Seismic risk scenarios in a cross-border zone of the Pyrenees

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SUMMARY:
Within the SISPYR project, a seismic risk evaluation is presented for a cross-border zone in the Pyrenees (Saint-Beat and Luchon in France and the Val d'Aran in Spain). This area has been selected because of recent seismic activity and the importance of tourism in this region. The vulnerability of existing buildings is assessed by using the vulnerability indices proposed by the RISK-UE project. The most representative building typologies of current buildings have been identified as well as their distributions within the zone. This information has been integrated into a GIS. The deterministic scenario considered is based on the observed and interpreted intensities of Vielha 1923 earthquake (maximum observed intensity VIII). Another scenario, based on the probabilistic seismic hazard for a return period of 475 years, is calculated taking into account the soil amplification map in for the valleys obtained from the site effects study carried out within the project.

Keywords: seismic risk, current building vulnerability, seismic scenarios, Pyrenees

1. INTRODUCTION

This paper presents the seismic risk scenarios performed in a border area of the Pyrenees: the region of the Val d'Aran in Spain and the cantons of Luchon and Saint-Béat in France (Fig. 1.1). The interest of this study area is the coincidence of a moderate seismic hazard level and great exposition in terms of population because it is an area with important ski resorts. The most recent significant earthquake was a magnitude 4.8 in 1999 (epicentre in Lege, France). The last earthquake with intensities VII or higher was in 1923 with its epicentre located 10 km southwest of Vielha (county town from Val d’Aran in Spain).

In terms of national seismic zonation, the whole area on French side is classed in medium hazard (French seismic code, 24 October 2010, planseisme.fr) which is the highest level in France continental (bedrock acceleration 0.16g). The acceleration of Spanish seismic code (NCSE, 2002) for municipalities in Val d’Aran in Spain is 0.04g.

In terms of exposition to risk, this is an area with a large tourist population, increasing significantly the number during the winter season because there are several ski resorts that are located in the region. This area comprises a total of 53 municipalities in France and 9 municipalities in Spain, with a permanent population of 5609 and 3802 in the cantons of Luchon and Saint-Béat respectively (census data from 2006), and 10203 inhabitants in the Val d'Aran (according to the census of 2010), being the most populous municipality Vielha-Mijaran (5633 inhabitants).

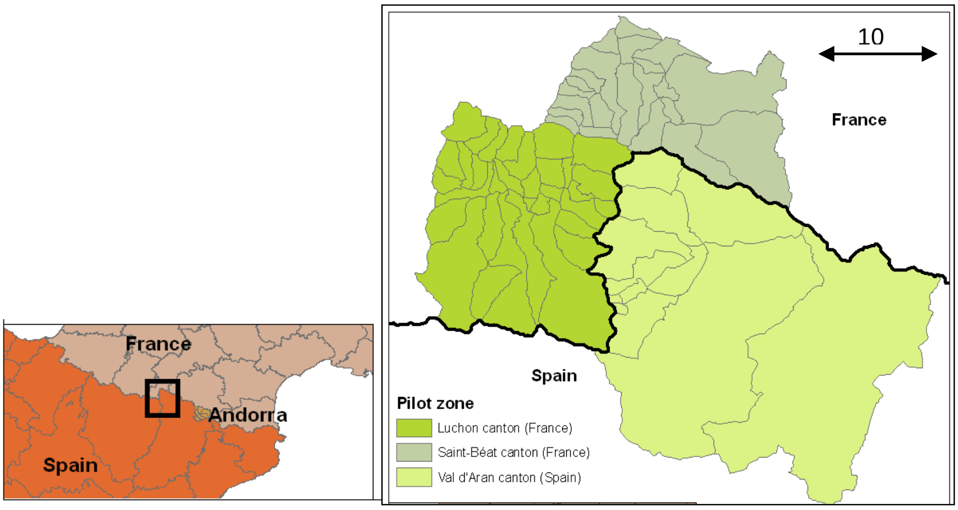

Figure 1.1. Location of the pilot zone.

