Programme opérationnel Interreg IVA

France-Espagne-Andorre 2007 – 2013

SISPYR

Sistema de Información Sísmica del Pirineo

Système d'Information Sismique des Pyrénées

Sistema d'Informació Sísmica dels Pirineus

Risk scenarios of level 0 in French departments: Haute-Garonne, Ariège, Aude and Pyrénées-Orientales

Action 4 – Sub Action 4.2

Main contributor: BRGM

2012-12-31

Auteurs: Daniel Monfort [5]

Keywords: seismic risk, seismic hazard, vulnerability, damage

1. IGC, Institut Geològic de Catalunya

2. OMP, Université Paul Sabatier, Observatoire Midi-Pyrénées

3. UPC, Universitat Politècnica de Catalunya

4. IGN, Instituto Geografico Nacional

5. BRGM

CONTENTS

TABLE OF ILLUSTRATIONS

1. Introduction

1.1. *General context*

The European project SISPyr, supported by POCTEFA 2007–2013 France-Espagne-Andorre involves the following partners: IGC (Institut Geològic de Catalunya) as leader, OMP (Observatoire Midi-Pyrénées) and BRGM (in France), IGN (Instituto Geográfico Nacional) and UPC (Universitat Politècnica de Catalunya) in Spain.

This program aims to federate different seismic networks with ultimate goals which are to get the response to a seismic crisis in Pyrenees better. Four main actions are developed:

- Seismic observation with exchange and sharing of seismological data all over he Pyrenees ;
- New knowledge on seismic hazard ;
- Development of automatic ground motion map in all Pyrenees (shake-map)
- Realisation of seismic scenarios in some particular places (pilot zones) in the Pyrenees.

This report treats with this last action. It presents seismic damage scenario for 4 French departments on the French side of Pyrenees.

1.2. *Level 0 seismic scenarios*

Within SISPYR project several seismic damage scenarios for 4 departments in French side of the Pyrenees: south Haute-Garonne, south Ariège, south Aude and Pyrénées-Orientales.

Figure 7 shows the 4 departments, including the Pyrénées Orientales which has been assessed in ISARD project using the building typology matrix which is implemented in Catalonia (Chavez 1998) to assess the current building vulnerability (Irizarry et al. 2007). The present work uses adapted typology matrix to the French construction evolution and French dwelling stat data. The seismic damage scenarios defined are the result of combining the several method and approaches used to evaluate the seismic hazard and vulnerability of the pilot zone.

Level 0 scenarios are based on simply correlations between dwelling stat data and building vulnerability classes according the EMS-98 scale (Grünthal, 1998). Based on the damage probability distribution obtained, losses can be calculated in terms of damages:

- to the building stock ;
- to population using the procedures proposed by Spence and Coburn (2002) and its adaptation used in RISK-UE project in Nice (Mouroux et al. 2004).

The objectives of Level 0 scenarios could be:

- Awareness of local institutions and population about risk
- Help decisions of civil protection services
- Identify the zones where supplementary risk studios are needed, use this maps as a prioritization criteria
- Integration of these scenarios in software which generates automatic risk scenarios as it has been done in Catalonia (SISMICAT).
- Preparation of seismic risk exercises for Civil Protection.

2. Level 0 vulnerability assessment

2.1. *Building typology*

Level 0 vulnerability assessment consists of applying a statistical method based on the classification of the building stock according to the EMS-98 vulnerability classes (Grünthal, 1998). Figure 1 shows the vulnerability classes associated by the EMS-98 scale to common structures of masonry, reinforced concrete, steel and wood indicating the most likely, the probable range and the range less probable for the vulnerability class for the structural types considered.

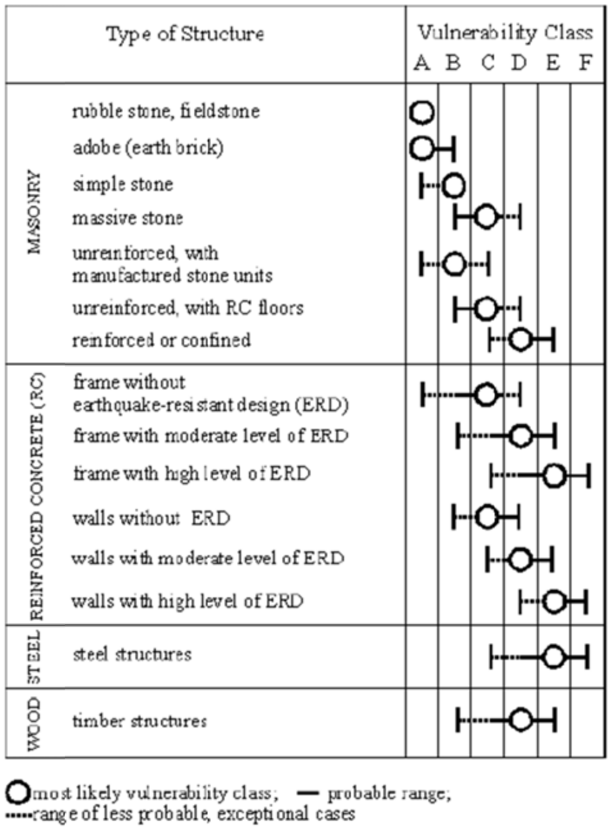


Figure 1: EMS-98 vulnerability classes (Grünthal, 1998).

Scenarios at level 0 consists to correlate this main building types coming from Grunthal et al. (1998) with the national dwelling stat data as a function of building ages.

The building typology in France – with a seismic point of view - depends on two main factors (Sedan et al. 2008): 1) history of technology and construction practices and 2) the development of constructive and seismic codes.

The historic building techniques in France are marked by different periods such as those related to the post-war, decolonization and economic growth:

- Pre-war: in general use of traditional technics, it means, unreinforced masonry
- 1945 -1950: reconstruction using conventional techniques of pre-war
- 1950 -1960: first prefabricated systems and new systems of reinforced concrete
- 1960 -1970: significant technological advances in the construction of prefabricated concrete elements, construction of towers and large buildings.
- 1970 -1980: consideration of horizontal forces in the methods of structural design, building construction of medium size and development of individual housing.
- Post-1980: gradual application of seismic codes.

The first codes of earthquake-resistant construction dates from 1971 (code PS69). These were then modified in 1982 (code PS69/82), then followed by the code PS92. New seismic code has been published in 2010 but it is not yet applied. It is possible to distinguish schematically two major periods:

- Before 1970: seismic codes do not exist,
- After 1970: Publication of seismic codes.

Before the first seismic codes, standards or other codes of calculation have been imposed on the construction: 1) to better reflect the new characteristics of materials (discovered after 1945 and widely used), but also 2) in 1960 to take into account the effects of snow and wind through the integration of horizontal forces in the calculation of structural design. The firsts bracing systems developed and implemented in France were after the Snow and Wind codes.

Based on these criteria and field visits on the study area Bouches du Rhone department, the project SDRS Bouche du Rhone (Seismic Risk Scenarios for the Department Bouches du Rhone) (Sedan et al. 2008) present a building typology for a simplified scenario risk level 0, which is a cross between the age of construction, number of storeys and type of construction. Each type of building is classified according to vulnerability classes of EMS98 scale.

Age / Etage	avant 15 et de 15 à 48				de 49 à 67 et de 68 à 74				de 75 à 81 et de 82 à 89				à partir 90				
	Type construction	Classe			Type construction	Classe			Type construction	Classe			Type cons-truction	Classe			
		A	B	C		B	C	D		C	D	E		C	D	E	F
1-2	Moellon brut/pierre tout venant				Maçonnerie de briques non renforcée/blocs de béton/éléments préfabriqués				Maçonnerie de briques non renforcée/ Blocs de béton avec niveau moyen de CPS				Tous types des systèmes de constructions calculés intégrant un niveau élevé (qualifié) de CPS				
3-5	Pierre brute/Pierre massive/ Béton sans CPS				Préfabriqué en béton armé avec niveau faible ou minimal de CPS				Maçonnerie porteuse/ Préfabriqué en béton armé avec niveau moyen CPS								
6-8	Pierre massive/ Béton sans CPS				Préfabriqué/ Mixte avec niveau faible ou minimal de CPS				Préfabriqué/ Mixte avec niveau moyen de CPS								
+8	Béton sans CPS				Mixte en béton armé avec niveau faible ou minimal de CPS				Mixte en béton armé avec niveau moyen de CPS								
Avec :				*Classe la plus probable*				*Classe la moins probable*					*Cas exceptionnel*				

Figure 2: Building typology proposed into SDRS-Bouche du Rhone project in order to assess the seismic risk in level

The types defined by the SDRS take into account four main periods of construction in four classes of number of floors. This time periods are directly the same ones used by the French Stats Institute (INSEE).

This building typology matrix, which has been created in Bouches de Rhone department (south-east of France near Marseille), has been adapted to the French Pyrenees context. During the Level 1 field survey done in Bagneres de Luchon sector (Haute Garonne department) (Monfort et al. 2012) (Figure 6) the main building typologies identified were:

- Traditional housing (2-3 levels), with stone masonry, built before 1950.
- Individual housing, with unreinforced masonry, built between 1950 and 1980.
- Recent individual housing (last 20 years), unreinforced masonry and sometimes reinforced masonry.
- Old apartment buildings, built before 1950, stone masonry, RC elements.
- Apartment buildings built during 1960-1970's, masonry and RC frames.

- Recent apartment buildings with high – medium seismic code.

According to field trip some modifications in building typology matrix of SDRS has been proposed in order to take into account two main phenomena:

- Individual housing built before 1950 varies between fieldstone and simple stone masonry categories (classes A and B in EMS98 scale). This distinction between two classes of vulnerability in old dwelling buildings for example has been also observed in L'Aquila downtown (Tertulliani et al. 2010).
- The application of seismic codes is not systematically applied in all individual housing built after 1990 (self-build phenomena).

Different distributions of EMS98 classes have been used in scenarios in order to take into account these phenomena and estimate the incertitude between different hypotheses (Table 1).

Achèvement période de construction	Avant 1915	1915 à 1948	1949 à 1967	1968 à 1974	1975 à 1984	1982 à 1989	1990 ou après
Nb d'étages							
1-2	T11		T12		T13		T14
3 -5	T21		T22		T23		T24
6 -8	T31		T32		T33		T34
9 et +	T41		T42		T43		T44

	Vi-	**Vi**	Vi+
T11	0.81	**0.9**	0.98
T12	0.353	**0.58**	0.83
T13	0.33	**0.49**	0.65
T14	0.19	**0.35**	0.51
T21	0.66	**0.8**	0.967
T22	0.49	**0.65**	0.81
T23	0.1934	**0.42**	0.65
T24	0.03	**0.26**	0.49
T44	0.03	0.19	0.35

	Vi-	**Vi**	Vi+
T31	0.687	**0.84**	0.98
T32	0.5	**0.64**	0.81
T33	0.19	**0.35**	0.51
T34	0.03	**0.19**	0.35
T41	0.81	**0.9**	0.98
T42	0.35	**0.51**	0.67
T43	0.19	**0.35**	0.51

Figure 3: vulnerability classes and values for the different building types proposed in SDRS building typology matrix.

Hypothesis	Individual housing < 1950	Individual housing 1950-1974	Individual housing 1974-89	Individual housing >1990
H1 (SDRS13)	100% A	100%C	50%C 50% D	100% D
H2	50% A 50% B	100% C	50%C 50% D	50% D 50% C
H3	30%A 70%B	100% C	80% C 20% D	80% C 20% D
H4	30%A 70%B	20% B 80% C	20% B, 50% C, 30% D	80% C 20% D
H5	30%A 70%B	50%B 50% C	20% B, 50% C, 30% D	80% C 20% D

Figure 4 : different hypothesis of distributions of seismic vulnerability for individual housing tested in the whole zone

Each EMS98 vulnerability class is transformed in vulnerability index based on the Figure 5 plot (vulnerability index interval for each EMS class).

