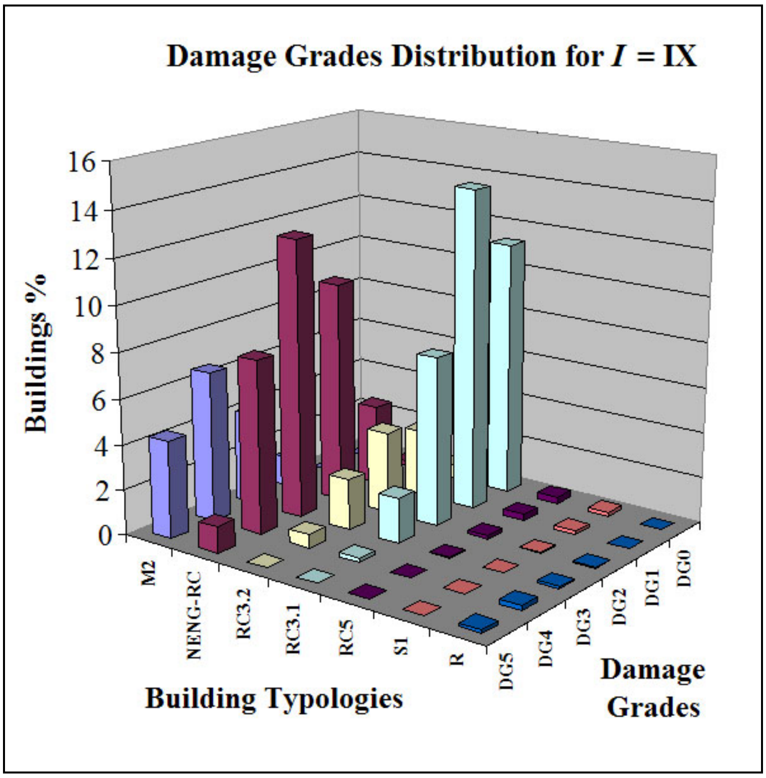


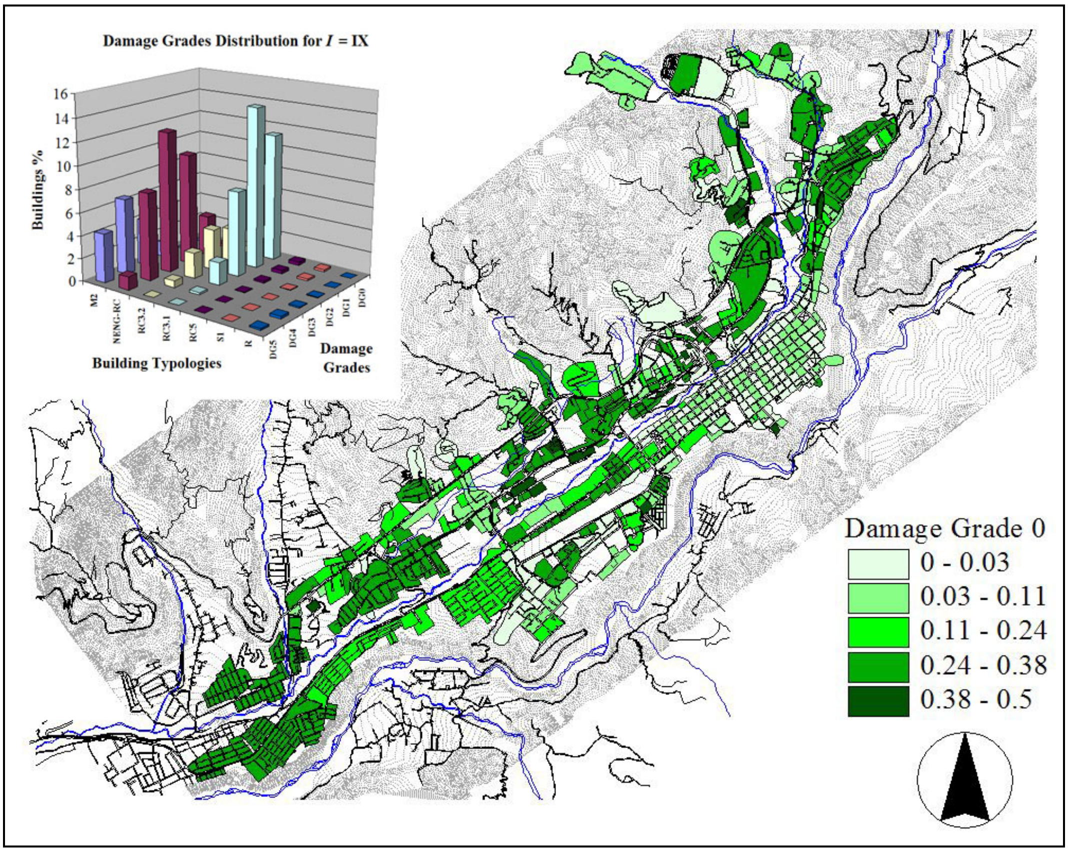
Figure 8.9: Damage grades distribution by vulnerability classes for Intensity *I* = IX.

Typology	R	M2	NENG-RC	RC3.2	RC3.1	RC5	S1	Totals
Damage Grade	%	%	%	%	%	%	%	%
Grade 0	0	0	0.23	0.62	11.28	0.3	0.18	12.61
Grade 1	0	0.04	3.57	2.94	14.17	0.3	0.16	21.18
Grade 2	0.02	1.3	9.78	3.6	7.44	0.14	0.04	22.32
Grade 3	0.09	4.08	12.3	2.24	2	0.02	0	20.73
Grade4	0.2	6.61	7.65	0.61	0.19	0	0	15.26
Grade5	0.14	4.3	1.16	0	0	0	0	5.6
TOTAL	0.45	16.33	34.69	10.01	35.08	0.76	0.38	97.7

Table 8.6: Damage grades distribution by vulnerability classes for *I* = IX.

8.6.1 Undamaged buildings for I = IX

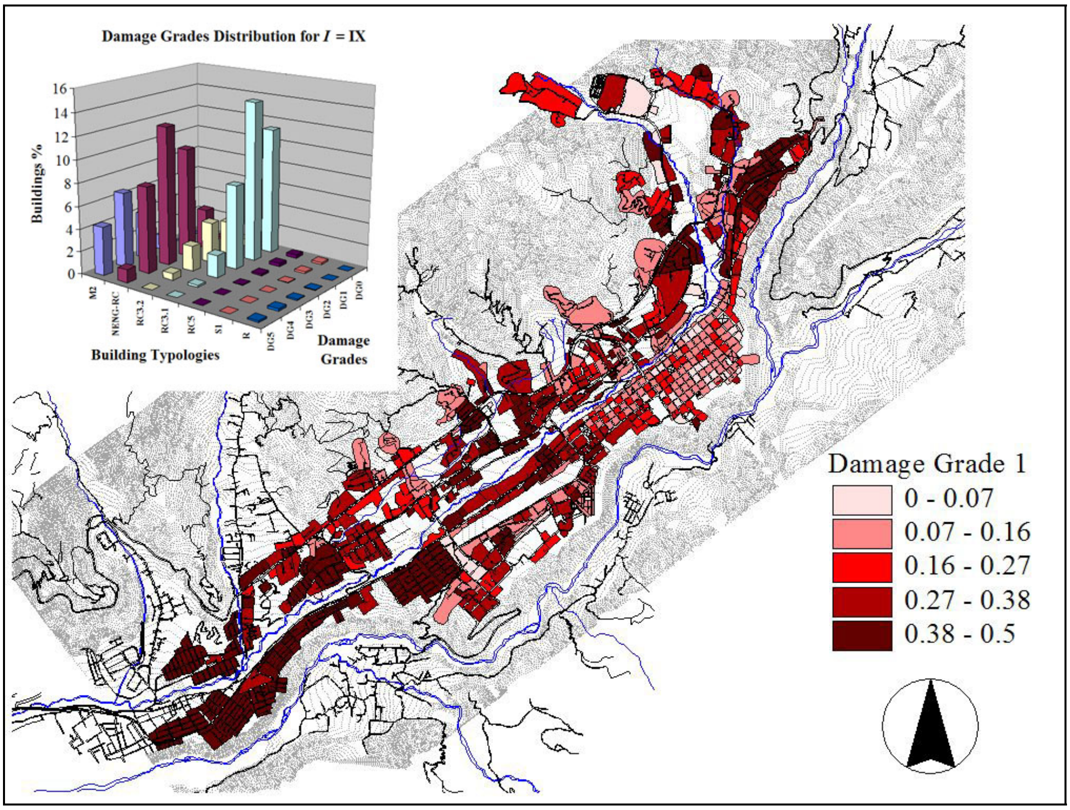
The distribution of undamaged buildings, as the percentage of buildings inside the sub-sectors is shown in Map 8.19, where the locations with greater concentrations of unaffected buildings (from 38% to 50% of the buildings in the sub-sectors) contain mostly buildings belonging to the RC5 and S1 typologies (which represent few subsectors in the survey), on the other hand, sub-sectors containing from a 24% to a 38% of undamaged buildings, contain mostly RC3.1 typology buildings, which is one of the most common typology in the building stock, and consequently, represents many sub-sectors in the survey. The reduction of the percentages of undamaged buildings in other sub-sectors depends on the increment of more vulnerable typologies buildings (R, M2, and NENG-RC) within these.



Map 8.19: Undamaged buildings for Intensity *I* = IX.

8.6.2 Damage Grade 1 (Fully Operational Performance Level) Distribution

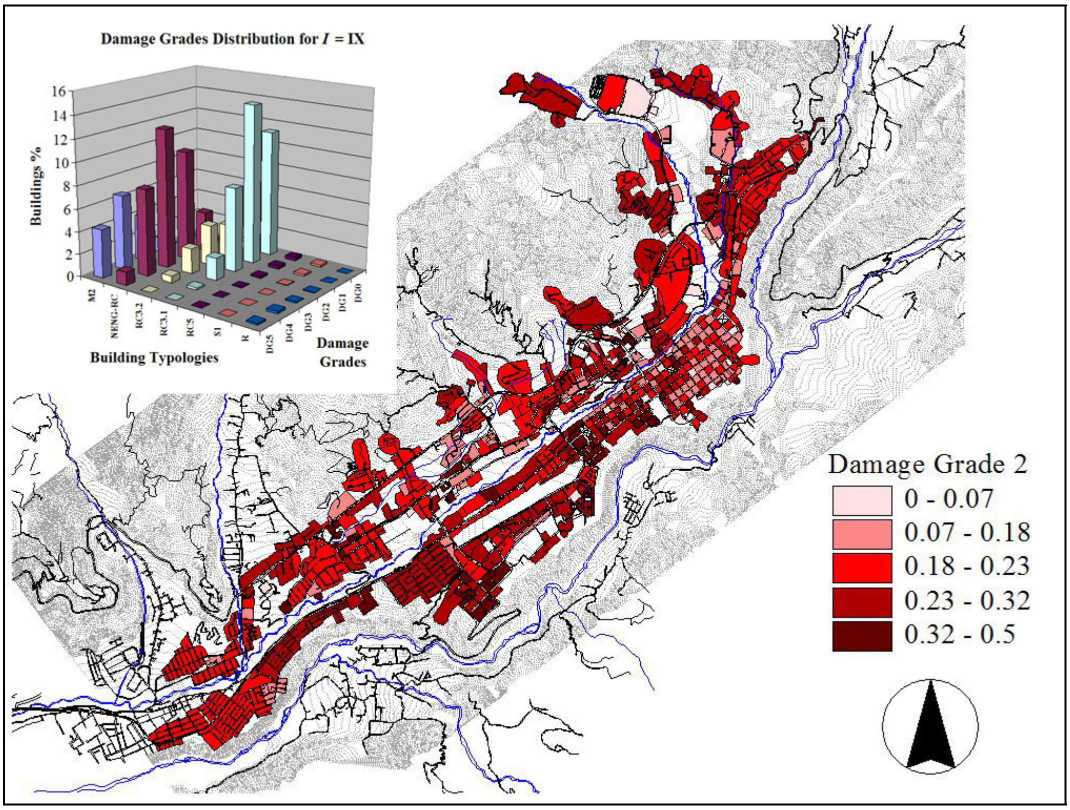
The damage Grade 1 distribution for the sub-sectors is presented in Map 8.20; where all the typologies are affected by this damage grade, except the Rancho typology (which is damaged at higher damage grades), the greater percentage of damaged buildings, from 38% to 50% of the buildings inside the sub-sectors with this damage grade belong to the RC3.1 typology (see Table 8.6), where these sub-sectors also contain important percentages of undamaged buildings, and are located at southerly and northerly the city.