The goal of this paper is to present seismic scenarios in terms of damages to current building, crossing the regional seismic hazard coming from whole Pyrenees seismic hazard map (ISARD, 2006) and from observations of historic earthquake from 1923; local site effects and current building vulnerability assessment.

2. SEISMIC HAZARD

2.1 Probabilistic scenario and local hazard assessment

According with the hazard evaluation of the Pyrenees region done in the framework of the ISARD project (Goula et al., 2007), a reference intensity of VII-VIII for a period of return of 475 years (Irizarry et al., 2007) has been adopted (Fig. 2.1).

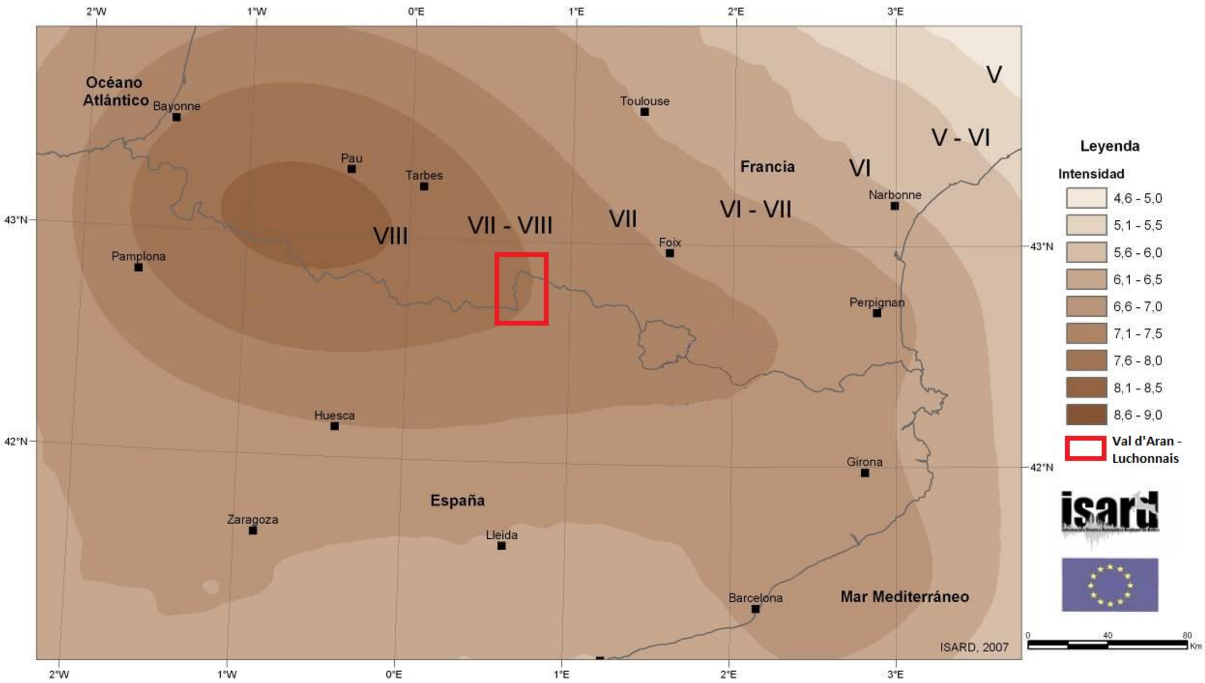

Figure 2.1. Seismic hazard map in terms of macroseismic intensity (return period of 475 years). (Irizarry et al, 2007).

Local geology can be responsible for important modifications of seismic ground motion both in amplitude and frequency content. It is then essential to take it into account in seismic scenario generation. In this study, site effects are taken into account through maps of homogeneous seismic response zones and corresponding specific acceleration spectra for each mapped zones. Specific acceleration spectra have been calculated through 1D linear equivalent simulation (Roullé et al. 2012 and Macau et al. 2012).