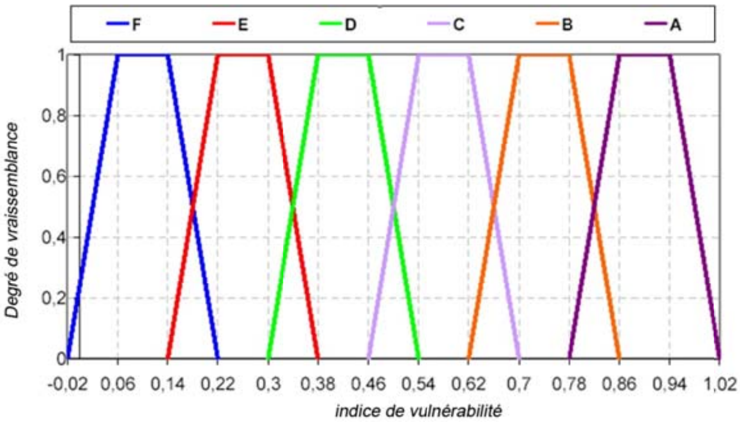


Figure 5 : correspondence between vulnerability classes from EMS98 scale and vulnerability index.

Mean damage is calculated with the following equation (mean damage depends on the simulated macroseismic intensity and the vulnerability index). The whole methodology to estimate damage distribution for the whole building stock has been exposed by Sedan et al. (2012), Sedan et al. (2008) and Giovinazzi (2005).

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25\,V_I - 13.1}{2.3}\right)\right]$$

 Traditional housing. Stone masonry. Type 11.	 Old apartment building, built before 1950. Stone masonry. Type 21.
 Individual housing, unreinforced masonry. Type 12 or 13.	 Apartment building, built between 1960 and 1980. Type 22 or 23.

	
Recent individual housing. Type 14.	Recent apartment building. Type 24.

Figure 6: examples of the main building types found in Bagneres de Luchon sector.

2.2. *Census data processing*

The risk scenarios are based on the identification of the type of building (previous chapter) and an assessment of the building distribution for each building type for each municipality or district, made with the available census data (INSEE is the French Statistics Data institute).

The Level 0 scenario needs therefore processing stats data to estimate a number of buildings for each type. In this project we have used two different INSEE census data:

- 1999 census data, with the number of individual houses and apartment buildings, the number of buildings and dwellings, classed by age and number of floors.
- 2006 census data, with the number of dwellings used as individual housing or residential buildings, classed only by period of construction.

Due to this loss of information of the new census in 2006 (information about the number of floors of apartment buildings has disappeared), it was decided to use census data of 1999 to assess the collective housing. The 2006 census data were used to estimate the number of new apartment buildings built during the period 1999-2006.

The number of buildings that has been estimated in each typology is the total, including those who are used as a secondary residence. Population values used are those of the population living in each municipality, excluding tourist population. In the case of some municipalities (especially those with residential areas close to the alpine resorts), which present a significant number of vacant buildings or secondary, it is possible that the ratio of inhabitants per building is very low.

This work has been done for the municipalities in the departments of Haute Garonne (31), Ariege (09) Aude (11) with a seismic hazard level medium or moderate after the seismic hazard map of France and in all the municipalities in the Pyrenees-Orientales department (66).

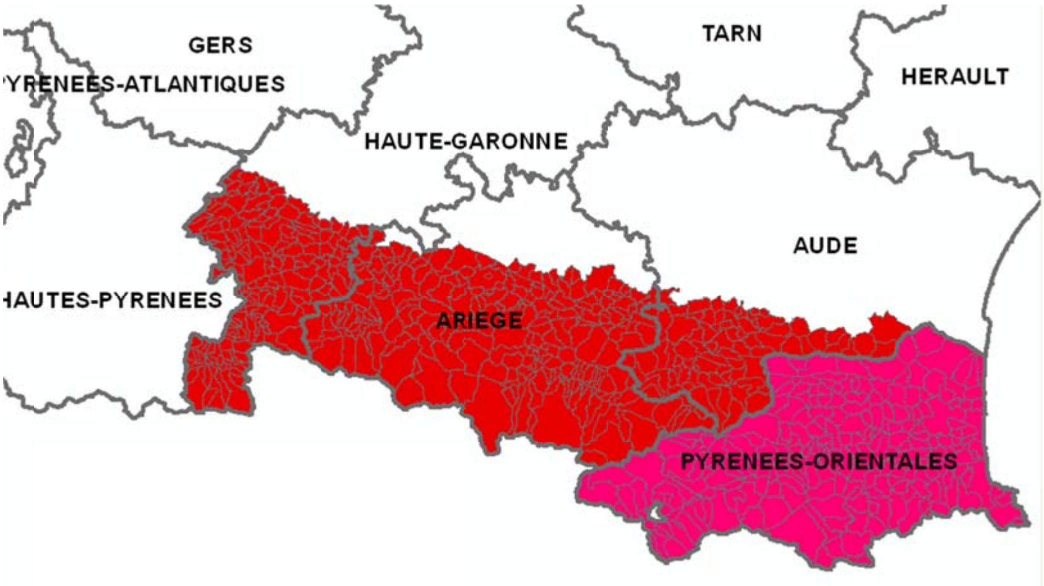


Figure 7: Location of the simulated municipalities and the departments. In pink colour the Pyrénées-Orientales department, which has been simulated into ISARD project but using another building typology (Chavez 1998).

Figure 8 presents the results of statistical treatment for the municipalities of the four departments involved in the study. The Pyrenees-Orientales department appears with a larger ratio of buildings less vulnerable because it is an area with a higher urban growth in recent decades.

	Haute Garonne	Ariège	Aude	Pyrénées-Orientales
A	13.71%	14.04%	15.56%	7.42%
B	46.96%	47.17%	49.76%	33.80%
C	30.67%	30.16%	27.05%	44.07%
D	8.59%	8.52%	7.58%	14.32%
E	0.07%	0.12%	0.05%	0.39%

Figure 8: Distribution of buildings into EMS98 vulnerability classes (hypothesis 5).

3. Risk scenarios

3.1. *Probabilistic scenarios*

3.1.1. Hazard

Probabilistic seismic hazard scenarios were performed on all municipalities. Two different sources of hazard maps have been taken into account: the seismic hazard zoning of France (MEDDAT) and the hazard probabilistic map (return period of 475 years) done during the project ISARD (Secanell et al. 2008).

The seismic hazard map in France do not attributes a unique PGA value for zone but an interval. In the present work the mean acceleration value for each interval has been considered, it means, 135 cm/s² for moderate hazard (interval 110-160 m/s²) and 230 for medium hazard level(160-300 m/s²).

These scenarios do not take into account the lithological and topographical site effects.

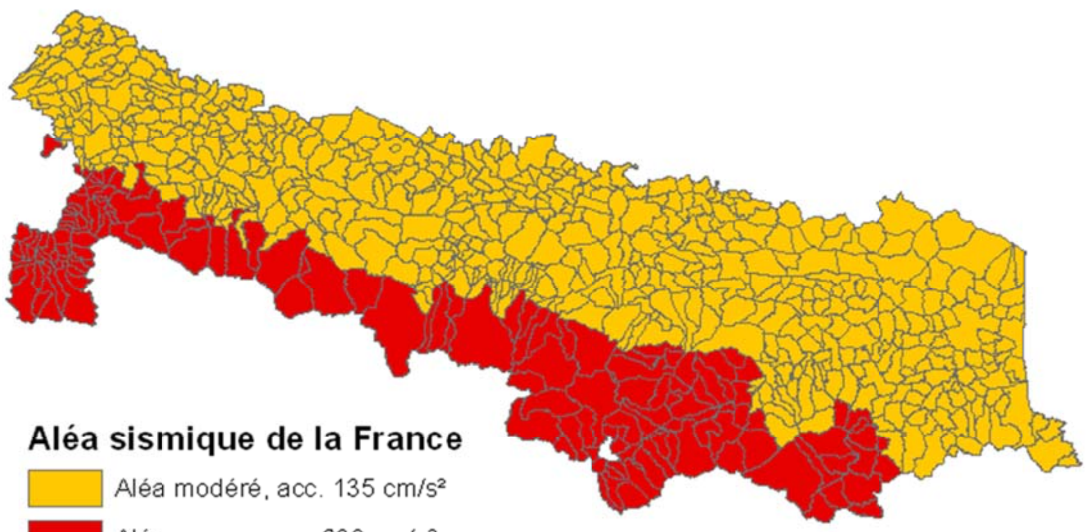


Figure 9: Map with the seismic hazard level per municipalities (source: Seismic hazard zoning of France, MEDDAT). Accelerations considered in the present scenario are, for moderate hazard level: 135 cm / s ²; for medium hazard level: 230 cm / s ².

These values of bedrock acceleration have been transformed into EMS98 intensities using the Atkinson et al. (2000) law.

For the French hazard map, the considered intensities are VII for the municipalities within Medium hazard level and VI for municipalities within Moderate hazard level.

For the ISARD hazard map intensities varies between VIII (for the municipalities in the South Haute Garonne Department) and VII (locally VI).

The intensities map can be viewed in the annex I.

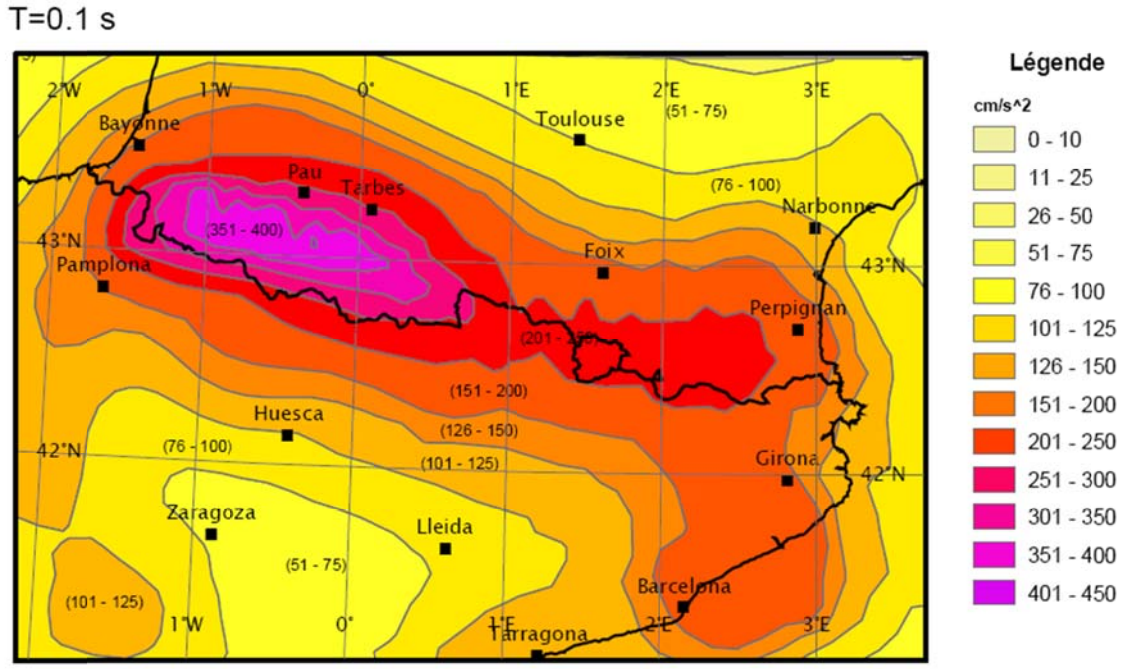


Figure 10: Map with the maximum median accelerations (at T=0.1s) for a return period of 475 years (Secanell et al., 2008) used for scenarios Level 0.

3.1.2. Results

Risk calculations in terms of damages have been calculated using Armagedom software (Sedan et al. 2012).

The different hypothesis of vulnerability distribution has been tested.

The goal was to know the influence of these different hypotheses in terms of damage ratios. The main differences are between H1: all individual building built before 1950 is in EMS98 class A and all recent individual building is in class D; and H5, with the individual housing built before 1950 between classes B and A and recent individual housing between classes C and D. In terms of damage ratio the differences between these 2 hypotheses reach the 10% in buildings in D0 damage state. In these report all the results that are shown comes from the last simulation (H5).