Map 8.20: Damage Grade 1 distribution scenario (Fully Operational) for Intensity *I* = IX.

8.6.3 Damage Grade 2 (Functional Performance Level) Distribution

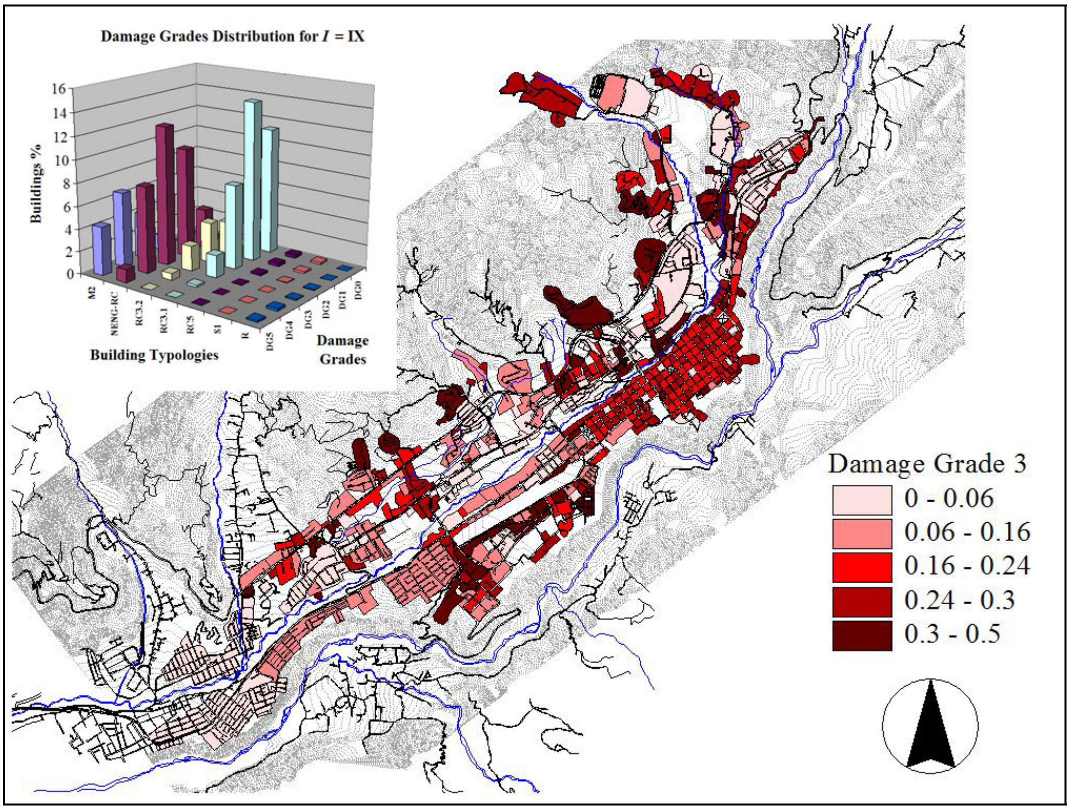
In Table 8.6, the distribution of damage grades by typologies is shown; where all typologies result affected by the damage grade, accounting in total for a 22% of all the buildings. The most affected typologies are the NENG-RC and the RC3.1 buildings with around a 10% and a 7% of all the buildings, respectively. The higher concentrations of this damage grade (between 32% and 50%) occur in the sub-sectors with greater concentrations of buildings belonging to the NENG-RC and RC3.2 typologies (Map 8.21), the following upper concentration (from 23% to 32% of the buildings in the sub-sectors) are identified as sub-sectors containing mostly NENG-RC typology buildings.



Map 8.21: Damage Grade 2 distribution scenario (Functional) for Intensity *I* = IX.

8.6.4 Damage Grade 3 (Life Safety Performance Level) Distribution

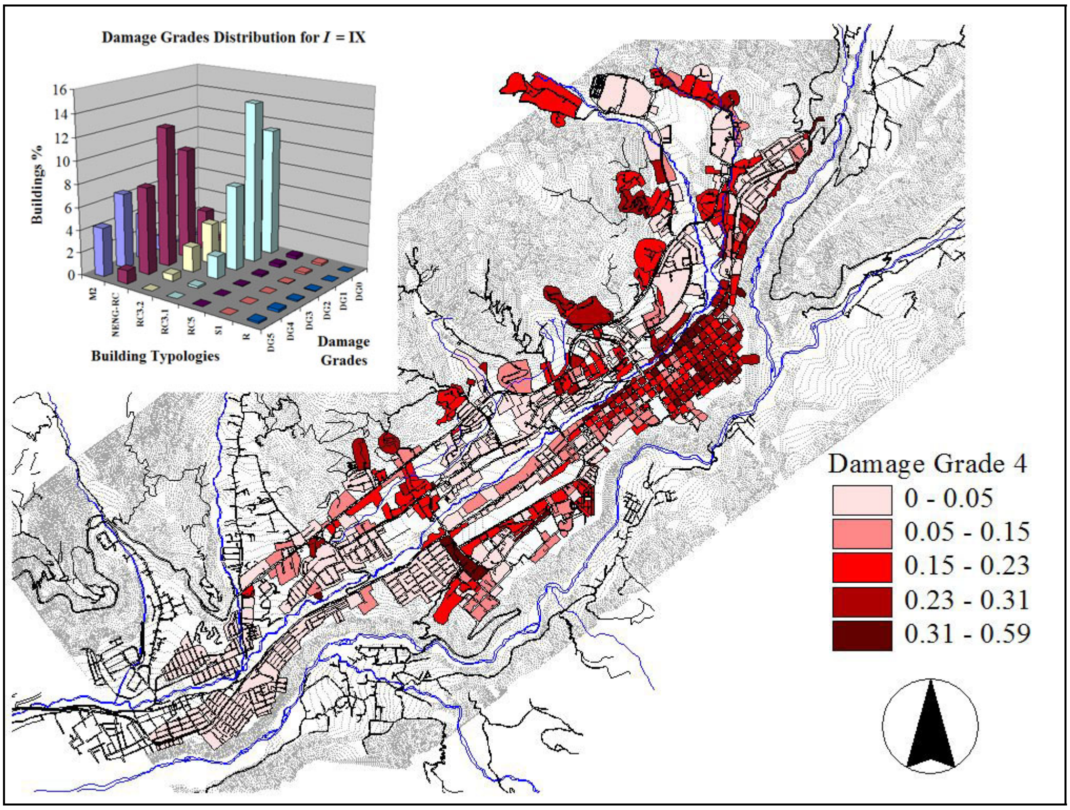
All the building typologies, except the S1 typology, undergo this damage grade (Table 8.6), the greater percentage of buildings undergoing Damage Grade 3 belong to the NENG-RC typology, with around a 12% of all the buildings in the survey, followed by buildings belonging to the M2 typology, with around a 4% of buildings. The rest of the typologies, account for Damage Grade 3 with a percentages up to a 2% and as low as a 0.02%. The distribution of Damage Grade 3 by sub-sectors is shown in Map 8.22, where the "Barrios" (NENG-RC buildings predominant sub-sectors) are the most affected with between a third and up to a half of all the buildings in the sub-sectors undergoing this damage grade.



Map 8.22: Damage Grade 3 distribution scenario (Life Safety) for Intensity *I* = IX.

8.6.5 Damage Grade 4 (Near Collapse) Distribution

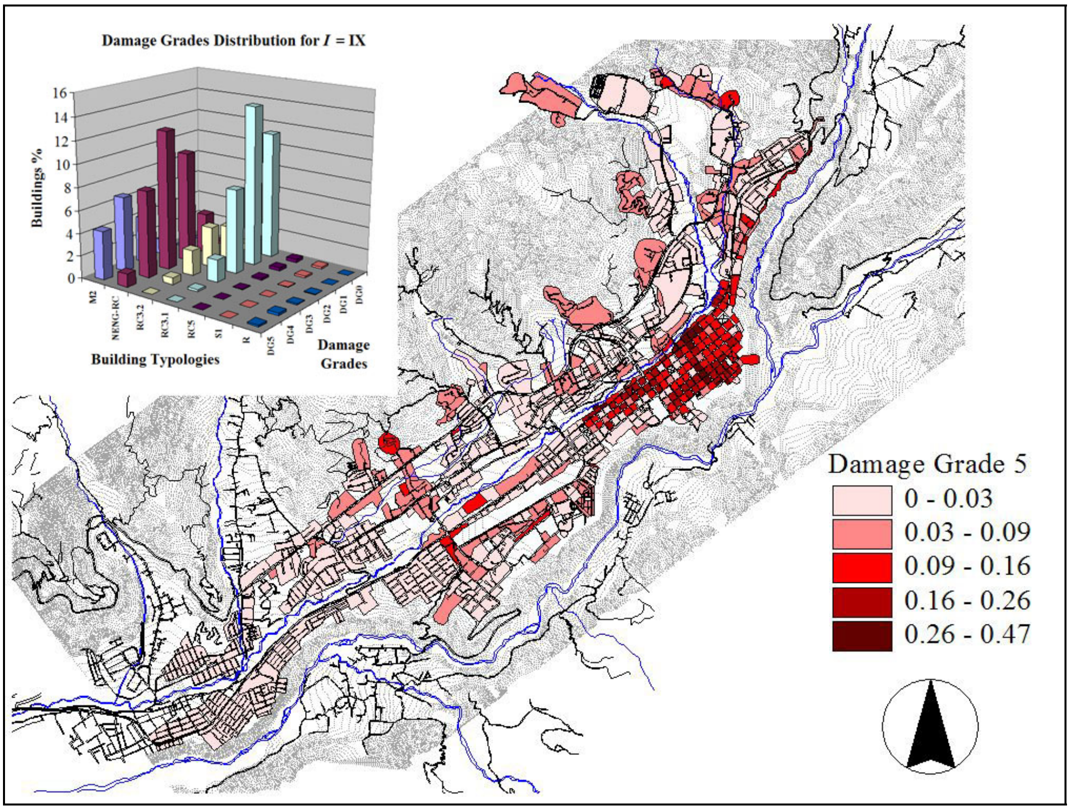
The Damage Grade 4 distribution by percentage of buildings in the sub-sectors is shown in Map 8.23, from Table 8.6 it is verified that over a 15% of all the buildings in the survey undergo Damage Grade 4 affecting mostly buildings belonging to the NENG-RC and M2 typologies, with around an 8% and a 7% of all the buildings in the survey, respectively. The Rancho typology buildings are affected by this damage grade representing a 0.2% of the buildings, the RC3.2 and RC3.1 buildings account for a 0.6% and a 0.2% of the buildings in the survey, respectively. The other two typologies, RC5 and S1 result unaffected by this damage grade. The greater percentages of damaged buildings with this damage grade (from a third to more than a half of all the buildings inside the sub-sectors) belong to sub-sectors containing mostly buildings belonging to the M2 typology.