In the French part of the area, a campaign of 75 H/V measurements, 21 MASW profiles and 3 seismic noise arrays measurements was carried out to fulfil the poor existing geological and geotechnical data. These measurements show unexpected low frequency resonances in the alluvial formations, with frequencies reaching 0.5 Hz in the central part of the Luchon valley. In the Spanish side, 98 H/V measurements were carried out. Soil fundamental frequency ranges between 1.7 and 9.0 Hz, typical values of thin soils. Ambient noise array measurements were carried out in 8 sites. Mean shear-wave velocity obtained from array techniques ranges from 300 to 500 m/s and thickness of the soil layer varies between 20 and 50 meters.

A combined interpretation of geological, geotechnical and geophysical data was performed to identify zones with homogeneous geology and frequency resonance and define representative 1D soil columns for each zone. With those soil columns, and for each defined zone, a specific acceleration spectra was calculated using results of the probabilistic seismic study performed in ISARD project (Secanell et al., 2008) as acceleration input data. After, these amplification coefficients were transformed into macroseismic intensity increment following the procedure recommended by Macau (2008). The figure 2.2 shows the macroseismic intensity increments considered for each urban unit.

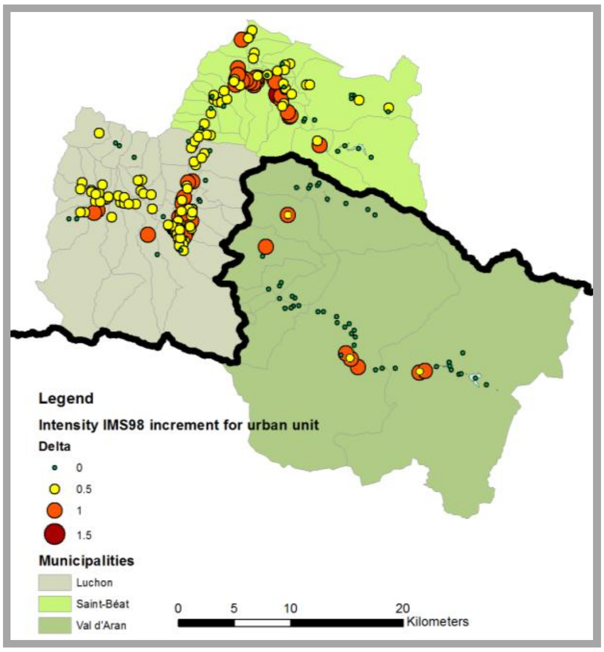

Figure 2.2. Macroseismic intensity increment for homogeneous urban units.

2.2 Historical scenario, the 1923 earthquake

Looking to historical earthquakes in the area, several major earthquakes occurred in the area over time. In 1373 there was an earthquake, with an epicentral intensity of VIII-IX, which devastated a large area of the Ribagorça at the south of the pilot zone (Olivera et al., 1994a). In 1427 and 1428 there were in the Eastern Pyrenees several earthquakes, with intensities between VIII and IX (Olivera et al., 1994b). In 1660, the Central Cordillera jerked destructive intensity VIII-IX. In the region of

Luchon and the neighboring region of Haut-Comminges during the nineteenth century there were several earthquakes (in 1870, 1855 and 1813) with maximum intensities of VII (SisFrance, 2012).

The earthquake chosen to simulate damages to present current building is the Vielha 1923 earthquake. The maximum intensities observed for this event are between VII and VIII. For all municipalities in the study area has been assigned an intensity of this event, as shown in Fig. 2.2, which are based on observed data (Susagna et al., 1994), and in the estimation of function unobserved intensities by the intensity attenuation with distance from the epicenter. The strongest damages of this earthquake were in Vielha (intensity VIII), where some buildings collapse (La Vanguardia, 1923). In Bagneres de Luchon, on French side, the intensity was VII and there were observed cracked walls, chimneys and roofs (Sisfrance.fr, Le Midi Socialiste, 1923). Across the bottom of the Val d'Aran, among Vielha and the French border, were also observed intensities of VII, as well as towns in the valley between Luchon and Cierp-Gaud (Fig. 2.3).