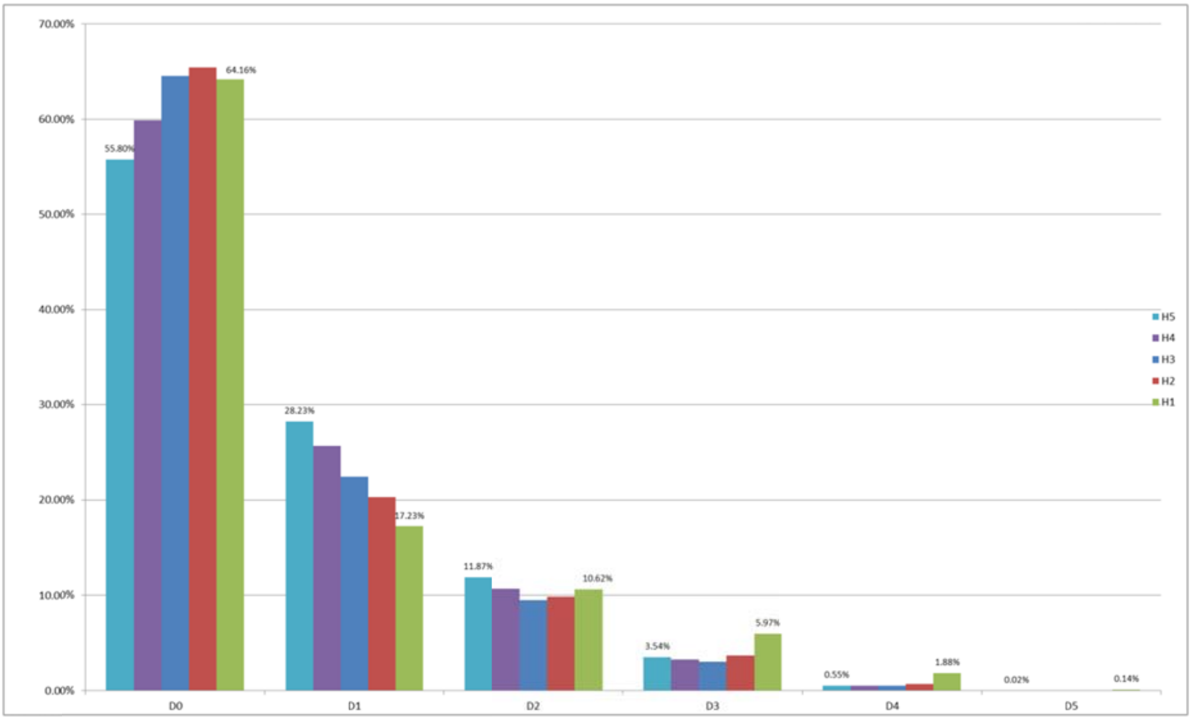


Figure 11: Damage distribution compared to EMS98 vulnerability classes distribution hypothesis

The results of the Level 0 scenarios in French departments, taking into account the two different hazard maps, shows the following results:

- Overall, the expected damage is low or very low. The damage states the most likely are D0 and D1. These results are quite coherent with the fact that intensities are low (VII and VI for the majority of municipalities).
- Intensities are greater for ISARD hazard map at T=0.1s than for French seismic hazard map so the damages ratios are greater.
- Municipalities with high percentages of recent buildings (built during the 80s, 90s and 2000s) have lower percentages of damage. It is often in municipalities with a large housing development related to tourism and ski resorts.
- On the other side, the municipalities with a very high percentage of buildings built before 1950 have a higher percentage of strong damages. Often these small rural villages do not grow since the 50s. The relative risk (in %) is high but the absolute risk (in number of damaged buildings) is very small.
- Municipalities with the greatest number of strongly damaged buildings (damage states D4 and D5) are those with a big historic centre. Human prejudices, which are directly linked to the damaged states D4 and D5 should be more important in these sectors.
- In large cities, where the number of buildings in D3 D4 D5 damage states is about some tens, the number of homeless people can reach a hundred. In the case of Perpignan, which is the largest city of the simulated area, the number of homeless would be around 2000-4000 people.

- These results are calculated for probabilistic hazards maps. It means that results at department scale have to be read in order to compare territories.

The Figure 15 plots for each municipality the absolute risk (in number of buildings in D4 D5 states) and the relative risk (in % on buildings in D4 D5 state). Some relevant points correspond to municipalities with a tradition of thermal tourism which means an important number of buildings built at the end of the XIX century and beginning of the XXth century (case of Bagneres-de-Luchon, Ax-les-Thermes, Amélie-les-Bains).

The department of Haute Garonne (31) has the highest percentage of damage, caused by a stronger hazard level. In the other side the Pyrénées Orientales department has the lowest ratios, due to a lower seismic hazard level and the fact that the area has too much recent urbanization (agglomeration of Perpignan, resorts of Argeles-sur-Mer, Canet or Barcarès).

The simulated municipalities of the department of Aude (11) have damage ratios stronger than the Pyrenees-Orientales department despite is an area with moderate hazard level. These municipalities have a low percentage of buildings constructed the last 30 years. The Ariege department (09) has similar results to the Aude, explained by hazard level between moderate and medium.

Department	Haute-Garonne (31)		Ariège (09)		Aude (11)		Pyrénées-Orientales (66)	
Hazard	ISARD	ZSF	ISARD	ZSF	ISARD	ZSF	ISARD	ZSF
Intensity EMS98	VII-VIII	VI-VII	VII-VIII	VI-VII	VII	VI	VII	VI-VII
Number of buildings in D4 D5	629	251	462	257	116	28	1084	525
% in D4 D5	1.84%	0.73%	0.83%	0.46%	0.84%	0.20%	0.56%	0.27%

Figure 12: Number and percentages of buildings in damage state D4 and D5 per departments

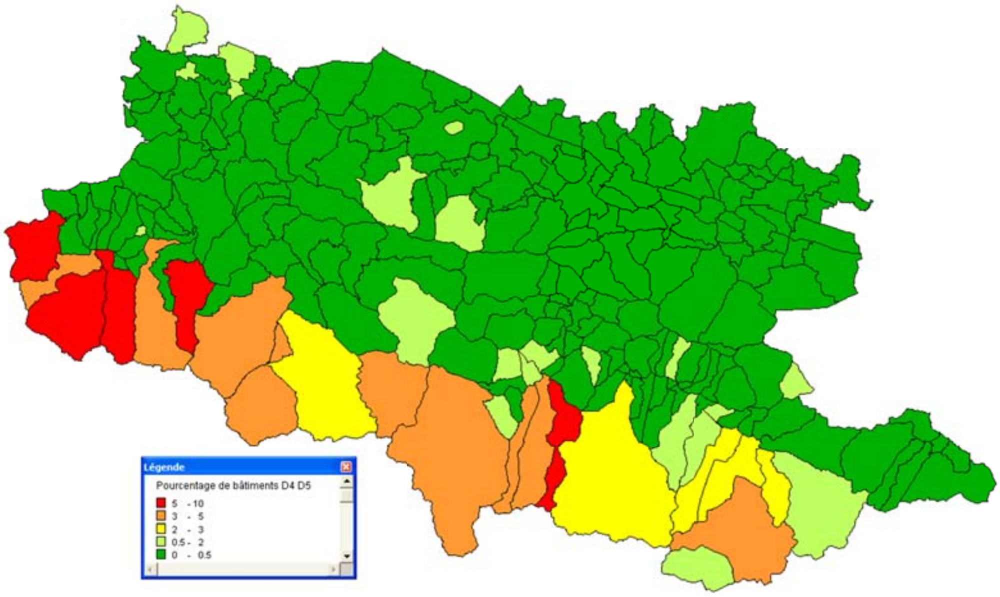


Figure 13: Example of scenario results of probabilistic seismic hazard map of France in the department of Ariege (percentage of buildings in damage states D4 and D5 per municipality)

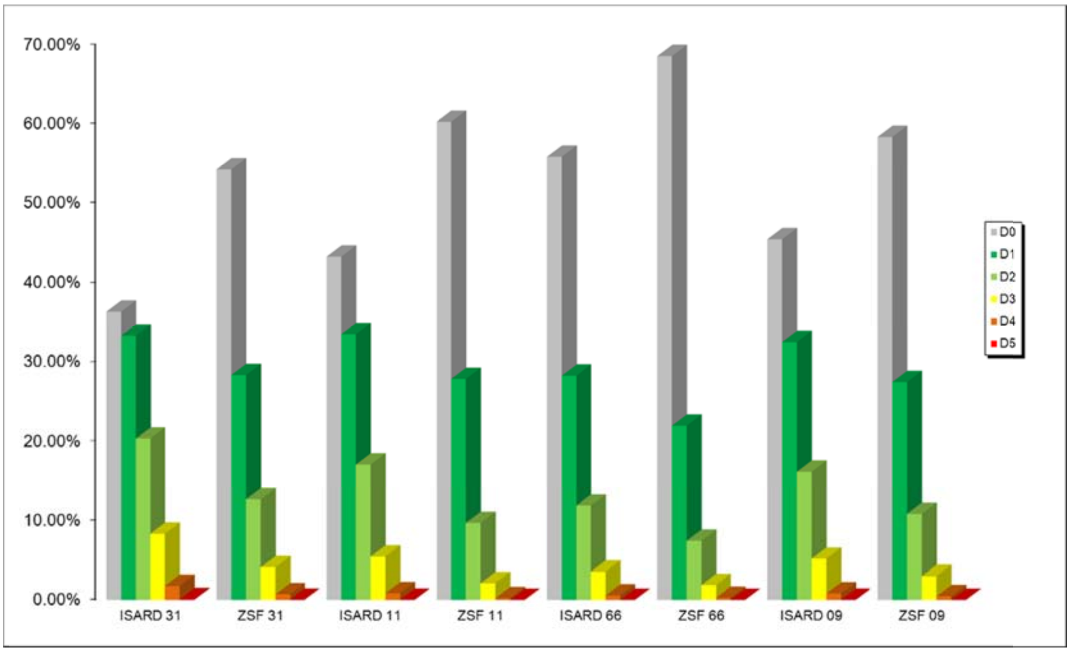


Figure 14: Graph with a summary of results of probabilistic scenarios throughout the area simulated. ISARD: scenario done with the hazard map of ISARD project, ZSF: scenario done with the French seismic hazard map. 31: Haute Garonne, 11: Aude, 09: Ariege and 66: Pyrenees Orientales.

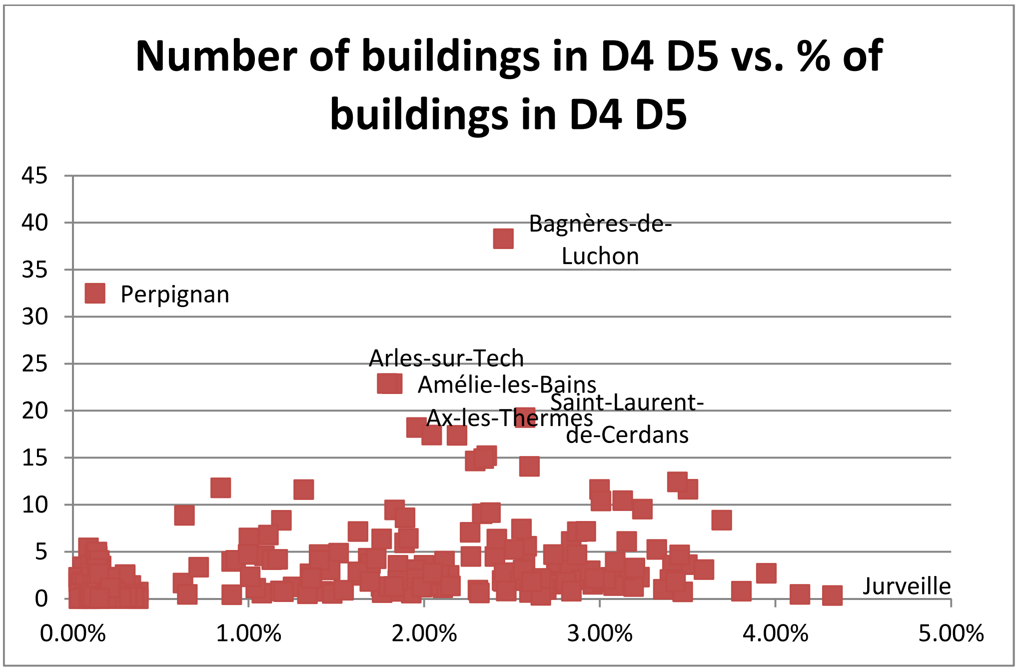


Figure 15: absolute risk (number of buildings in D4 D5 states) and relative risk (% of buildings in D4 D5 states) for French Seismic Hazard map in France

3.2. *Comparison between results using SDRS building typology and Chavez over the French Cerdanya sector*

A comparison was made between the results of the scenario of Level 0 from ISARD project, done in the French Cerdanya sector (Irizarry et al. 2007) and the results above presented in the same municipalities using SDRS building typology.