Map 8.23: Damage Grade 4 distribution scenario (Near Collapse) for Intensity *I* = IX.

8.6.6 Damage Grade 5 (Total Collapse) Distribution

The worst expected damage grade in the damage scenarios is Damage Grade 5 for this Intensity, the percentage of buildings undergoing this damage grade accounts for an 5.6% of all the buildings in the survey, where a 4.3% belongs to the M2 typology and a 1.2% to the NENG-RC typology (see Table 8.6). From the results shown in Map 8.24, this damage grade is seen extended over downtown Mérida, where up to almost a half of all buildings within these sub-sectors collapse. The buildings in the “Barrios” may suffer collapse in around a 3% and up to a 9% of the buildings within the sub-sectors.



Map 8.24: Damage Grade 5 distribution scenario (Collapse) for Intensity *I* = IX.

8.6.7 Damage Grades Distribution by Parishes for Intensity *I* = IX

The damage grades distribution for the different parishes in Mérida city is shown in Figure 8.10, the least affected parishes are the Osuna Rodríguez, the Mariano Picón Salas and the Lasso de La Vega parishes with a 35%, a 32% and a 28% of undamaged buildings. Five parishes result affected with important percentages of damage for damage grades 3 to 5: the El Sagrario parish, with a 66% of buildings , the Arias parish with a 63% of buildings, the Domingo Peña parish accounting for a 56% of damaged buildings, and, the Antonio Spinetti Dini and the El Llano parishes where a 46% of buildings result damaged with these damage grades (3 to 5). The discrimination of damage grades distribution by parishes is as follows:

1. Antonio Spinetti Dini: Around an 11% of the buildings in the parish remain undamaged. Repairable damage occurs in around a 43% of the buildings, where Damage Grade 1 (Fully Operational Performance Level) accounts for a 19% of buildings, and Damage Grade 2 (Functional Performance Level) for around a 24% of the buildings in the parish. Damage Grade 3 (Life Safety Performance Level) accounts for a 25% of the buildings, which may need to be repaired without occupancy. Around a 21% of all the buildings in the parish may undergo collapse in two different manners, a 17% of the buildings suffering Damage Grade 4 (Near Collapse Performance Level) and around a 4% of the buildings with total or near total collapse (Damage Grade 5).
2. Arias: Undamaged buildings in the parish represent around a 5% of the buildings. A 12.5% of the buildings undergo Damage Grade 1 (Fully Operational), around a 19% of the buildings account for Damage Grade 2, and, a 24% of the buildings undergo Damage Grade 3 (Life Safety); in total, a percentage of around a 50% of the buildings in the parish are repairable, and from these, around the half of the buildings may have to be repaired without occupancy. Almost a 40% of the buildings may undergo

collapse, with a 26% of buildings affected with Damage Grade 4 (Near Collapse) and a 13% with Damage Grade 5 (total or near total collapse).

3. Caracciolo Parra: A 20% of the buildings in the parish remain undamaged. Around a 68% of the buildings in the parish undergo repairable damage, where a 20% accounts for Damage Grade 1 (Fully Operational), around a 27% undergoes Damage Grade 2 (Functional), and a 22% of the buildings suffer Damage Grade 3 (Life Safety), where this last percentage of buildings may probably need to de unoccupied for repairs. Damage Grades 4 and 5 sums up to a 13% of the buildings in the parish, where Damage Grade 4 (Near Collapse) represents an 11% and Damage Grade 5 (Collapse) around a 3% of the buildings in the parish.
4. Domingo Peña: A small percentage of buildings (4.7%) result undamaged in this parish. Repairable damages are sustained by around a 69% of the buildings in the parish, with a 15% presenting Damage Grade 1 (Fully Operational), a 25% Damage Grade 2 (Functional), and a 29% of the buildings Damage Grade 3 (Life Safety). Superior damage grades account for a 27% of the buildings in the parish, where Damage Grade 4 (Near Collapse) accounts for a 21% and Damage Grade 5 (Collapse) for a 6%.
5. El Llano: Around a 9% of the buildings remain undamaged. Damage Grades 1, 2 and 3 account for around a 66% of all buildings in the parish, with around 21% undergoing Damage Grade 1, 24% Damage Grade 2, and a 21% Damage Grade 3 (Life Safety). Around a 25% of the buildings undergo collapse, where Near Collapse Performance Level (Damage Grade 4) accounts for a 16% of the buildings, and Collapse for a 9% of the buildings in the parish.
6. El Sagrario: Only a 3% of the buildings result unaffected by damage. A 54% of the buildings undergo repairable damages, where a 12% remains Fully Operational undergoing Damage Grade 1, a 19% remains Functional undergoing Damage Grade 2, and a 23% undergoes Damage Grade 3 (Life Safety Performance Level). Around a 43% of all buildings in the parish account for collapse, where a 26% bears Damage Grade 4 (Near Collapse) and a 17% Damage Grade 5 (total or near total collapse).
7. Juan Rodríguez Suárez: Undamaged buildings account for a 27% of the buildings in the parish. Repairable damage in the parish sums up to around a 72% of the buildings, with a 40% of buildings undergoing Damage Grade 1, a 40% Damage Grade 2 (Functional), and an 8% of the buildings undergo Damage Grade 3 (Life Safety). Superior damage grades occur only in a 1.4% of the buildings in the parish, where Damage Grade 4 (Near Collapse) accounts for a 1.35% and Damage Grade 5 (total or near total collapse) for a 0.06%.
8. Lasso de La Vega: The undamaged buildings in the parish account for a 28% of the buildings. Damage Grades 1, 2 and 3 account for around a 68% of all buildings in the parish, with around 36% undergoing Damage Grade 1, 21% Damage Grade 2, and an 11% Damage Grade 3 (Life Safety). A 4.4% of the buildings undergo collapse, where Near Collapse Performance Level (Damage Grade 4) accounts for a 4% of the buildings, and Collapse for a 0.4% of the buildings in the parish.
9. Mariano Picón Salas: Around a 32% of the buildings remain undamaged. Repairable damaged buildings in the parish represent a 65% of the buildings, from where a 38% is accumulated in Damage Grade 3 (buildings may be unsafe to occupy until repair), a 20% is in Damage Grade 1 (Fully Operational), and a 7% of the buildings are in Damage Grade 2 (Functional). A percentage of 2.8% of the buildings suffer the superior damage grades 4 and 5, from which a 1.4% corresponds to Damage Grade 4 (Near Collapse) and a 0.4% to Damage Grade 5 (total or near total collapse).

10. Milla: An 11% of the buildings in the parish remain undamaged. Repairable damage is sustained for around a 65% of the buildings in the parish, where an 18% undergoes Damage Grade 1 (Fully Operational), a 23% undergoes Damage Grade 2 (Functional), and a 24% of the buildings suffer Damage Grade 3 (Life Safety). Superior damage grades 4 and 5 affect a 24% of the buildings in the parish, from which an 18% correspond to Damage Grade 4 (Near Collapse), and a 6% to Damage Grade 5 (total or near total collapse).
11. Osuna Rodríguez: Undamaged buildings in the parish represent around a 35% of the buildings. A 40% of the buildings undergo Damage Grade 1 (Fully Operational), around a 19% of the buildings account for Damage Grade 2, and, a 5% of the buildings undergo Damage Grade 3 (Life Safety); in total, a percentage of around a 65% of the buildings in the parish are repairable, and from these, around a tenth of the buildings may have to be repaired without occupancy. From the superior damage grade only Damage Grade 4 occurs representing a 0.6% of the buildings in the parish.

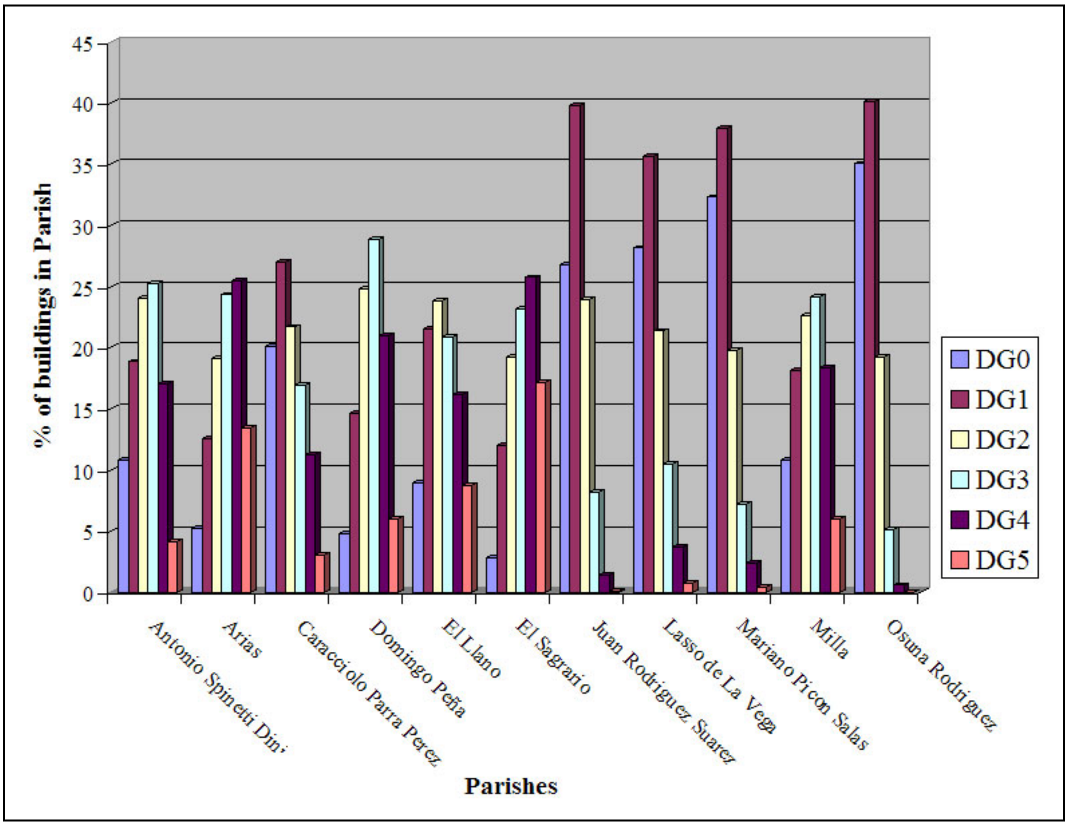


Figure 8.10: Damage Grades distribution by parishes for Intensity *I* = IX.