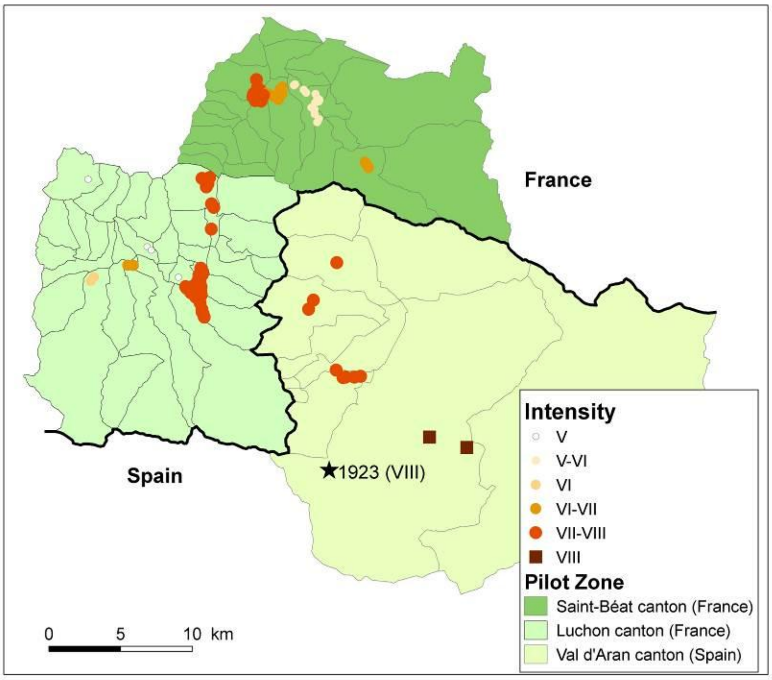

Figure 2.3. Interpreted and observed intensities from 1923 earthquake.

3. CURRENT BUILDING VULNERABILITY

The current buildings of the whole zone has been characterized taking into account the criteria of vulnerability index method of RISK-UE (Mouroux and Lebrun, 2006), known within SISPYR as Level 1 (Lungu et al., 2001; Milutinovic et al., 2003). In total the region of Val d'Aran has a total of 2859 buildings (Census data from 2001, INE) and 8300 buildings in the counties of Luchon and Saint Béat (12655 total dwellings in the area in 2006, INSEE). The identification and characterization of the most common types of buildings in the area was done during a field survey that visited several locations and through interviews with local architects and constructors. Establishing “local” typologies of buildings was the first step and then the local typologies were related to the types of buildings proposed within the RISK-UE project (Lungu et al., 2001) as already done in the previous ISARD project for the region of the Cerdanya and Andorra (Irizarry et al., 2007; Rousillon et al., 2006; Gonzalez, 2010). Fig. 3.1presents the building typologies finally used and Table 3.1 their vulnerability index with a regional modifier included because of some differences from corresponding typology defined in Risk-UE project.

Thus each type of construction will have a medium vulnerability index. The main additional modifying factors of vulnerability associated to each building type were considered (Milutinovic et al., 2003, Giovinazzi et al. 2006). These factors are applied consistently well above all the types of building or only in certain cases when the statistical data and field allows it. These vulnerability factors were: 1) the number of stories, which is applied differently if they are buildings of masonry or concrete, 2) the conservation state and for buildings of stone masonry (T1 and T1 ') and 3) two factors which penalizes the structural system (stone bear walls) and roofs structures in wood with weak connection to bear walls. Finally, for downtown areas with a large percentage of aggregate buildings was considered a factor that penalizes the fact that between neighbouring buildings may have damages due to differences in height, slabs at different levels, etc.

Table 3.1. Main current building types.