The scenario of ISARD project used classes of vulnerability and damage probability matrices proposed by Chavez (1998), implemented in Spanish Catalonia to assess the seismic risk in all the municipalities.

The comparison has been done with two scenarios, one probabilistic with the hazard map of 475-year return period proposed in the ISARD project, and a deterministic one, with the intensities of the Ripollès earthquake in 1428.

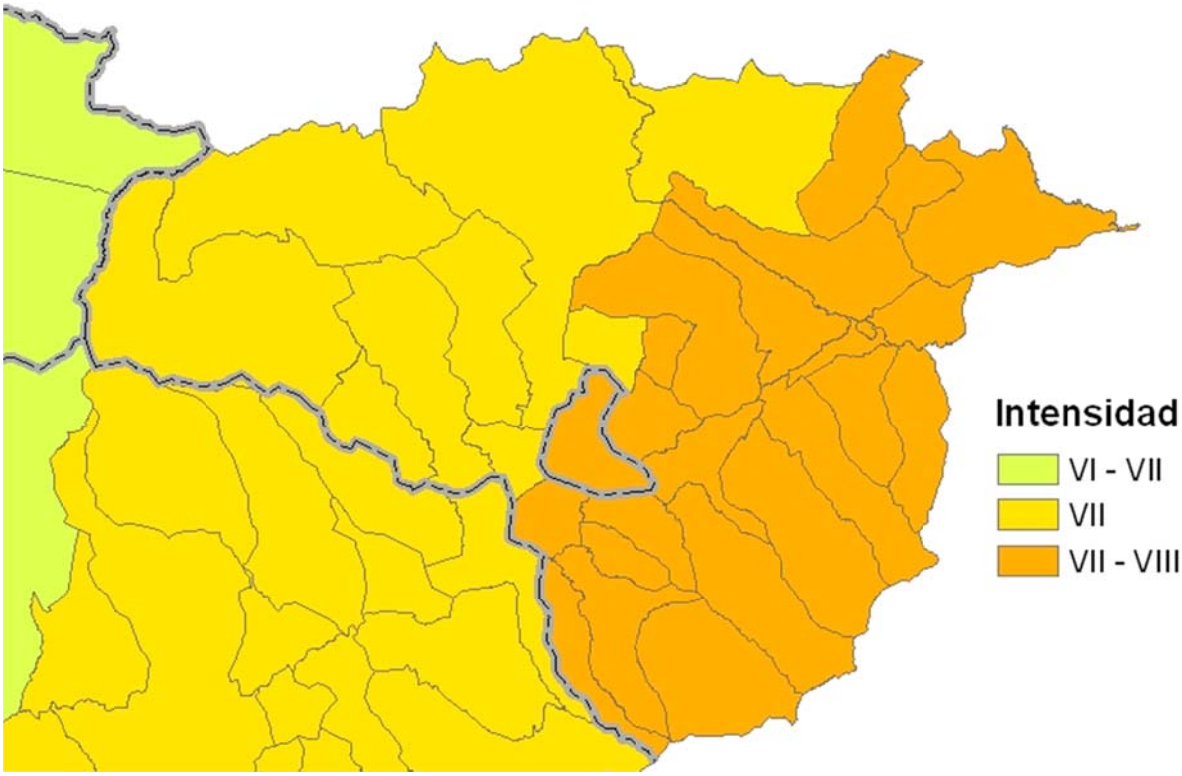


Figure 16: intensity map from the 1428 Ripollès Earthquake simulation.

In general the percentage of D0 damage state on all municipalities is larger for the scenario done with the typology of SDRS than results using Chavez. However, the addition of percentages of D1 and D0 states are more or less the same ones for the two scenarios.

The two methods consider recent constructions in different ways. Constructions made after 1970 have medium-high vulnerability for Chavez while the values of the SDRS (Sedan et al. 2008) for this period are clearly lower. This explains the large differences between the percentages of low damage (D0 and D1). Chavez (1998) considers all buildings built after 1970 in the same group of vulnerability. Instead, the SDRS typology, based on years of application of various seismic codes in France, for the same period (1970 to present) considers two groups (1974-1990 which corresponds to the first generation of seismic code in France and 1990 to present).

For other damage states, the results are more similar to each other; D4 damage state is low in the two scenarios (less than 5% on almost all municipalities) and only a small proportion can suffer collapse (D5 damage state) in the two scenarios. Vulnerability classes of two methods for old buildings (built before 1950) are quite similar.

Again, villages which have not had a lot of construction after the 1950s appear to be municipalities with the highest percentages of medium or heavy damages (D3 D4 D5 states).

Fecha de Construcción		Hasta 1950		1951-1970		Después de 1970	
Área de Localización		Urbana	Rural	Urbana	Rural	Urbana	Rural
Altura	< 5 plantas	20A+80B	30A+70B	5A+50B+45C	15A+70B+15C	85C+15D	5A+20B+65C+10D
	= 5 plantas	20A+80B	40A+60B	10A+60B+30C	20A+70B+10C	5A+20B+65C+10D	10A+30B+55C+5D
	> 5 plantas	40A+60B	60A+40B	15A+70B+15C	30A+65B+5C	8A+27B+60C+5D	15A+45B+40C

Figure 17: distribution of vulnerability classes EMS-92 established by Chavez (1998) to assess the seismic risk in Spanish Catalonia. This matrix distinguishes between urban and rural sectors, considering that constructions in rural zones are more vulnerable

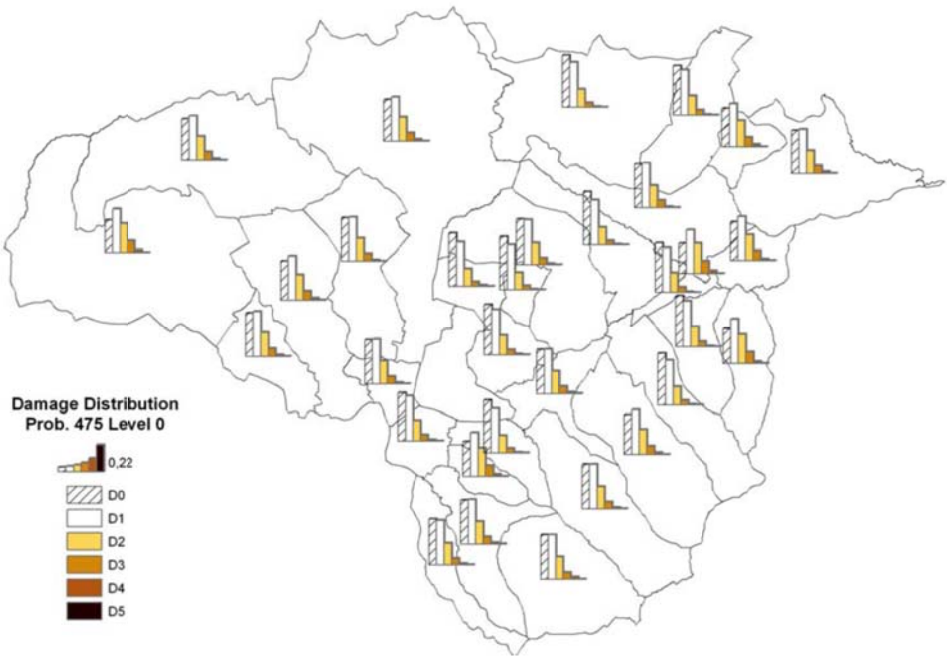


Figure 18: Level 0 probabilistic damage probability distribution for French Cerdanya municipalities (ISARD project) using building typology from Chavez (from Irizarry et al. 2007).

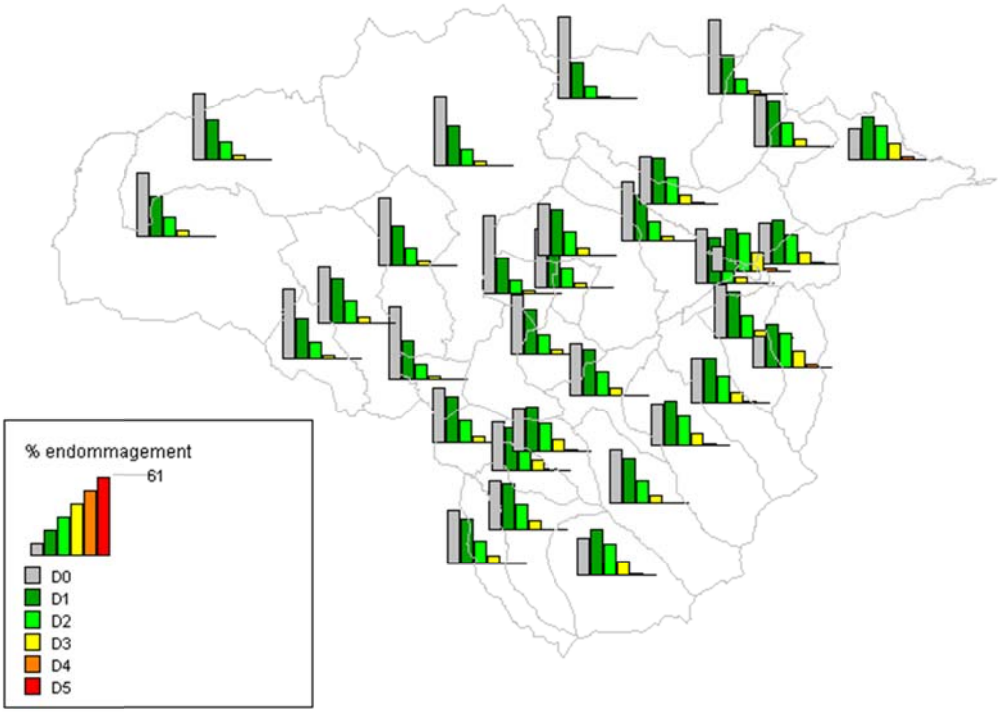


Figure 19: Results over the French Cerdanya obtained with the SDRS building typology and with intensity VII (hazard map of 475-years period return from ISARD project).

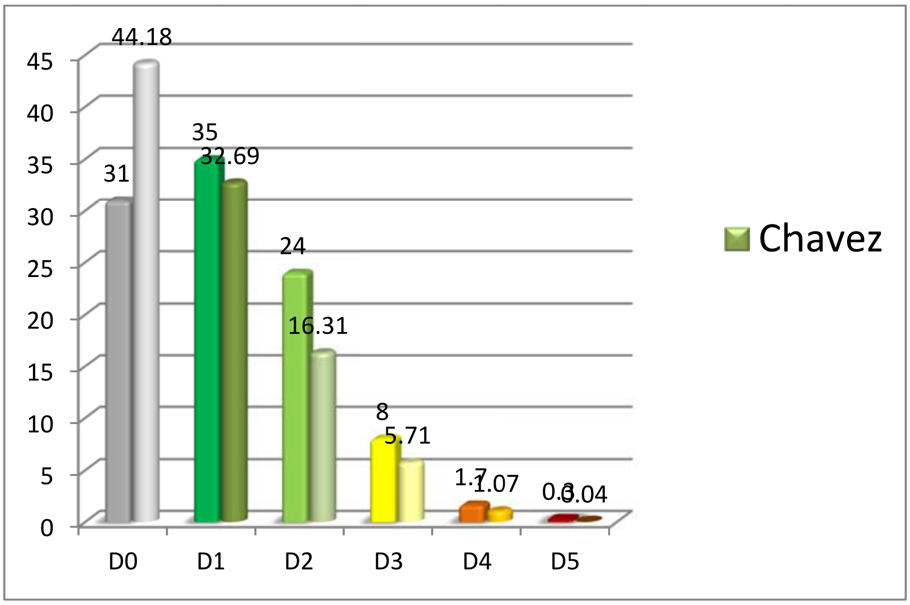


Figure 20: Comparison between the results of ISARD project and the results obtained for the French Cerdanya with the SDRS building typology in a deterministic scenario (Ripollès earthquake 1428).