8.7 Other observations for the Damage Scenarios

Some other observations of damage for the different scenario events in the city may be performed based in considerations pertaining to the damage definitions used (EMS-98 and Vision 2000), which complement each other and may be considered as equivalent in the description for the different damage states. Taking into account the definitions of the Standard Performance Levels in Vision 2000 [SEAOC, 1995], additional information on reparability and occupancy of the buildings is available for each of the damage grades; also, the possible effects to the occupants of the buildings (life-threatening) is described for these performance levels. Observing Table 8.2, at least two thresholds may be inferred for the performance of the buildings and its consequences, the first to appear is the reparability of the buildings threshold, located between the Life Safety (Damage Grade 3) and the Near Collapse (Damage Grade 4) performance levels, and identifies the buildings presenting the three first performance levels as repairable, and the fourth as probably not practical to repair (Heavy structural damage, Very heavy non-structural damage). The second threshold corresponds to the occupancy of the buildings after the earthquake, located between the Functional (Damage Grade 2) and the Life Safety (Damage Grade 3) performance levels, identifying the buildings presenting the two first performance levels with *Immediate Occupancy* (IO) and the third performance level with a conditional occupancy based in *Life Safety* (LS) where the buildings must be inspected for damage to guarantee life safety of the occupants; the superior performance levels do not allow occupancy of the buildings as they represent a life threatening risk to the users. The terms Immediate Occupancy and Life Safety are defined in the FEMA-310 handbook, based in the seismic performance of the buildings, where for the Immediate Occupancy Performance Level the "*…basic vertical and lateral-force resisting systems retain nearly all of their pre-earthquake strength and stiffness. The level of risk for life-threatening injury as a result of damage is very low. Although some minor repairs may be necessary, the building is fully habitable … and the needed repairs may be completed while the building is occupied…*"; and for the Life Safety Performance Level the building's performance "*…includes significant damage to both structural and nonstructural components … though at least some margin against either partial or total structural collapse remains. Injuries may occur, but the level of risk for life-threatening injury and entrapment is low.*" These definitions are very clear in the damage description and the consequences upon the occupants, and naturally coincide with those in the Vision 2000 document as both are based in the seismic performance levels of the buildings.

From the observations, a summarized table (Table 8.7) is built; the identification of the damage based in reparability and occupancy may be useful to evaluate (in a different fashion) the impact of the different scenario events in the city, which is identified as "Proposed Description" in the table. It is noticeable that the two superior performance levels expected (Damage Grades 4 and 5) are defined as collapse, due to the fact that the buildings in these damage states have suffered at least partial collapse or partial structural failure, and also, because the term "collapse" gives a better idea for non-serviceability of the building than the term "unreparable".

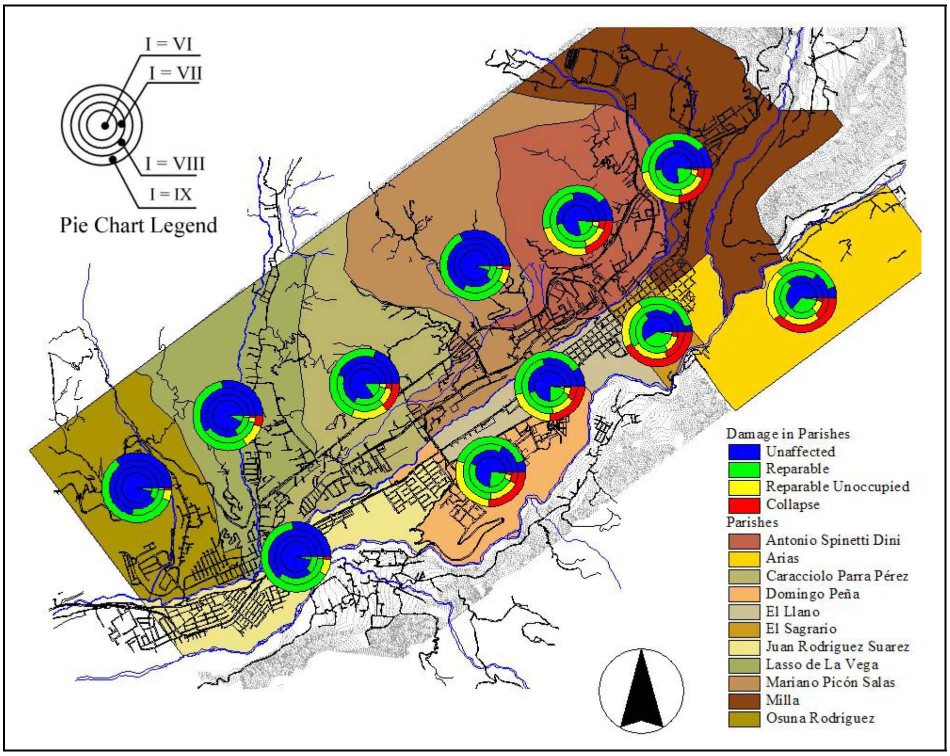
Performance Levels (Vision 2000)	Damage Grades (EMS-98)	**Reparability**	**Occupancy**	Proposed Description
Fully Operational	Damage Grade 1: Negligible to slight	Repairable	Yes	Repairable
Functional	Damage Grade 2: Moderate			
Life Safety	Damage Grade 3: Substantial to heavy damage		Probably Not	Repairable Unoccupied
Near Collapse	Damage Grade 4: Very Heavy damage	Not repairable	No	Collapse
N/A	Damage Grade 5: Destruction			

Table 8.7: Equivalence for damage descriptions in Vision 2000 and EMS-98 (N/A: Not Available).

Observing the scenarios presented to this point, it is convenient to use a coverage of the city that summarizes the effects of scenario events, for this purpose, the damage distribution by parishes is selected, as it shows the effects of the scenario earthquakes in broader extensions of the city, and also because the parishes constitute the smallest political units in which the political territorial divisions in Venezuela are based.

An integrated events-effects map, for the parishes, is built based on information about Reparability-Occupancy of the buildings, showing the percentage of buildings (with respect to the total number of buildings in the parishes) corresponding to the different classifications of damage (Unaffected, Repairable, Repairable Unoccupied, and Collapse) for all the scenario events. To include such information in the map, concentric pie-charts of damage classification percentages with increasing diameter of the pie-chart for each of the successive scenario events, are located at the centers of the parishes (Map 8.25). In this map, the evolution of damage through the scenario events allows to establish an order in the parishes, from the most to the least affected: the El Sagrario, Arias, and Domingo Peña parishes, followed by the Milla, El Llano and Antonio Spinetti Dini parishes; the Caracciolo Parra Pérez, Lasso de La Vega and Mariano Picón Salas parishes, and the least affected, the Juan Rodríguez Suárez and the Osuna Rodríguez parishes, with a percentage of collapsed buildings around a 1% of the buildings in the parish (for I = IX, in Figure 8.10).

In the light of this damage order for the parishes, for the last scenario event (I = IX), it is expected that the most affected zone in the city, is the city's downtown (the Arias and the El Sagrario parishes), where the percentages of damaged buildings at the upper damage grades (Damage Grade 4 and Damage Grade 5) represent around a 40% all the buildings in the parish (see Figure 8.10); within these parishes are buildings containing the headquarters for political and administrative activities (regional and national government), and several university facilities, including the headquarters of centralized university government, also, principal offices for banks, and the catholic church government headquarters and cathedral. This most affected zone is surrounded by three other parishes (the Milla, at the northeast, the El Llano parish at the southwest of the El Sagrario parish, and the Antonio Spinetti Dini, at the northwest) which are in the subsequent orders of affected parishes.



Map 8.25: Damage percentage distribution by parishes, in Mérida.

On the other hand, if the number of damaged buildings is discriminated by the parishes (for the same scenario event: *I* = IX), it is verified that the greater number of damaged buildings are within the Milla, the Domingo Peña and the Antonio Spinetti Dini parishes (in the correlative order of quantity, from most to least), where the number of buildings undergoing the last stages of damage (collapse) are similar to the number of buildings with repairable unoccupied damage description (Figure 8.11), also, these parishes contain the most extended "Barrios" in Mérida city, which explains why damage is more frequent and important, based in the knowledge that these settlements mostly contain typology NEN-RC buildings. For the Arias and El Sagrario parishes, it is observed how the buildings in the last stages of damage (collapse) are greater than the number of buildings undergoing repairable unoccupied state (Figure 8.11), and also, it is observed how the unaffected number of buildings is much lower than the number of buildings undergoing the superior damage state of collapse.

Accounting for the damage generated by the *I* = IX event in the different city's parishes and considering the Potential Earth Science Hazards that may occur at this event, a critical scenario may be built where the zones of the tableau with the susceptibilities to liquefaction (northerly of the Albarregas River at the limits with the La Culata Sierra) and susceptibilities to Landsliding (slopes of the Chama and Mucujún Rivers canyons, at the southerly border of the tableau) configure zones of higher risk than the rest of the tableau's surface. These potential local induced effects configure additional sources of damage to the buildings, as they describe the possibility of permanent ground deformations, consequently affecting the building's foundations, and also affecting the lifelines such as pipes, electrical lines, water sewage systems, streets/avenues and roads, which may suffer damage by the action of these local induced effects.