Type	Structural system	RISK-UE type	Description	V_I
T1	Stone masonry	M1.2	Simple stone bearing walls, wooden slabs. Traditional housing.	0.74
T1’		M1.2-M1.3	Big hotels in Bagnères de Luchon. Masonry stone bearing walls, combining simple stone and massive stone on corners	0.74 - 0.616
T2	Unreinforced masonry	M3.3	Unreinforced masonry. Composite slabs.	0.704
T3		M3.4	Unreinforced masonry. Concrete slabs.	0.616
T4	Reinforced Concrete (RC)	RC3.2	RC frames. Infill walls. Structure with irregularities.	0.522
T5		RC2	Shear walls	0.386
T6	Steel	S3	Steel frames and infill walls in masonry.	0.484
T7	Wood	W	Wood chalets.	0.447

T1) T1’) T4) T5) T2)

Figure 3.1. Some examples of the main building types into the zone.

Once the type of buildings in the area has been identified, the geographical distribution throughout the territory was assessed (relative percentage and absolute number) as has been described by Rousillon et al., 2006 and Sedan et al. (2008). Data from statistical agencies of both countries has been used. In all cases, work was carried out using GIS mapping of urban areas, looking for example to separate the downtown areas of expansion or new residential areas. Inside each inhabited area was estimated total number of buildings and a distribution in percentages of the various types of construction (Fig. 3.2). This distribution was done using different criteria: 1) visiting built zones and establishing a distribution during field survey, 2) according to statistics from the age of buildings, 3) opinion of architects and constructors in the area, 4) by similarity with other similar residential areas and 5) dating the mean age of the constructions comparing old maps and aerial images with newest ones.

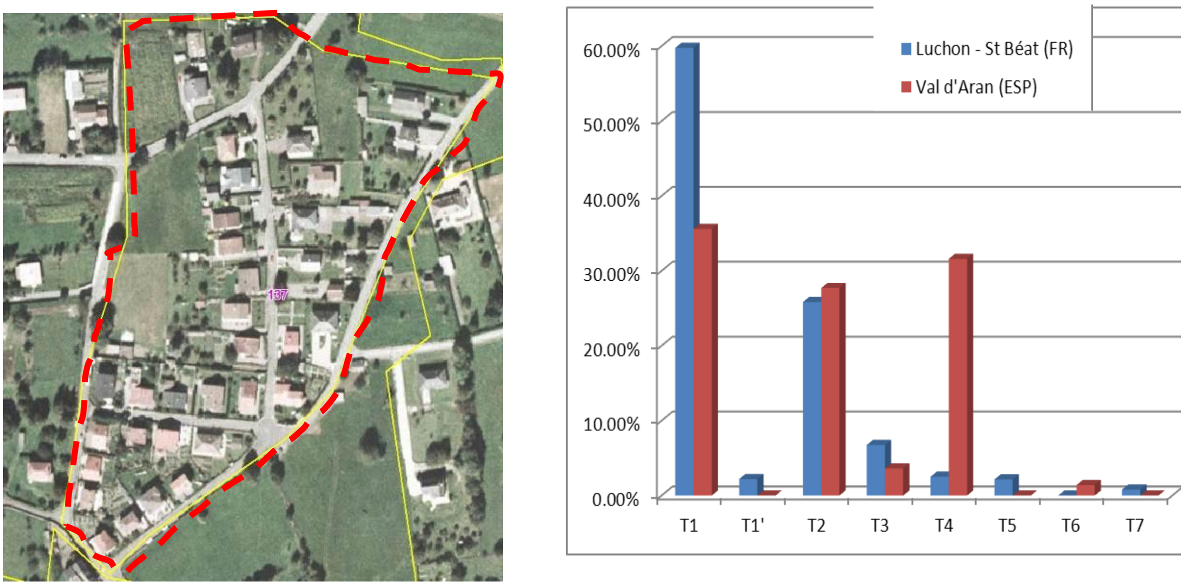

Figure 3.2. On the left example of delimitation of homogeneous built areas. On the right the distribution of building types on the 2 zones.