3.3. *Saint Paul de Fenouillet 1996 earthquake scenario*

A simulation of the earthquake in St. Paul Fenouillet in 1996 was made with the building typology used in the SDRS Bouche du Rhone study.

On February 18, 1996 an earthquake of magnitude 5 struck St. Paul Fenouillet (Pyrenees Orientales, East of the Pyrenees). The magnitude values provided the same day of the earthquake vary in a broad range: Ml 5.6 (ReNaSS), 5.5 M (LDG), M 5.1 (SISMALP) M 5.3 (ING, Rome), Mb 5.0 (IGN Madrid), Ml 5.3 (ICC / CMS) and Mb 4.8 (USGS). The intensity in the epicentral area did not exceed the level VI on the MSK scale (minor damages) (AFPS 1996).

MSK	EMS-98
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	–[a]

_a : this intensity is defined in such a way that it relates to phenomena that do not represent strength of shaking, e.g. those due to surface faulting, or reaches a saturation point in the scale where total damage refers to total damage to buildings without antiseismic design.

Figure 21: Non-prescriptive guidelines to conversion from MSK scale to EMS-98

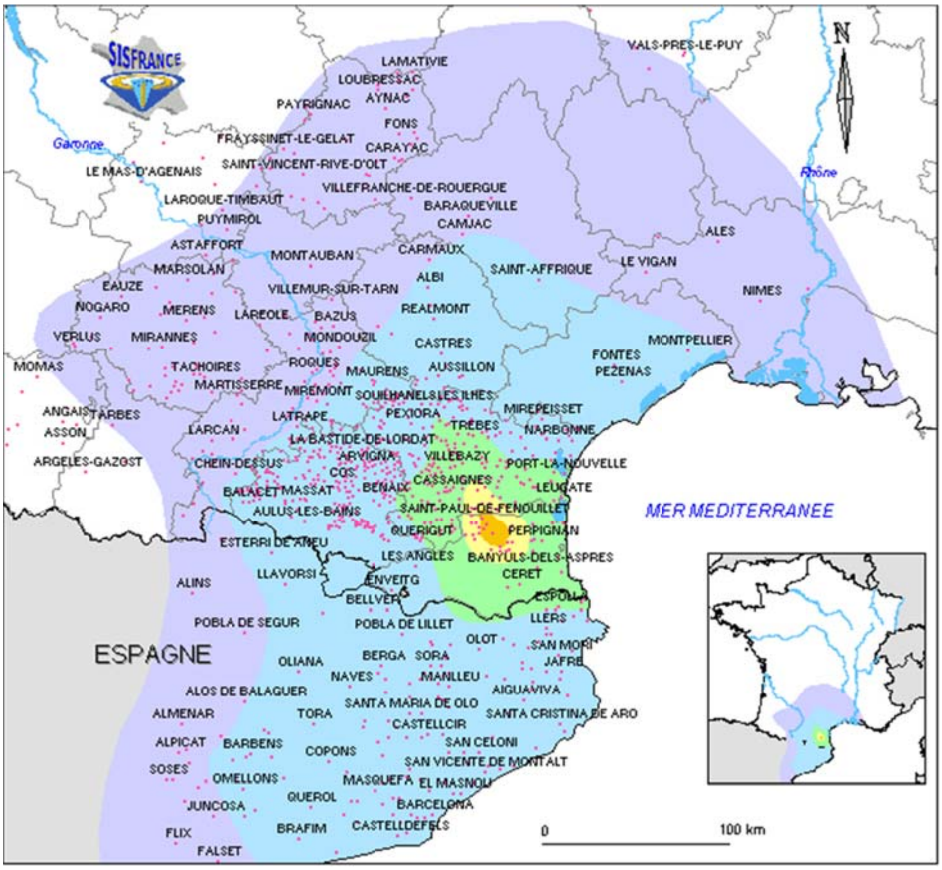


Figure 22: observed intensities of Saint Paul de Fenouillet earthquake (from Sisfrance website)

Intensity degree (Macroseismic scale MSK) 2 et 2.5 : hardly perceptible 3 et 3.5 : weak (felt by some people) 4 et 4.5 : largely observed 5 et 5.5 : fairly strong (majority of people) 6 et 6.5 : strong (slight damages)

For the simulation of the earthquake the following parameters were considered:

- Magnitude: 5
- Depth: 13 km
- Attenuation law: Campbell and Bozornia reverse fault.
- No topographic or lithological site effects
- Types of building and vulnerability classes from SDRS 13

The scenario was simulated for all municipalities in the department of Pyrenees-Orientales and the municipalities of the Aude department with moderate seismic hazard level (based on the seismic hazard map of France).

The intensity varies between VI in the epicentral area and IV on the rest of municipalities farthest from the epicentre (Figure 22). These results are quite consistent with the results of post-seismic surveys presented above.

The only number that allows comparison of scenario results with field observations is the report of 300 new cracks on houses after the earthquake in Saint Paul de Fenouillet (AFPS mission report). The estimated total number of buildings in D1 D2 and D3 damage states in this municipality varies between 200 and 280.

The small magnitude of this earthquake do not allows continuing the back analysis. The result is in the same order of magnitude of damage than observations, but this is not sufficient to confirm or validate the method. Even one hypothetical scenario done with extreme vulnerability classes everywhere would give results with a relatively low ratio of damage and not too far from reality.

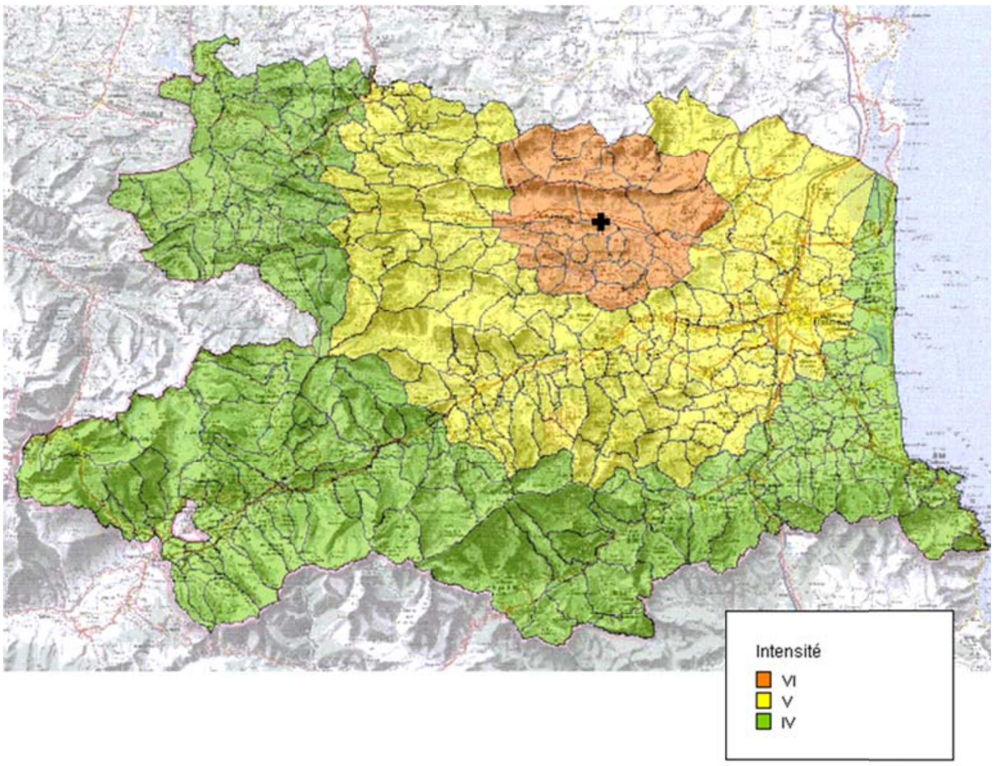


Figure 23: simulated intensity map of Saint Paul de Fenouillet 1996 earthquake.

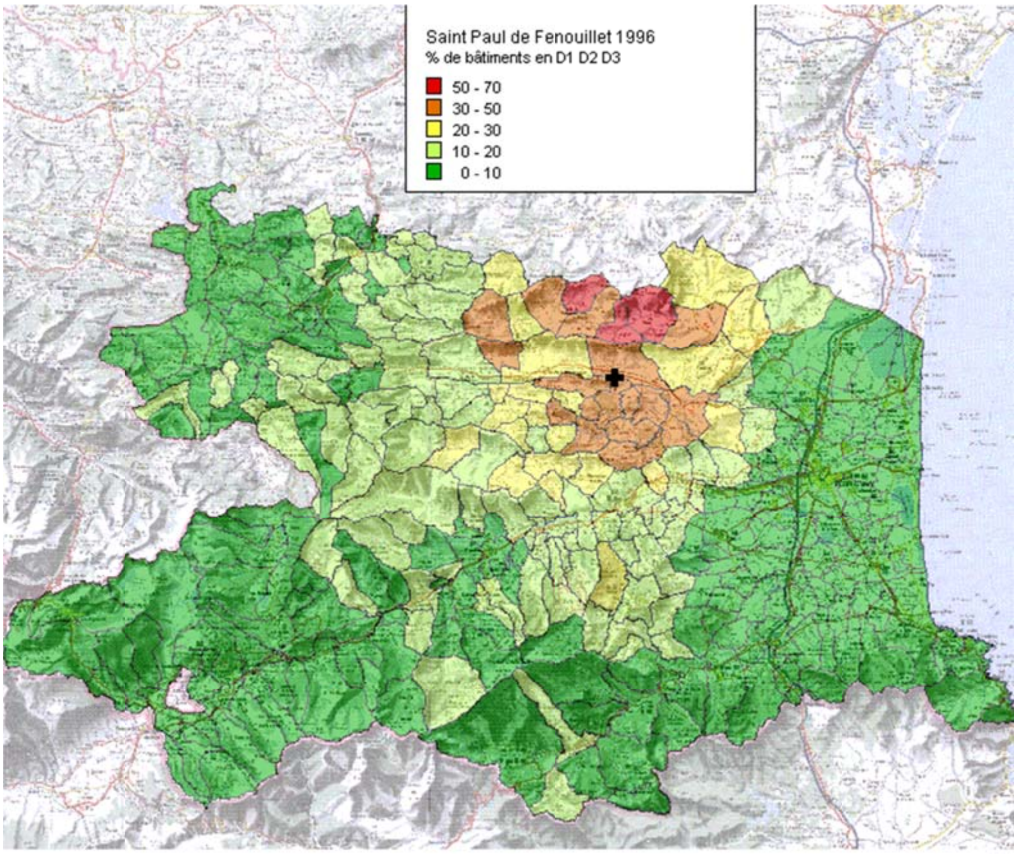


Figure 24: percentage of buildings in damage state D1 D2 and D3.

4. Conclusions

These probabilistic scenarios are based on the maximum acceleration levels provided by the seismic hazard zoning of France and the ISARD project (Secanell et al. 2008). Soil amplifications have not been taken into account in these scenarios, so results could underestimate damages in some sectors.

These scenarios are done with correlations between building ages, number of floors and vulnerability EMS98 classes. These correlations are based in observations done in pilot zone (Luchon sector) and in precedents work (Sedan et al. 2008, Chavez et al. 1998). Between different zones great heterogeneities can be found between the traditional housing (globally made with stone masonry and timber floors in the Pyrenees), because stone quality and builder practices could vary locally. In general construction after the 1950s tends to be more homogeneous all around. As consequent these results should be read as a first approach. Building database with construction material (as available in Italy (Giovinazzi 2005) or Greece (Karababa et al. 2010)) would be a good instrument to perform these scenarios, always combined with fieldtrip.

Difference distributions of vulnerability classes in individual housing have been tested in scenarios. The most important differences appears on low damage ratios (D1 and D0 damage states) and very heavy (D5), due to the different ways to consider vulnerability of the oldest and the newest buildings. These results can be a first idea of the incertitude degree concerning the vulnerability distribution for the current building stock.