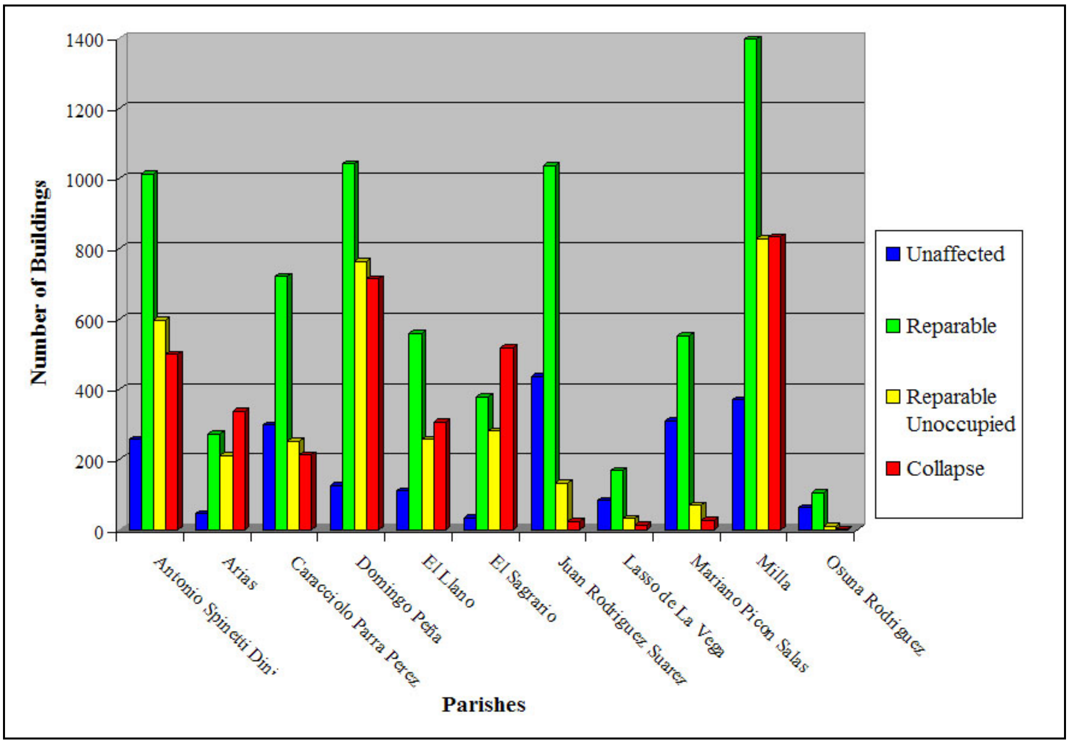
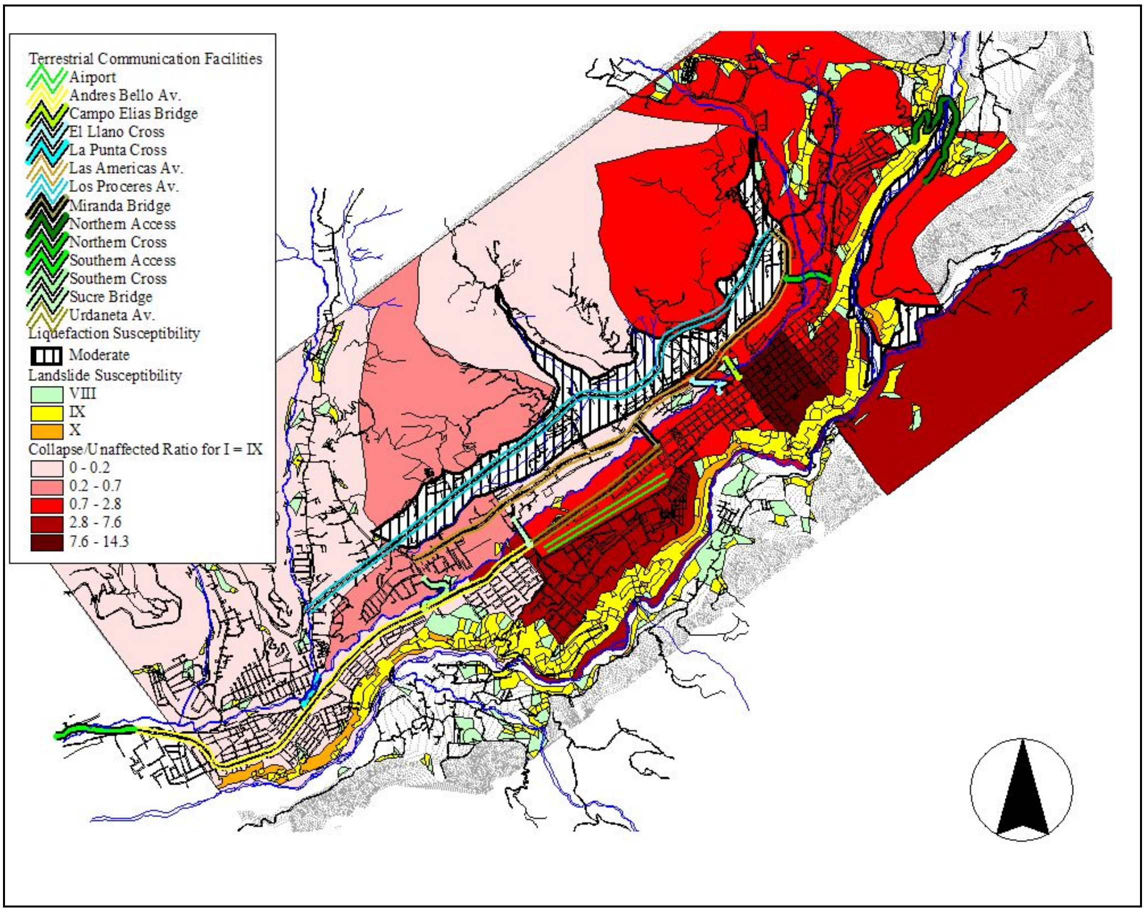


Figure 8.11: Damage distribution by number of buildings in the parishes, for *I* = IX.

In Map 8.26, this critical scenario is shown; the damage in the parishes is described by means of the ratio between the number of collapsed buildings and the number of unaffected buildings, when this ratio is greater than the unity, the number of collapsed buildings is greater than the number of unaffected buildings in that proportion. The liquefaction susceptibility zone (northerly stripe) runs along three parishes in northeast-southwest direction: the Antonio Spinetti Dini, the Mariano Picón Salas and the Caracciolo Parra Pérez parishes, this zone also contains the Los Próceres Avenue, one of the most important terrestrial lifelines in the city. The connections through the Albarregas River are produced by bridges in all cases: the viaducts, with around 200 m to 300 m in longitude, and the bridges in the crosses, mostly not longer than 50 m. The landslide susceptibility zone (southerly stripe, mostly with landslide susceptibility class IX) runs through the southern limits of five parishes: the Arias, the El Sagrario, the Domingo Peña and the Juan Rodríguez Suárez parishes, where buildings are located in the border of the slope.

The previous observations in the critical scenario configure several additional elements to be considered in future assessments, such as the lifelines, which should be separated in terrestrial communications lifelines and public services lifelines, based in the contributing services that each may perform in emergency plans for the city. Terrestrial communications are essential after the impact of a catastrophic earthquake, the ambulances, fire-trucks, and particular vehicles are the first means of transportation of the wounded to the hospitals or emergency attention centers, and also to evacuate population to safer zones of the city (open squares, parks), if in Mérida, some of the bridges across the Albarregas River would collapse or suffer extended damage, some portions of the city would be isolated, remembering also, that the accesses to the city (northerly and southerly) are produced by means of bridges, this would leave the rescue and evacuation missions in hands of aerial support to be performed (helicopters). The electric supply network, mostly aerial, could suffer damage by means of the collapse of buildings or parts of the buildings over the posts or the lines, as well as the telephone supply network, which has similar configuration. Some other collateral effects not related to lifelines should be considered as possible, as for example: the Albarregas River canyon in the central portion of the city (downtown sector) is surrounded by informal settlements, containing mostly the vulnerable building type: non-engineered housing with RC frame and hollow clay block infill walls; the extensive damage in these settlements could produce debris accumulation in the river with the possibility of generating accidental dams. All these effects should be expected as possible, however, an adequate assessment of occurrence probabilities through a standard or consensus methodology, would give to the decision-making process of emergency planning and countermeasures a reliable platform in which to be developed.



Map 8.26: Critical scenario for *I* = IX.

8.8 Human casualties for the earthquake scenarios

The number of people affected by the adverse impact of earthquakes may be accounted as the people suffering different levels of injuries (requiring first aid/outpatient treatment, hospitalization, or major surgery) and the people resulting dead; the principal cause of the statistics for earthquake casualties are generated by the collapse of buildings, although other collateral causes may be identified, and may range from the medical conditions induced by the shock of experiencing ground motion, accidents that may occur during the disturbance, epidemic risks among the homeless, and shootings during martial law [Vacareanu et. al., 2004].

However other causes may generate casualties, the most important is the collapse of buildings, which account for about a 70% of the fatalities (mortality rate) and nearly a 100% of injuries (morbidity rate) [Spence et. al., 1991]. The building damage-related casualties may be classified in a four level scale of injury severity, ranging from light injuries to life-threatening injuries in three levels, requiring an increasing degree of medical care and facilities, and the last and most severe level, which consists in mortal injuries or instantaneous death of people [Seligson et. al., 2004;Vacareanu et. al., 2004]. A scale may be presented by the severity classification and description in the fashion of the NIBS/FEMA injury severity scale [HAZUS-99-SR2, 2002], with the breakdown of typical injury ratios for a population affected by a severe-case earthquake scenario (Table 8.8).

Injury Severity Level	Description	Typical Injury Ratios
Severity 1	Injuries requiring first aid/outpatient treatment	50% - 70%
Severity 2	Injuries requiring hospitalization	5% - 10%
Severity 3	Injuries requiring major surgery	1% - 2%
Severity 4	Instantaneously killed or mortally injured	20% - 30%

Table 8.8: Breakdown of typical injury ratios for severity levels, after [Vacareanu et. al., 2004].

The forecast of possible casualties generated by a scenario earthquake is performed by means of a casualty model, which relates the number of buildings that collapse with the number of people that may result affected (at different injury severity levels). *The RISK-UE-WP7 Report: Seismic Risk Scenarios Handbook* [Vacareanu et. al., 2004], presents a methodology to perform the casualties forecast using a casualty model for the different building typologies undergoing the damage state of collapse. The expression for the casualty model is:

$$K_S = C \times [M1 \times M2 \times M3(M4 + M5(1 - M4))] \qquad \text{eq. 8.3}$$

where *C* is the total number (or floor area) of collapsed buildings belonging to a typology.

M1 is the occupancy rate or number of people by built area (people/built m^2). The occupancy rate may be also expressed as the number of people per building (*P/B*) in low-rise residential building stock, where the number of people is equivalent to the average family size living in each house.

M2 is the occupancy of the buildings at the time of earthquake occurrence, which is a changing factor that depends on the time of the day. In Figure 8.12, the distribution of population inside the buildings by the time of day is shown for urban residential buildings, non-residential buildings, and rural agricultural society buildings, as the percentage of the occupants or the occupancy rate.

The *M3* factor represents the percentage of occupants trapped by collapse. When a building collapses by earthquake action, not all the occupants are likely to be trapped inside, in fact, occupants may are escape before collapse, or the collapse of the structure is not total, or they are able to free themselves shortly after. This *M3* factor depends on much in the height configuration of the buildings, as for the single story buildings there is evidence that many people are able to escape from the buildings before it collapses, unless collapse is produced instantaneously; in the case of multi-story buildings fewer people are able to escape from the building once shaking has started. The estimated average percentage of occupants trapped by collapse is shown in Table 8.9, for different macroseismic intensities in the case of Masonry buildings, and for two different epicentral distances (near-field and distant) of the earthquake for RC buildings.

Factor *M4* gives the injury severity levels distribution at collapse, where a proportion of the buildings occupants are killed outright when collapse occurs and others are injured to various degrees of severity. In Table 8.10, these proportions of severity levels are given, for three different building typologies: low strength masonry, masonry, and RC buildings.

The last factor *M5*, represents the mortality post-collapse, which depends on the capability of the community to respond quickly to the emergency, rescuing and providing medical treatment to the people trapped and injured after the earthquake has occurred. If a great percentage of people from the community result trapped in collapses, the capability of rescuing its own victims may be reduced and even may be lost, due to both the reduction of manpower and because it becomes psychologically and socially incapacitated by the disaster. In Table 8.11, these percentages of trapped survivors that subsequently die depending on the situation of the community are shown; it is clear that as the capacity of the community diminishes, the percentage of dying trapped survivors increases.