The results show that municipalities with a high urbanization ratio during the last 30 years have a lower damage ratio. The method for assessing the vulnerability of current buildings (SDRS) penalizes one side the old buildings (built before the 1950s) with high vulnerability and on the other side classes with low vulnerability modern buildings (built after the 1980s).

Rural municipalities, with very high percentages of old buildings, present the higher percentages of damages.

Absolute risk (expressed in number of buildings in damage states D4 and D5) is higher for cities with important historical centres (high concentration of vulnerable buildings). At the same time these cities have the highest numbers of potential casualties and homeless. For the instance only censed population has been taken into account, underestimating probably the effect of touristic fluctuations of population, in general difficult to estimate in a zone that has numerous ski and beach resorts.

In general, on all municipalities strong damage (D4 and D5 states) does not exceed 5% of the stock. The percentage of buildings in D3 damage state varies between 15% and 3% and D2 state varies between 10 and 30%. The damage states the most likely are D1 and D0 (slight damages).

The comparison between the methods of Chavez (applied in Catalonia) and SDRS (applied in France) made on the area of the French Cerdanya shows results not too different. The greatest differences appear in municipalities with a high number of new buildings: new building stock is classed more vulnerable for Chavez than for SDRS. But it should be noted that a method of Level 0, which is based on census data, must be adapted to the format of the statistical data of each country as well as the changing construction practices and Earthquake Resistance codes of each territory.

Results of the scenario of Saint Paul de Fenouillet earthquake (1996) are fairly consistent with observations. But for earthquakes with so small magnitude (about 5) these kinds of scenarios are very limited. The results, even with a false scenario with extremely vulnerability everywhere, would not be too different.

These results should be read as a first approach to estimate the potential damages. Performances could be done incorporating a better knowledge of material construction and seismic code application (building database), the incorporation of lithological site effects and better knowledge of population fluxes.

5. References

AFPS (1996). Le séisme de Saint Paul de Fenouillet (Pyrénées Orientales, France) du 18 Février 1996. Rapport de mission.

Atkinson G.M., Sonley E. (2000) - Empirical relationships between Modified Mercalli intensity and response spectra. Bull. Seism. Soc. Am. 90, 537–544.

Bureau Central Sismologique Français http://www.franceseisme.fr/

CHAVEZ, J. (1998). Evaluación de la vulnerabilidad y el riesgo sísmico a escala regional. Aplicación a Cataluña. *PhD Thesis*. University of Barcelona, 343 pp.

COBURN A., SPENCE R. (2002). Earthquake protection. Second edition. Wiley editions.

Grünthal, G. (Editor), (1998). European macroseismic scale 1998, Cahiers du Centre Européen de Géodynamique et de Séismologie, Vol. 15, Luxembourg, 1-99.

Giovinazzi S. (2005). The vulnerability assessment and the damage scenario in seismic risk analysis. Dissertation.

IRIZARRY J., GONZALEZ M., ROUSSILLON P., (2007). ISARD Module 2, Seismic Risk scenarios for Current Buildings- Rapport de fin de projet du Programme Européen INTERREG 3A France – Espagne 2000 – 2006

Karababa F. and Pomonis A. (2010). Damage data analysis and vulnerability estimation following the August 14, 2003 Lefkada Island, Greece, Earthquake. *Bull Earthquake Eng*.

Mouroux P., Le Brun B., Depinois S., Bertrand E., Masure P. (2004) – Projet européen RISKUE : application à la ville de Nice. Rapport BRGM/RP-53202, 137 p., 43 ill., 3 Annexes.

MUSSON R., GRUNTHAL G., STUCCHI M. (2010). The comparison of macroseismic intensity scales. *Journal of Seismology* Volume 14, Number 2, 413-428

Secanell, R., Martin, Ch., Goula X., Susagna T, Tapia M., Bertil D., Dominique P., Carbon D. and Fleta J. (2008), “Probabilistic seismic hazard assessment of the Pyrenean region”. *Journal of Seismology*.

SEDAN O., TERRIER M., NEGULESCU C., WINTER T., ROULLE A., DOUGLAS J., ROHMER J., BES-DEBERC S., DE MARTIN F., ARNAL C., DEWEZ T., FONTAINE M. (2008) - Scénario départemental de risque sismique- Méthodologie et processus de réalisation. Rapport BRGM/RP-55415-FR, 459p, 96 fig., 45 tabl., 25 annexes

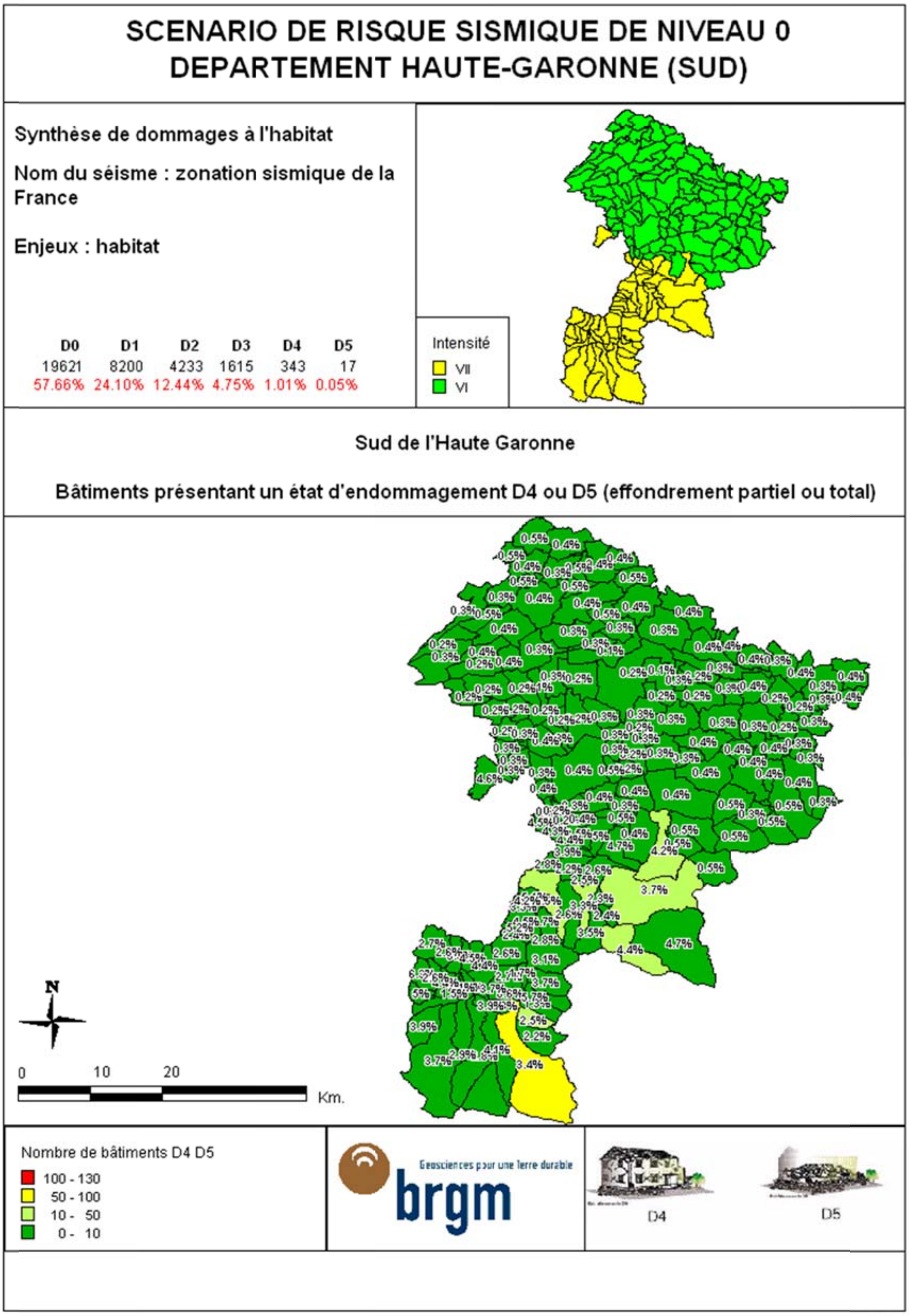
Sedan O., Negulescu C., Terrier M., Roullé A., Winter T., Bertil D. (2012) - Armagedom – A Tool for Seismic Risk Assessment Illustrated with Applications. Journal of Earthquake Engineering, DOI:10.1080/13632469.2012.726604.

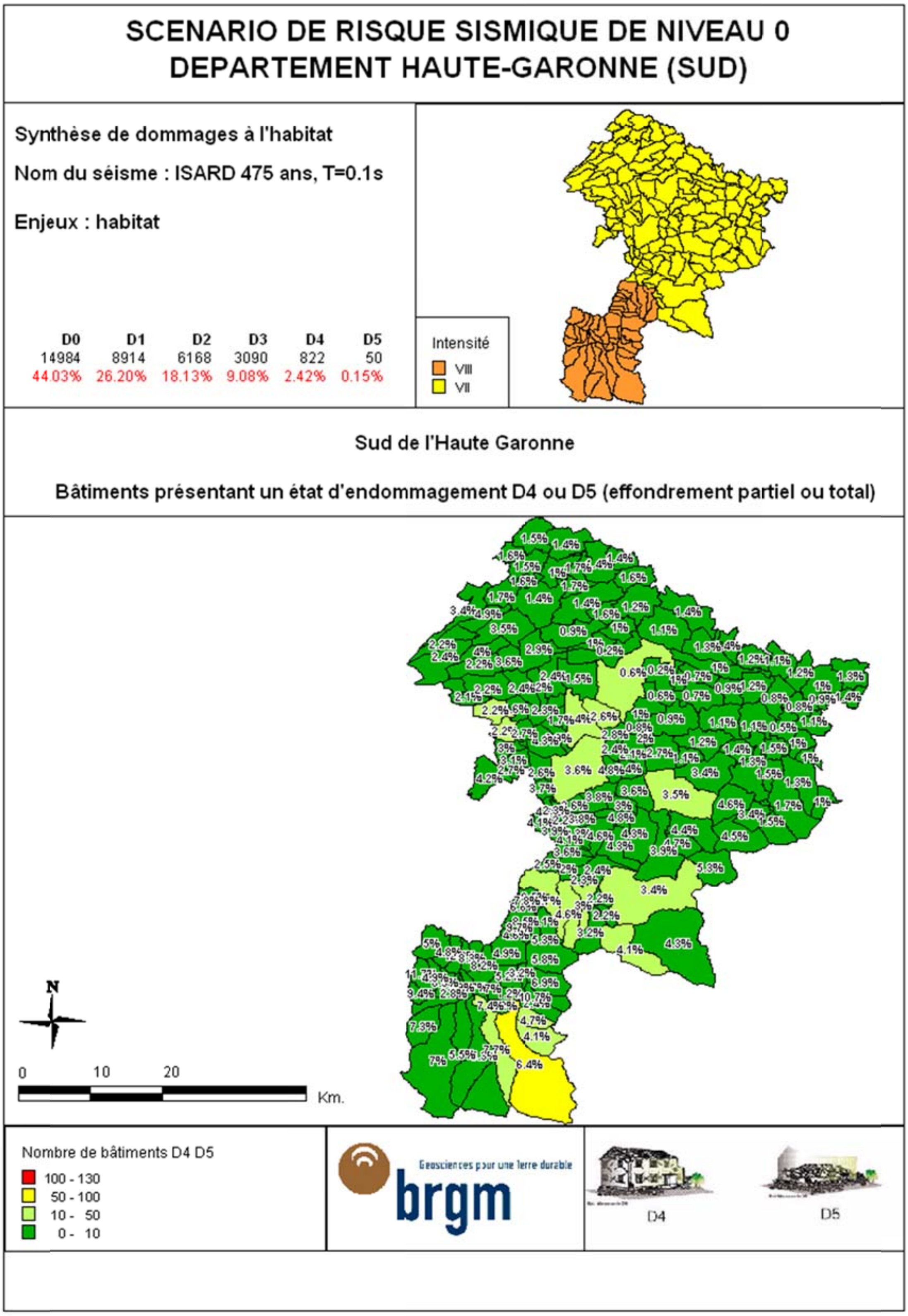
Zonage sismique de la France. MEDDAT.