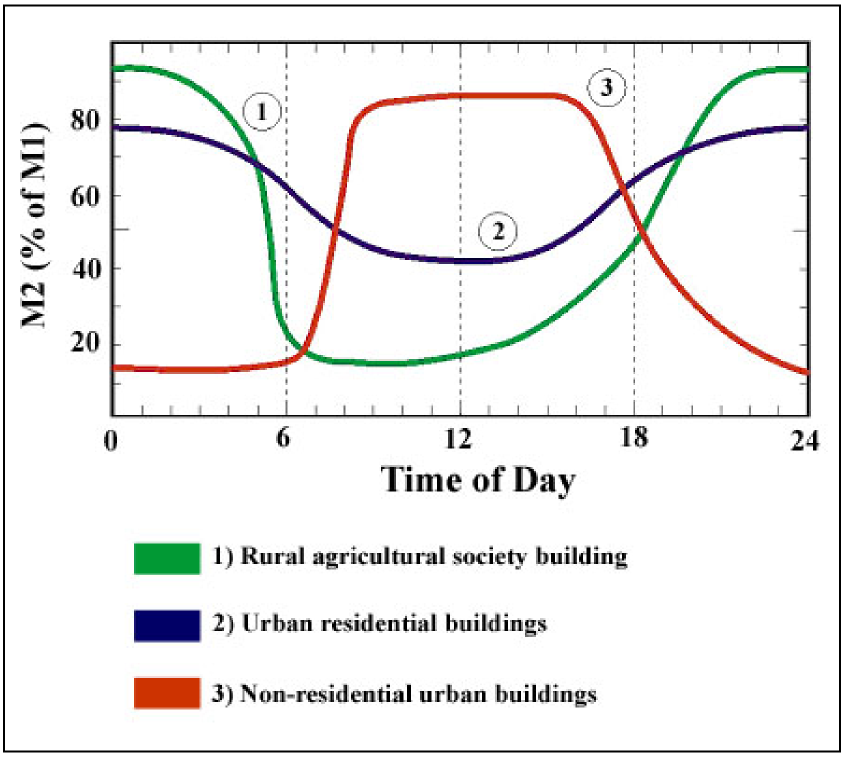


Figure 8.12: Factor M2, Occupancy at time of earthquake, after [Coburn and Spence, 2002].

Building type		Seismic Intensity (MSK Scale)			
		VII	VIII	IX	X
Masonry buildings(up to 3 stories)	Non earthquake resistant	5	30	60	70
	Earthquake resistant	-	10	30	60
RC structures	Near-field high frequency ground motion				70
	Distant, long-period ground motion				50

Table 8.9: Factor M3, Average percentage of occupants trapped by collapse, after [Coburn and Spence, 2002].

Injury Severity Level	Low strength masonry	Masonry	RC
Dead or unsavable	10	20	40
Life threatening cases needing immediate medical attention	20	30	10
Injury requiring hospital treatment	30	30	40
Light injury not needing hospitalization	40	20	10

Table 8.10: Factor M4, Estimated injury distribution at collapses, in percentage of occupants trapped by collapse, after [Coburn and Spence, 2002].

Situation	Masonry	RC
Community incapacitated	95	-
Community capable of organizing rescue activities	60	90
Community + emergency squads after 12 hours	50	80
Community emergency squads SAR experts after 36 hours	45	70

Table 8.11: Factor M5, Percentage of trapped survivors in collapsed buildings that subsequently die, after [Coburn and Spence, 2002].

The application of the aforementioned human casualties' estimation methodology is performed in Mérida. For this purpose, the seismic damage scenarios are reviewed in search for the occurrence of building collapse, where the scenario events *I* = VIII and *I* = IX are the ones capable of generating building collapse in the area studied. The building typologies affected by the collapse damage grade (Damage Grade 5) are: for the *I* = VIII scenario: the M2 and the NENG-RC typologies, and for the *I* = IX scenario, the typologies undergoing this damage grade are the R, the M2 and the NENG-RC typologies. The buildings belonging to these typologies are mostly residential buildings. The percentages of buildings belonging to these typologies with this damage grade for the scenario events, are shown in Table 8.5 (for *I* = VIII) and in Table 8.6 (for *I* = IX). The occupancy rate of the typologies is estimated based in the average number of family members, which for Venezuela is 4.3 people/family [INE, 2001], the total number of people by building is obtained by multiplying the average number of levels of the building typology by the number of family members. In this fashion, the R and M2 typology buildings are found to present only one level, thus, the population per building (P/B) is considered as 4.3 P/B, in the case of the NENG-RC typology buildings, it is expected that the most vulnerable should undergo collapse, reviewing the index quantification for this typology, the most vulnerable buildings present an average number of levels equal to 3, thus, the occupancy rate is estimated as 12.9 P/B.

The organization of the casualties estimation, depends on the time of the day at which the earthquake may occur (Figure 8.12), as the occupancy of the buildings vary depending on this parameter, as is, it is expected that an almost full occupancy is produced at midnight (around an 80%), and the least occupancy percentage is produced at noon (around a 40%). By examining the percentages presented in the curves of Figure 8.12, three different estimations of the casualties due to building collapse are performed by time of day (for each of the two scenario events considered): the midnight, the noon, and the first and last hour of a Labor Day (6:00 AM and 6:00 PM).

8.8.1 Casualties for scenario event *I* = VIII

Applying the model in equation 8.3, the general casualties' estimation is shown in Figure 8.13, where the greater number of victims (578 casualties, suffering the different severity levels) is expected at midnight, followed by the 6 AM/6 PM time of the day (first and last hour of labor day) with 452 casualties in total, and finally, the casualties generated at noon, where the number of casualties is around a half of those in the midnight estimation (304 casualties). The distribution for the different severity levels is observed almost uniform; this is due to the fact that most of the buildings collapsed belong to Masonry typology buildings, where high percentages of trapped victims having serious injuries are expected [Vacareanu et. al., 2004]. The distribution of casualties is presented also by its occurrence inside the parishes, so to obtain a more detailed distribution of the victims.

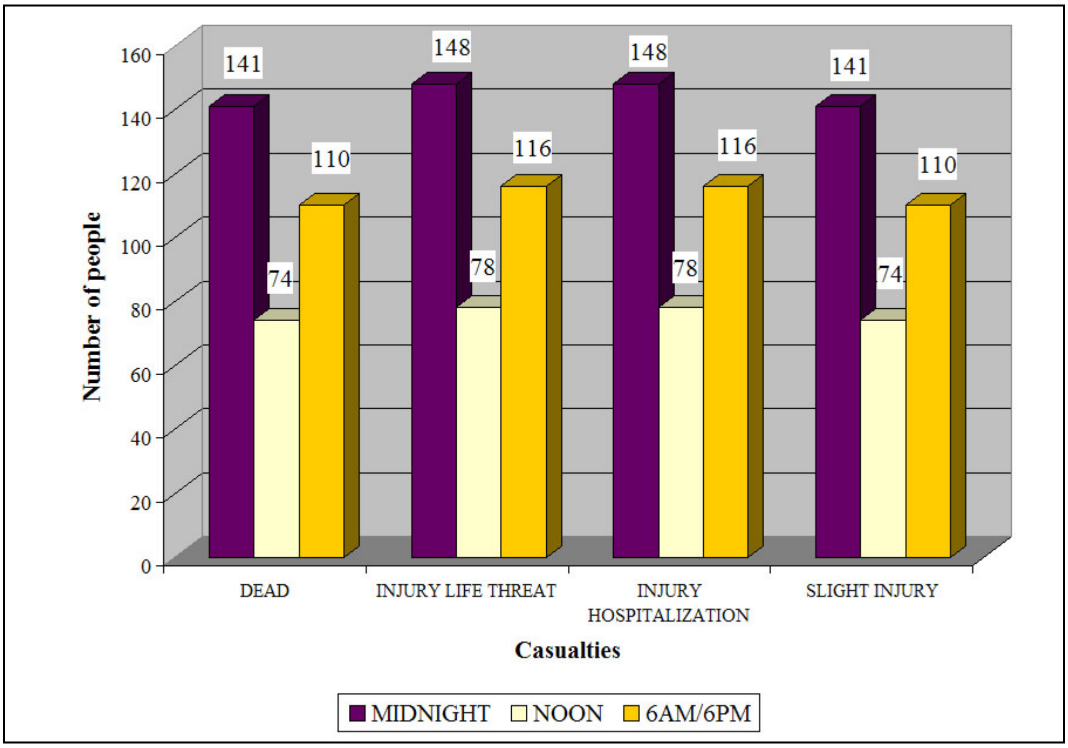


Figure 8.13: Distribution of the casualties for scenario event *I* = VIII.

8.8.1.1 Casualties by parishes for I = VIII

The distributions of the casualties generated inside the parishes for the different times of the day considered, are shown in Figure 8.14, it is observed how the midnight distribution accounts for the greater number of casualties, as an almost full occupancy is expected in the buildings. The most affected parish is the El Sagrario parish, with 184 casualties of different severity levels at midnight, 96 casualties at noon, and 144 casualties at the first and last hours of a Labor Day. The order of the parishes in decreasing number of casualties is: the El Llano, the Arias, the Domingo Peña and Milla, the Antonio Spinetti Dini and the Caracciolo Parra Pérez parishes. On the other hand, no casualties are generated in the Juan Rodríguez Suárez, Lasso de La Vega, Mariano Picón Salas and Osuna Rodríguez parishes.

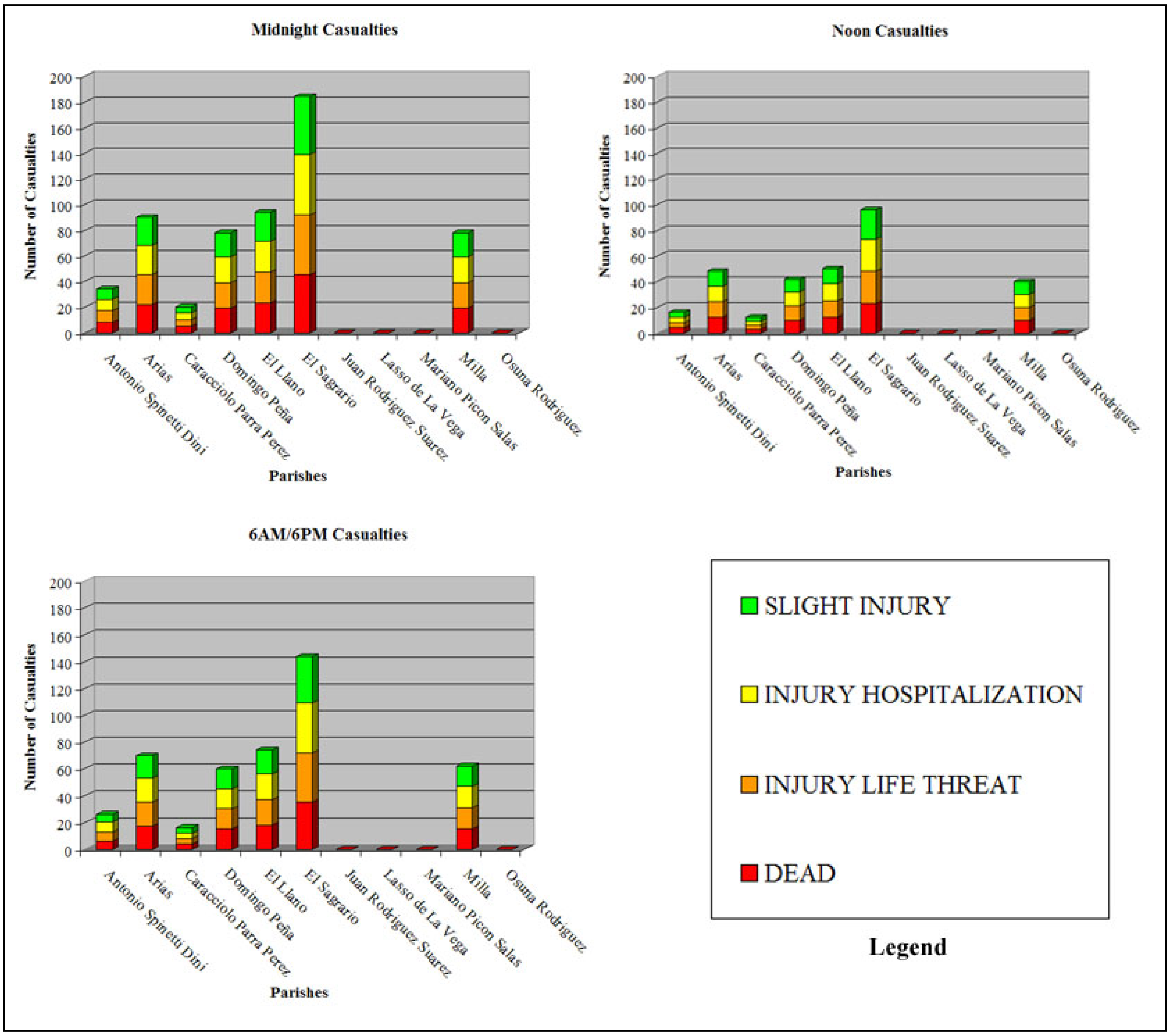


Figure 8.14: Distribution of the casualties in the parishes, for scenario event *I* = VIII.

8.8.2 Casualties for scenario event *I* = IX

The distribution of casualties at the three times of the day chosen, is shown in Figure 8.15, the total number of casualties for midnight occurrence is 8,518 victims from which 2,140 people result dead, 2,119 with life threatening injuries, 2,197 are injured requiring hospitalization and 2,062 people result slightly injured. In the first and last hours of a labor day, the total number of victims is 6,550 people, from which the death toll is 1,647 people, victims with life threatening injuries account for 1,628 people, a number of 1,690 people require hospitalization, and 1,585 people suffer slight injuries. The least affecting hour of the day is at noon, where the number of victims is around a half of those generated by the midnight hour.

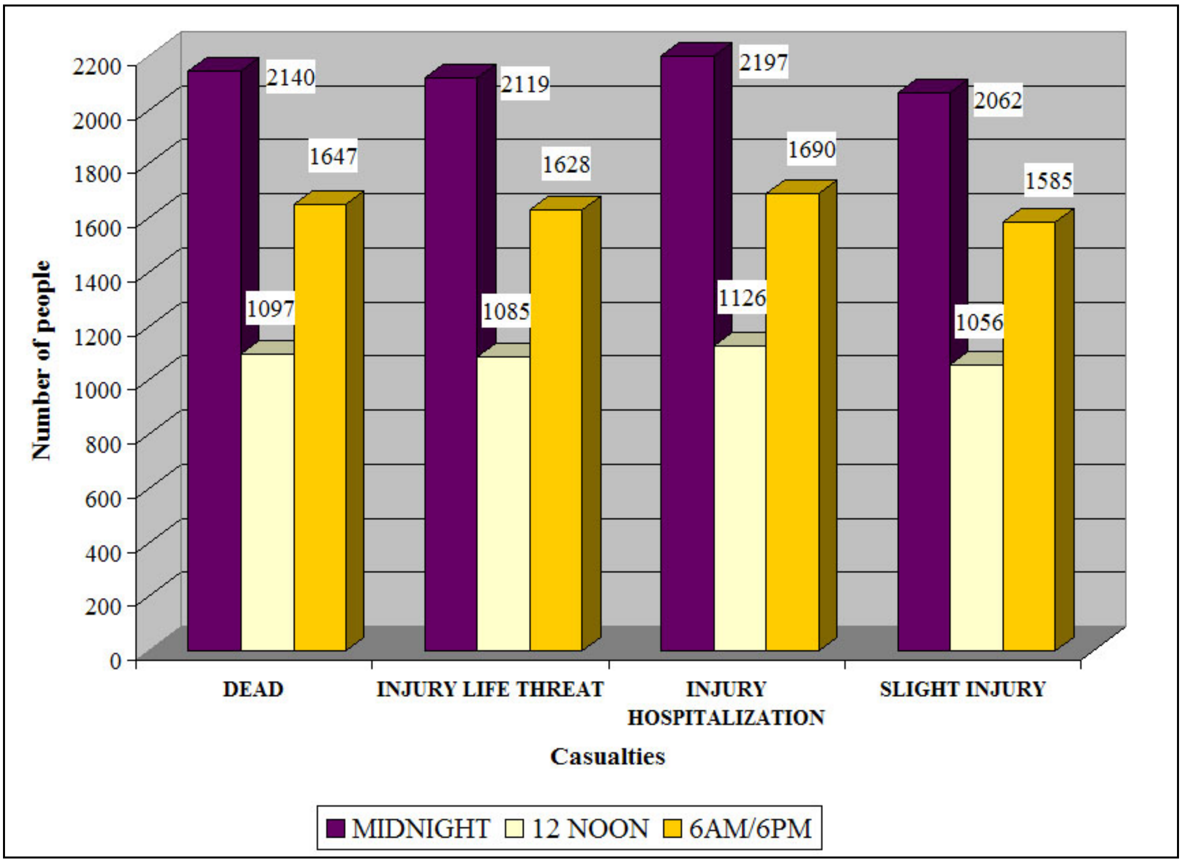


Figure 8.15: Distribution of the casualties for scenario event *I* = IX.

8.8.2.1 Casualties by parishes for I = IX

The distribution of the casualties inside each of the parishes for the three different day time considered, are shown in Figure 8.16, where once again it is noticed how an *I* = IX seismic event occurring at midnight generates the greater quantity of victims at all severity levels, and affecting mostly the parishes where the M2 and NENG-RC buildings are more common. In this fashion, the most affected parishes are the Milla, the El Sagrario, and the Domingo Peña parishes, with a total number of casualties (at different severity levels) of 1,924 people, 1,816 people and 1,418 people injured, respectively. In decreasing order of victims, the following parishes are observed: the Arias parish with 1,054 casualties, the El Llano parish with 992 casualties, the Antonio Spinetti Dini parish with 868 casualties, and the Caracciolo Para Pérez parish with 406 casualties. The least affected parishes are the Mariano Picón Salas with 36 casualties, and the Lasso de La Vega with only 4 casualties (1 victim for each injury severity level). The two remaining parishes: the Juan Rodríguez Suárez and the Osuna Rodríguez parishes have no casualties within their premises.

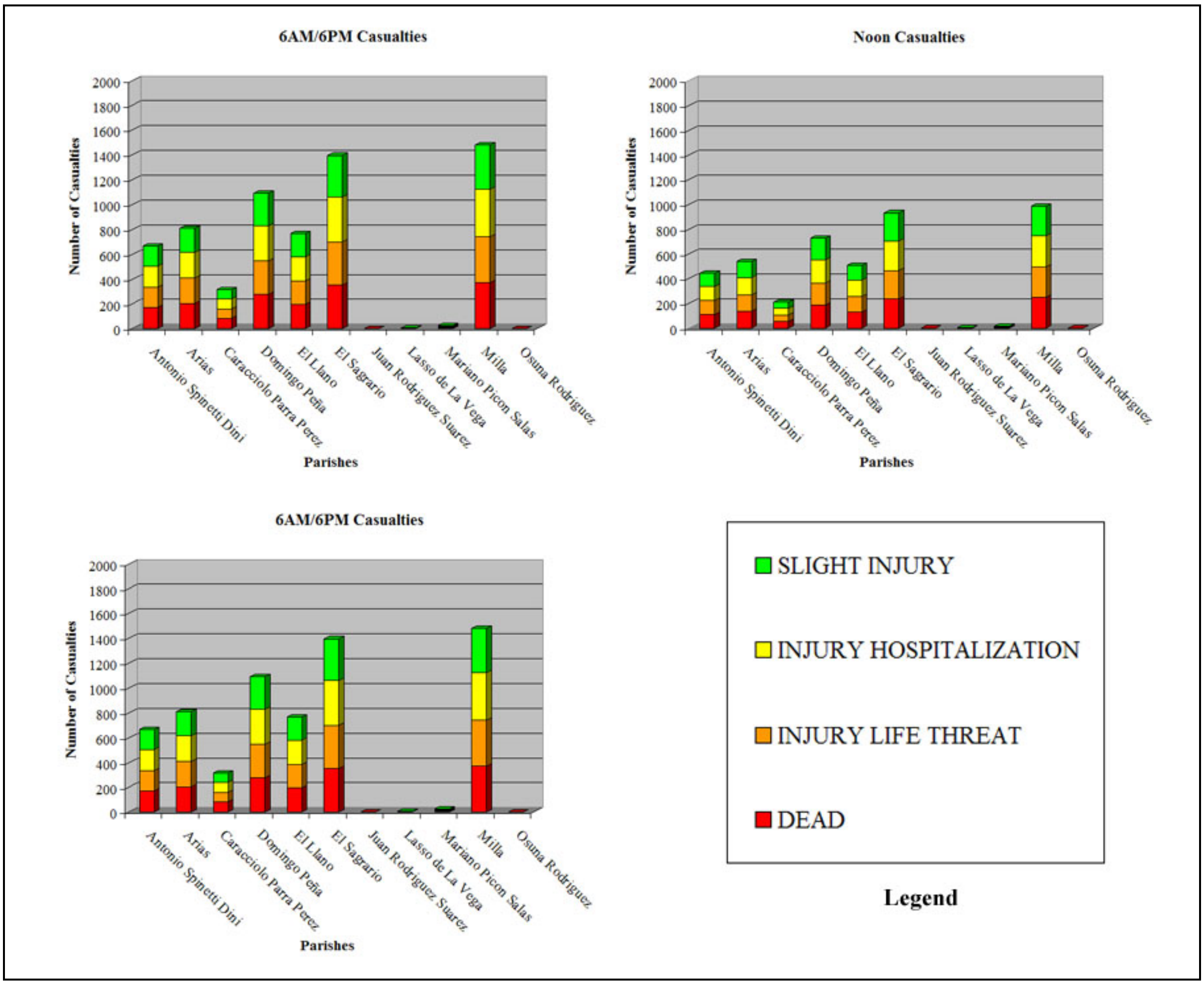


Figure 8.16: Distribution of the casualties in the parishes, for scenario event *I* = IX.