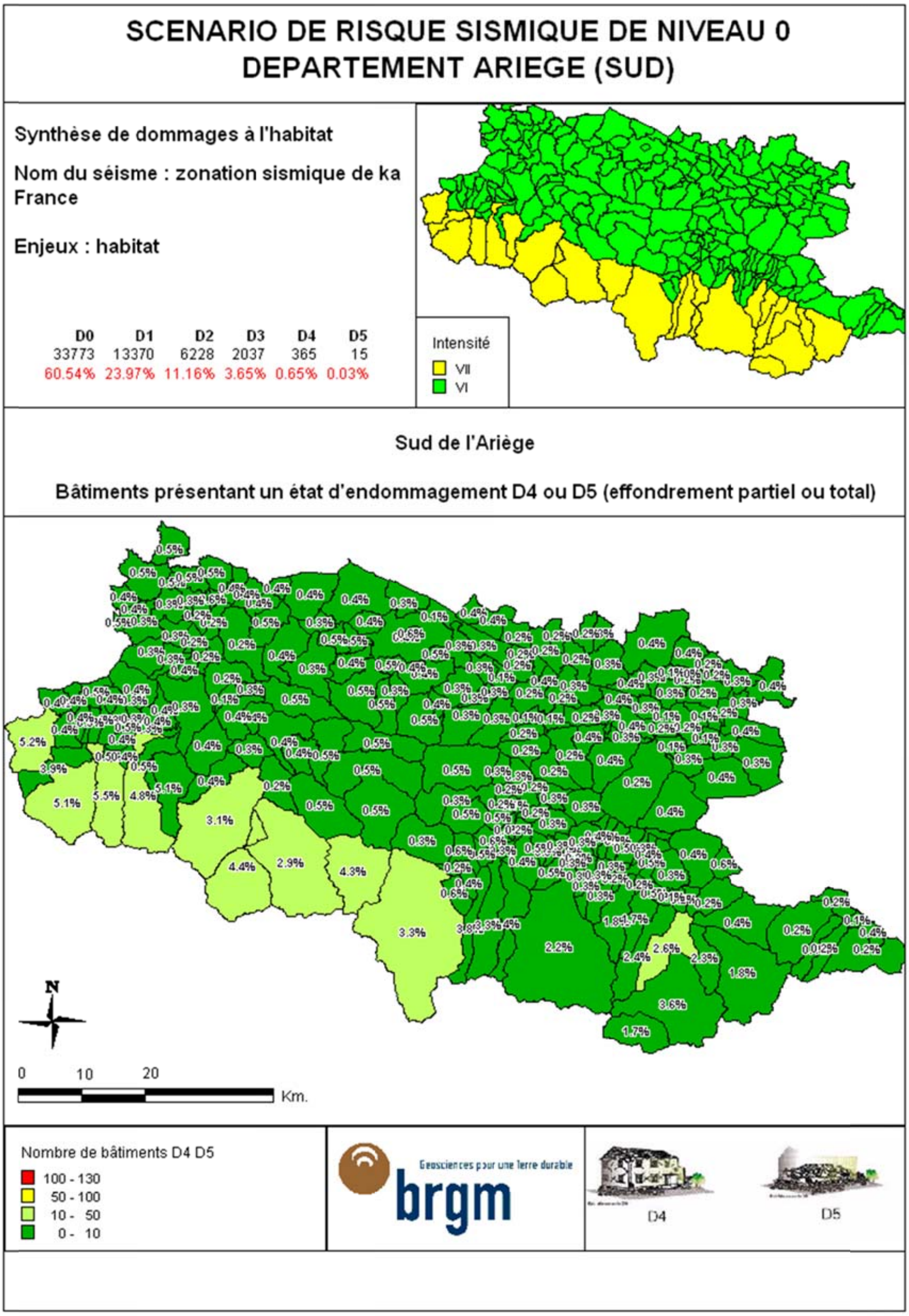
A. Tertulliani · L. Arcoraci · M. Berardi · F. Bernardini · R. Camassi · C. Castellano · S. Del Mese · E. Ercolani · L. Graziani · I. Leschiutta · A. Rossi · M. Vecchi (2010). An application of EMS98 in a medium-sized city: The case of L'Aquila (Central Italy) after the April 6, 2009 Mw 6.3 earthquake. *Bull Earthquake Eng*.

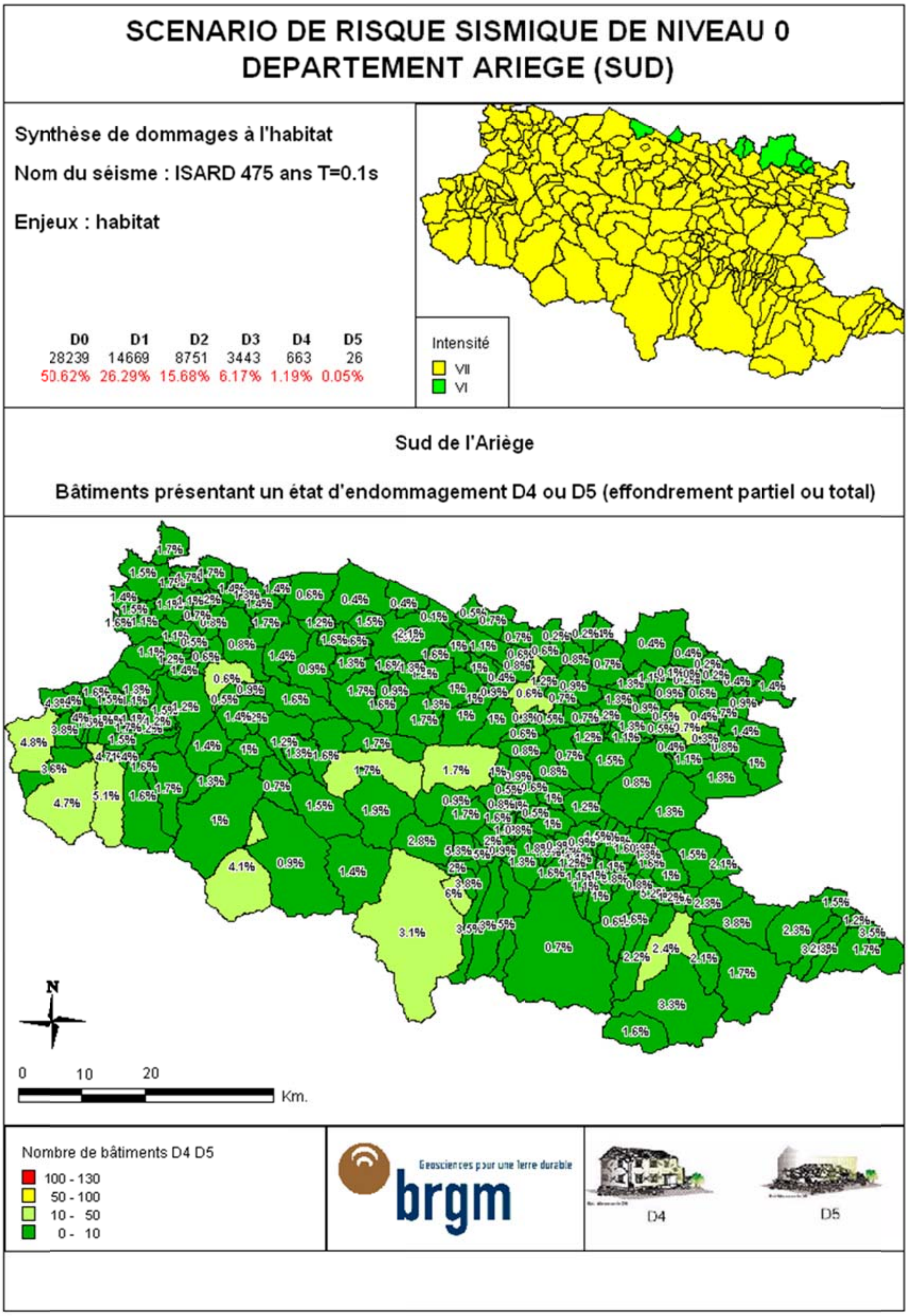
Appendix

Results maps


SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT HAUTE-GARONNE (SUD)
Synthèse de dommages à l'habitat
Nom du séisme : zonation sismique de la France
Enjeux : habitat
D0 D1 D2 D3 D4 D5
19621 8200 4233 1615 343 17
57.66% 24.10% 12.44% 4.75% 1.01% 0.05%
Intensité
VII
VI
Sud de l'Haute Garonne
Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)
N
0 10 20
Km.
Nombre de bâtiments D4 D5
100 - 130
50 - 100
10 - 50
0 - 10
Geosciences pour une Terre durable
brgm
D4
D5


SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT HAUTE-GARONNE (SUD)
Synthèse de dommages à l'habitat
Nom du séisme : ISARD 475 ans, T=0.1s
Enjeux : habitat
D0 D1 D2 D3 D4 D5
14984 8914 6168 3090 822 50
44.03% 26.20% 18.13% 9.08% 2.42% 0.15%
Intensité
VIII
VII
Sud de l'Haute Garonne
Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)
N
0 10 20
Km.
Nombre de bâtiments D4 D5
100 - 130
50 - 100
10 - 50
0 - 10
Geosciences pour une terre durable
brgm
D4
D5


SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT ARIEGE (SUD)
Synthèse de dommages à l'habitat
Nom du séisme : zonation sismique de ka France
Enjeux : habitat
D0 D1 D2 D3 D4 D5
33773 13370 6228 2037 365 15
60.54% 23.97% 11.16% 3.65% 0.65% 0.03%
Intensité
VII
VI
Sud de l'Ariège
Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)
N
0 10 20
Km.
Nombre de bâtiments D4 D5
100 - 130
50 - 100
10 - 50
0 - 10
Geosciences pour une terre durable
brgm
D4
D5


SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT ARIEGE (SUD)
Synthèse de dommages à l'habitat
Nom du séisme : ISARD 475 ans T=0.1s
Enjeux : habitat
D0 D1 D2 D3 D4 D5
28239 14669 8751 3443 663 26
50.62% 26.29% 15.68% 6.17% 1.19% 0.05%
Intensité
VII
VI
Sud de l'Ariège
Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)
N
0 10 20
Km.
Nombre de bâtiments D4 D5
100 - 130
50 - 100
10 - 50
0 - 10
Geosciences pour une terre durable
brgm
D4
D5

SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT AUDE (SUD)

Synthèse de dommages à l'habitat

Nom du séisme : Zonage sismique de la France

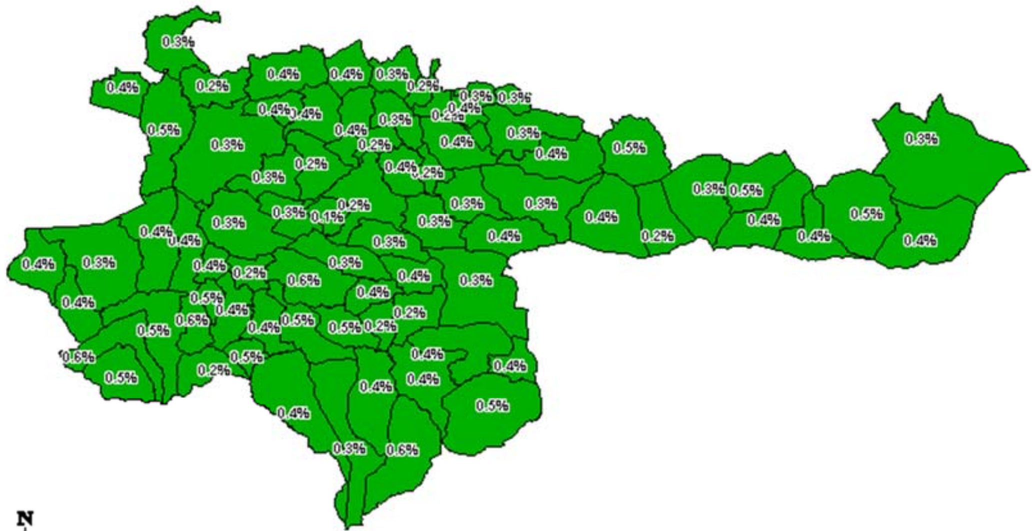
Enjeux : habitat

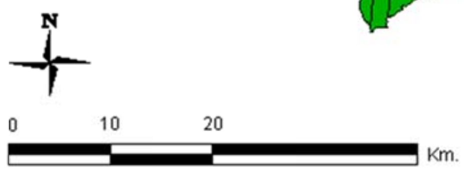
D0	D1	D2	D3	D4	D5
8290	3491	1475	381	44	1
60.59%	25.52%	10.78%	2.79%	0.32%	0.01%

Intensité
VII
VI

Sud de l'Aude

Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)





Nombre de bâtiments D4 D5
- 100 - 130
- 50 - 100
- 10 - 50
- 0 - 10

Geosciences pour une terre durable

brgm

SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT AUDE (SUD)

Synthèse de dommages à l'habitat

Nom du séisme : ISARD 475 ans T=0,1s

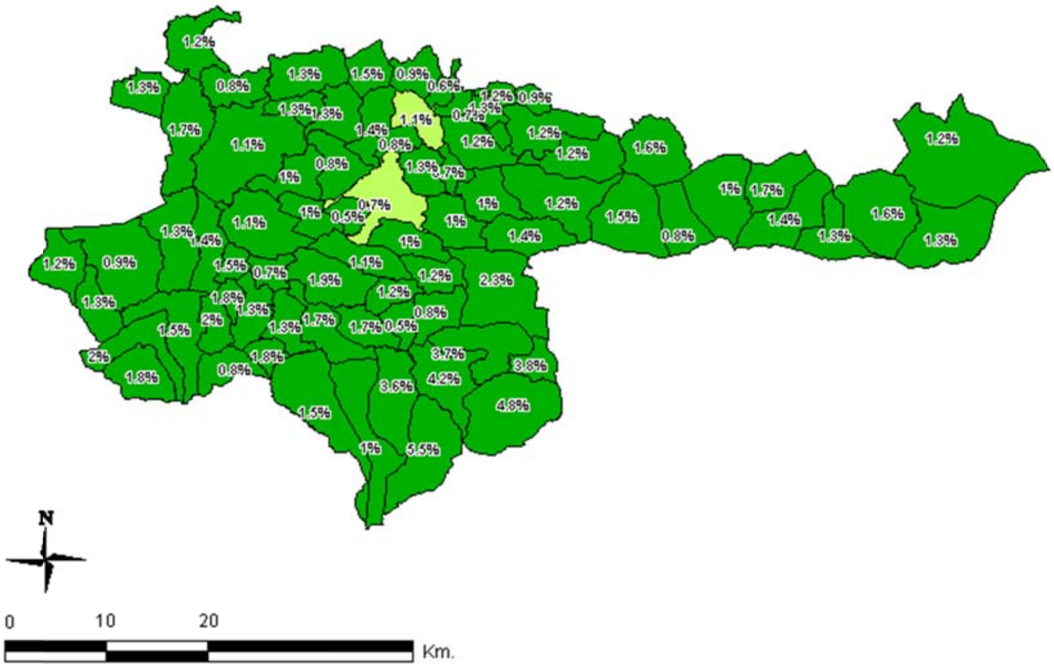
Enjeux : habitat

D0	D1	D2	D3	D4	D5
6465	3783	2341	916	171	6
47.25%	27.65%	17.11%	6.70%	1.25%	0.05%

Intensité
- VII
- VI

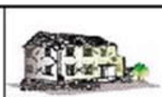
Sud de l'Aude

Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)



Nombre de bâtiments D4 D5
- 100 - 130
- 50 - 100
- 10 - 50
- 0 - 10

Geosciences pour une terre durable
brgm



D4

D5

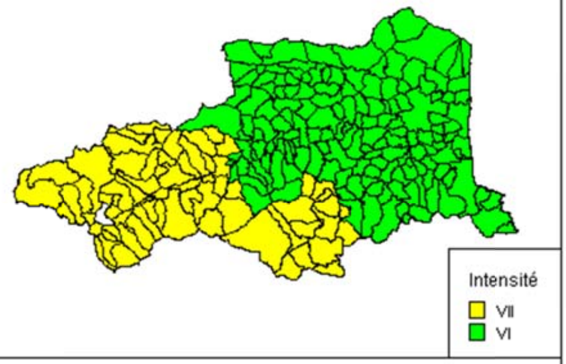
SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT PYRENEES-ORIENTALES

Synthèse de dommages à l'habitat

Nom du séisme : Zonage sismique de la France

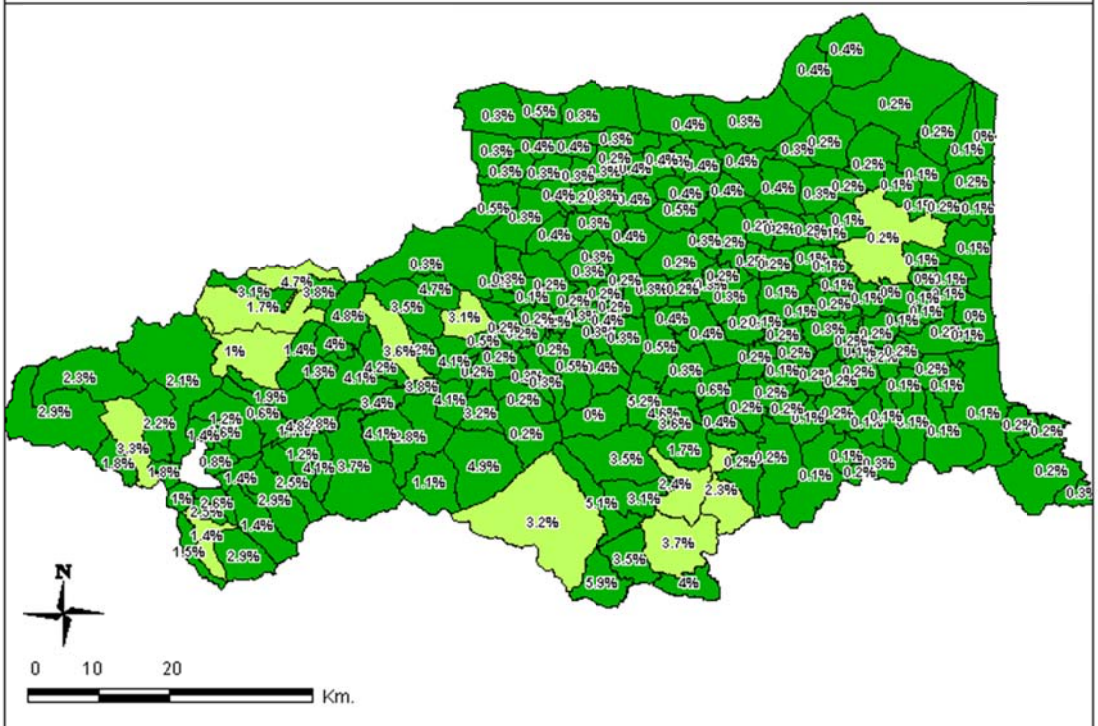
Enjeux : habitat

D0	D1	D2	D3	D4	D5
141750	32089	12642	3900	691	29
74.17%	16.79%	6.62%	2.04%	0.36%	0.02%



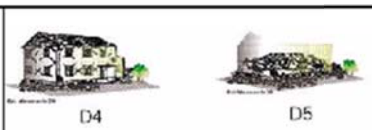
Département des Pyrénées-Orientales

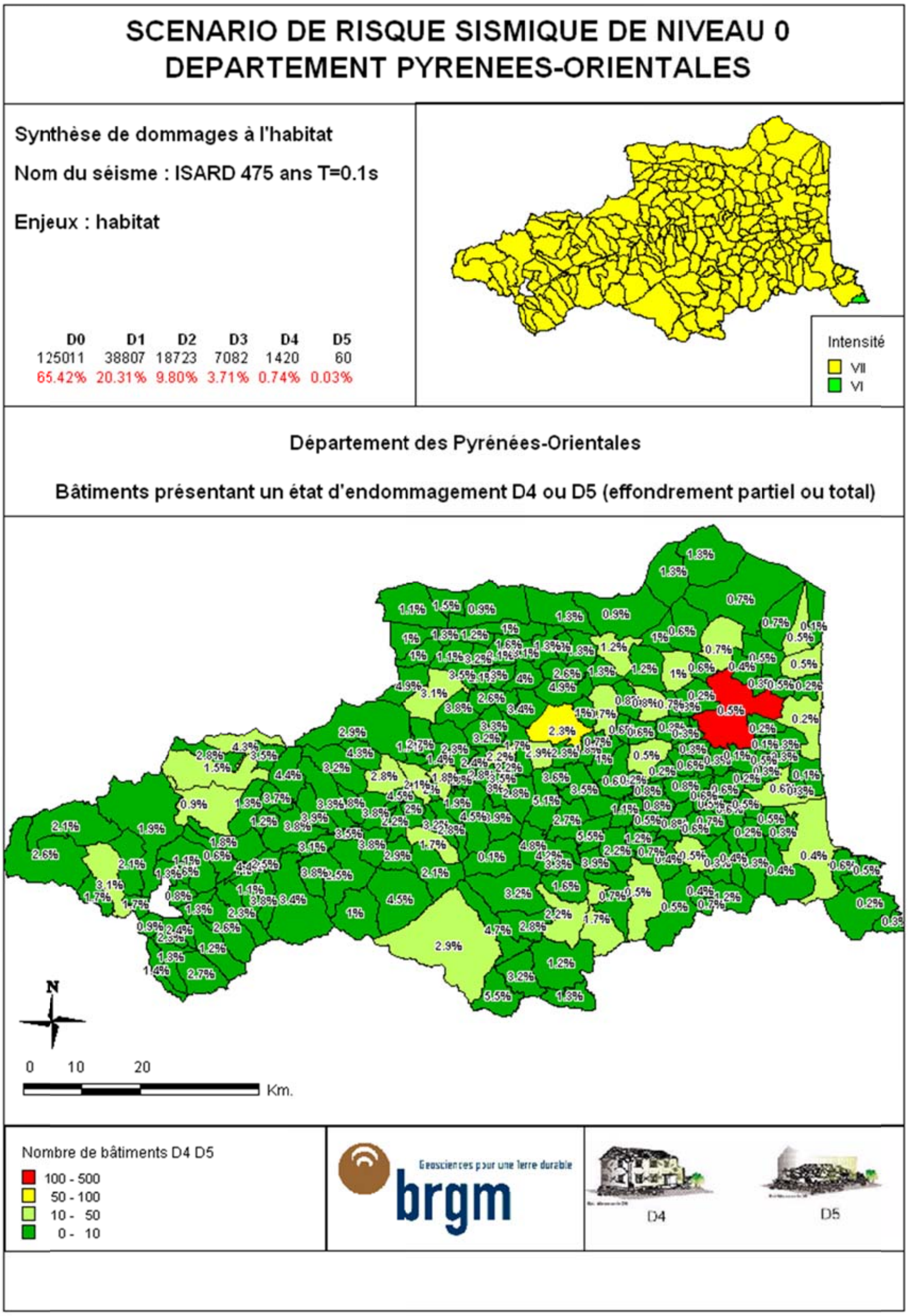
Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)



Nombre de bâtiments D4 D5
- 100 - 130
- 50 - 100
- 10 - 50
- 0 - 10

Geosciences pour une terre durable
brgm




SCENARIO DE RISQUE SISMIQUE DE NIVEAU 0
DEPARTEMENT PYRENEES-ORIENTALES
Synthèse de dommages à l'habitat
Nom du séisme : ISARD 475 ans T=0.1s
Enjeux : habitat
D0 D1 D2 D3 D4 D5
125011 38807 18723 7082 1420 60
65.42% 20.31% 9.80% 3.71% 0.74% 0.03%
Intensité
VII
VI
Département des Pyrénées-Orientales
Bâtiments présentant un état d'endommagement D4 ou D5 (effondrement partiel ou total)
N
0 10 20
Km.
Nombre de bâtiments D4 D5
100 - 500
50 - 100
10 - 50
0 - 10
Geosciences pour une terre durable
brgm
D4
D5