Taking into account the number of casualties for each of the scenario events, and the capacity of the major hospital in Mérida (the University Hospital, with 586 beds), it might be said that for the *I* = VIII scenario event occurring at midnight, the hospital will present difficulties in attending around 300 injured needing hospitalization, from which around a half are expected to receive immediate surgical attention. For the case of an *I* = IX event occurring at the same hour of the day, the hospital is expected to collapse in service and attention, as the demand of beds (over 4,000 injured, where near the half requires immediate surgical attention) is around seven times the full capacity of the hospital. The hospital is located inside the Domingo Peña parish, which presents a number of casualties requiring hospitalization of around 700 people, thus, the demand of beds for this parish is expected to be 1.2 times the capacity of the hospital in beds.

8.9 Summary

A series of damage scenarios, using the Damage Probability Matrices based in the WP4-LM1 methodology, are generated for the city of Mérida. The damage descriptors used are those from the European Macroseismic Scale [EMS, 1998] and the Vision 2000 document [SEAOC, 1995], which are similar in the different damage levels descriptions. The scenarios are presented in the fashion of maps, generated by means of a Geographical Information System (GIS), which in this case is the ArcView® software. Additional information is available, for each of the scenario events, by means of estimating the damage generated inside the parishes that conform the study zone, an order of damage from most to least damaged parishes (as damage takes greater percentages of buildings within the parish) may be established, also, if the number of damaged buildings are estimated inside these political units, the results indicate that the parishes containing the settlements called “Barrios” accumulate greater quantities of damage at the superior damage grades. In the same fashion, the distribution of the typologies within the parishes allows to rapidly foresee the damage grades distribution inside the parishes based in the predominant building typology inside these, along with the information on the mean damage grade of the typology at a given macroseismic intensity.

The building typologies distribution for the parishes is shown in Table 8.12, where the greater percentage of buildings belonging to a certain typology are identified in bold numbers; as is, the M2 building typology is predominant in the Arias and the El Sagrario parishes, with percentages around 45%; typology NENG-RC is predominant in the Antonio Spinetti Dini, the Domingo Peña, and the Milla parishes, with percentages from around 50% and up to 64%; buildings belonging to the RC3.2 typology are predominant in the El Llano parish, with a percentage around 35% of the buildings in the parish. Buildings belonging to the RC3.1 typology are predominant in the parishes: Caracciolo Parra Pérez (55% of the buildings in the parish), Juan Rodríguez Suárez (99% of the buildings), Lasso de La Vega (74% of the buildings), Mariano Picón Salas (84% of the buildings in the parish), and in the Osuna Rodríguez parish (100% of the buildings).

PARISH	R	M2	NENG-RC	RC3.2	RC3.1	RC5	S1
Antonio Spinetti Dini	0.8	11.53	**58.04**	0.59	26.73	1.56	0.76
Arias	0.23	**43.01**	27.97	18.18	10.02	0	0.58
Caracciolo Parra Perez	0.27	11.4	29.4	3.57	**54.62**	0.07	0.67
Domingo Peña	0.04	12.95	**64.03**	14.92	8.07	0	0
El Llano	0	23.69	15.39	**35.54**	25.06	0	0.32
El Sagrario	0	**46.59**	13.8	33.85	5.26	0	0.49
Juan Rodriguez Suarez	0	0.06	0.18	1.05	**98.46**	0.06	0.18
Lasso de La Vega	0	0.68	14.58	8.47	**74.24**	2.03	0
Mariano Picon Salas	0.1	1.96	6.1	0.31	**83.97**	7.55	0
Milla	1.55	18.95	**47.08**	4.7	26.43	0.15	1.14
Osuna Rodriguez	0	0	0	0	**100**	0	0

Table 8.12: Building typologies distribution by parishes.

A compact manner of estimating damage distribution is available with the WP4-LM1 methodology, as the predominant building typologies in the parishes may be related with the mean damage grade for each typology at the intensities considered. In this fashion, observing Figure 8.17, the mean damage grades for the typologies at intensity I = VI show that the mean damage expected is below Damage Grade 1 for six out of the seven typologies (except the R typology which is slightly over Damage Grade 1), this forecast is verified in the damage grades distribution by parishes obtained for that intensity (Table 8.13), where the predominant damage grade for all parishes is Damage Grade 0. However this damage grade is predominant, important percentages of Damage Grade 1 are observed in the Arias and in the El Sagrario parishes, where the percentages are around a 25% of the buildings in the parish, which is due to the predominance of the M2 typology within these parishes. The same relationship may be practiced for the rest of the scenario events, the results for the damage grades distribution are shown in: Table 8.14 for I = VII, Table 8.15 for I = VIII, and Table 8.16 for I = IX scenario event.

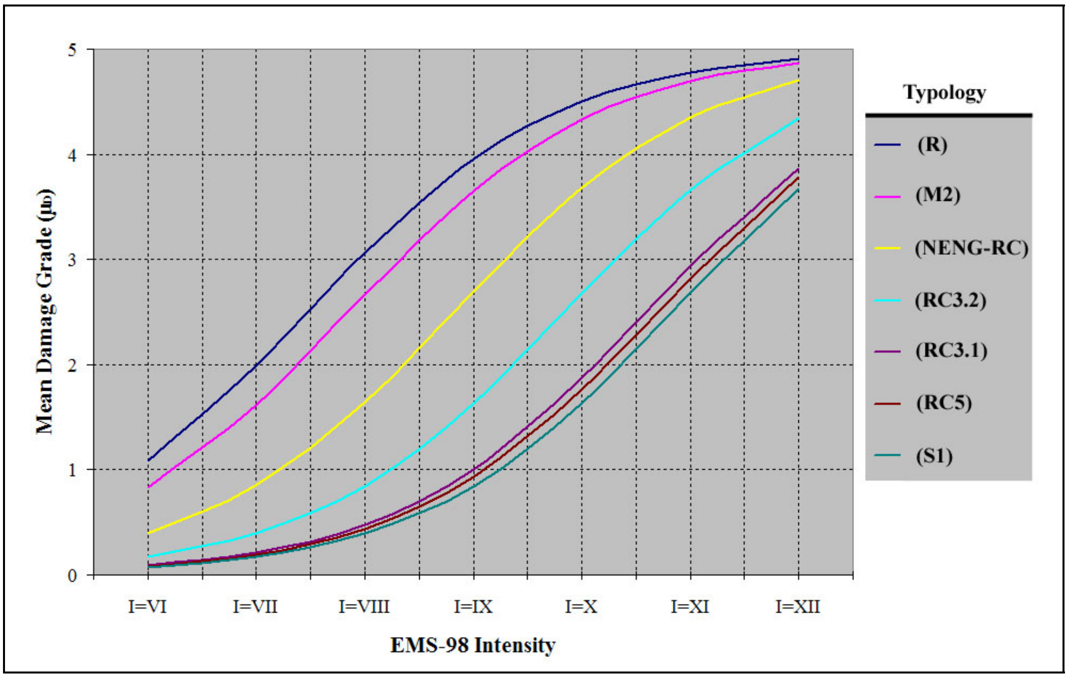


Figure 8.17: Mean semi-empirical vulnerability functions.

PARISH	DG0	DG1	DG2	DG3	DG4	DG5
Antonio Spinetti Dini	79.26	**16.22**	3.89	0.63	0	0
Arias	63.47	**24.82**	9.37	2.34	0	0
Caracciolo Parra Perez	84.94	**11.68**	2.97	0.41	0	0
Domingo Peña	73.82	**19.88**	5.31	0.95	0.04	0
El Llano	75.04	**17.29**	6.04	1.63	0	0
El Sagrario	58.42	**26.39**	12.12	3.07	0	0
Juan Rodriguez Suarez	95.57	**4.06**	0.37	0	0	0
Lasso de La Vega	93.56	**5.76**	0.68	0	0	0
Mariano Picon Salas	95.02	**4.57**	0.42	0	0	0
Milla	76.7	**17.63**	4.96	0.71	0	0
Osuna Rodriguez	96.09	**3.35**	0.56	0	0	0

Table 8.13: Scenario *I* = VI damage distribution in parishes.

PARISH	DG0	DG1	DG2	DG3	DG4	DG5
Antonio Spinetti Dini	53.25	**28.79**	13.36	3.96	0.63	0
Arias	36.76	**29.17**	21.00	10.27	2.80	0
Caracciolo Parra Perez	67.12	**20.57**	9.07	2.84	0.41	0
Domingo Peña	44.35	**32.78**	16.46	5.46	0.95	0
El Llano	54.01	**23.89**	14.33	6.32	1.46	0
El Sagrario	34.16	**27.28**	22.22	12.85	3.48	0
Juan Rodriguez Suarez	87.08	**10.82**	1.97	0.12	0.00	0
Lasso de La Vega	82.31	**13.27**	3.74	0.68	0.00	0
Mariano Picon Salas	87.07	**10.11**	2.40	0.42	0.00	0
Milla	51.22	**28.19**	14.59	5.33	0.67	0
Osuna Rodriguez	90.96	**7.91**	1.13	0.00	0.00	0

Table 8.14: Scenario *I* = VII damage distribution in parishes.

Parish	DG0	DG1	DG2	DG3	DG4	DG5
Antonio Spinetti Dini	27.57	**28.16**	24.78	14.55	4.65	0.30
Arias	16.30	22.54	**24.74**	21.97	12.37	2.08
Caracciolo Parra Perez	44.63	**25.25**	16.75	9.79	3.38	0.20
Domingo Peña	17.74	**29.05**	28.37	17.78	6.47	0.61
El Llano	28.65	**27.52**	20.18	14.37	7.75	1.53
El Sagrario	13.88	22.15	**23.31**	22.40	15.21	3.06
Juan Rodriguez Suarez	63.68	**27.23**	7.68	1.35	0.06	0.00
Lasso de La Vega	60.20	**25.17**	10.54	3.40	0.68	0.00
Mariano Picon Salas	67.36	**22.91**	7.11	2.20	0.42	0.00
Milla	27.20	**26.46**	24.09	15.63	6.12	0.50
Osuna Rodriguez	72.32	**22.03**	5.08	0.56	0.00	0.00

Table 8.15: Scenario *I* = VIII damage distribution in parishes.

Parish	DG0	DG1	DG2	DG3	DG4	DG5
Antonio Spinetti Dini	10.83	18.83	23.99	**25.22**	17.01	4.10
Arias	5.21	12.50	19.10	24.31	**25.46**	13.43
Caracciolo Parra Perez	20.05	**27.01**	21.67	16.95	11.28	3.04
Domingo Peña	4.73	14.61	24.79	**28.88**	21.01	5.98
El Llano	8.92	21.49	**23.84**	20.84	16.14	8.76
El Sagrario	2.81	11.99	19.19	23.16	**25.72**	17.12
Juan Rodriguez Suarez	26.77	**39.75**	23.94	8.12	1.35	0.06
Lasso de La Vega	28.14	**35.59**	21.36	10.51	3.73	0.68
Mariano Picon Salas	32.29	**37.93**	19.75	7.21	2.40	0.42
Milla	10.77	18.16	22.59	**24.17**	18.30	6.01
Osuna Rodriguez	35.03	**40.11**	19.21	5.08	0.56	0.00

Table 8.16: Scenario *I* = IX damage distribution in parishes.