GIS analyse of soil occupancy, census data and field survey results notes that the two sides of the frontier have followed very different urban growth. The Luchon and Saint-Béat cantons are characterized by a large number of buildings T1, as the urban growth of these towns over the past 40 years is reduced. Bagneres de Luchon, the most important town on the French side, was developed mainly in the early twentieth and late nineteenth century due to thermal tourism. New constructions in the area are primarily residential neighbourhoods (T2 and T3) with a few numbers of blocks of flats (T4 and T5) (Fig. 3.3). On the Spanish side, in the Val d'Aran, with a strong urban development from the 1970s to 2000s after the construction of the ski resort of Baqueira-Beret, it can be observed a similar distribution between the traditional house (T1), buildings in masonry (T2) and blocks of RC frames (T4).

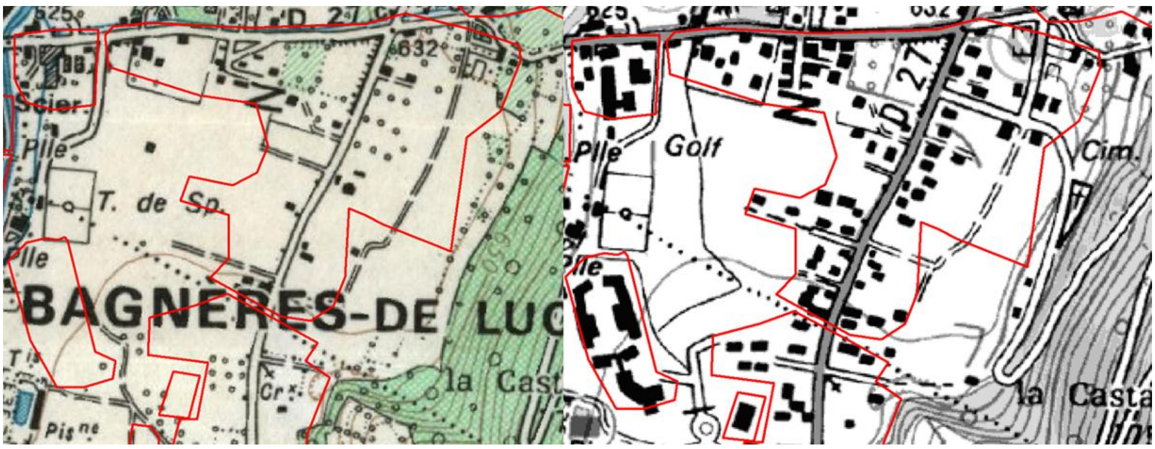

Figure 3.3. Example of the method to date the built zones, on the left the topographic map of 1971, on the right the newest topographic map. Almost all the buildings in the image have been built after 1971.

The most vulnerable constructions over the zone are those with stone bearing walls (T1 and T1') (Fig. 3.1). Even if there is a brickwork between the stones, connection between perpendicular walls is not enough strong. Additionally, connectivity between wooden slabs and roofs and the walls is poor. Some special cases were the traditional houses with recent works as rising the height, partial demolitions and reinforcements. But these works cannot be considered as seismic reinforcement; so the hypothesis of "no changes" in vulnerability was chosen, meaning that no reduction or increment of vulnerability index.

The RC frames and infill walls structures has been considered irregular by default, because during the fieldtrip several factors were identified frequently: soft storey, irregular forms, balconies, cantilevers, short and captured columns. In moderate seismic zones another important vulnerability aspect for this kind of constructions are the non-structural elements.

Important and strategic buildings along the area were visited; it means schools, hospitals, police, fireman, town hall and other buildings. Detailed descriptions were carried out identifying the main structural system and the vulnerability factors for each type of structure. These data were integrated into individual form for each building. However, these building require a more detailed and specific damage evaluation which we are not going to show here.

Concerning the damage, the vulnerability index method of Level 1method (RISK-UE) recognizes a no-damage state, denoted as None or D0, and five damages states named as Slight (D1), Moderate (D2), Substantial to Heavy (D3), Very Heavy (D4) and Destruction (D5) (Grünthal 1998).

4. RISK SCENARIO AND RISK MAP

Considering the damage grade distribution obtained for the historic scenario of 1923 (Fig. 4.1a), the damages expected for current building would be moderate. The percentages of severely damaged buildings (damage states D4 and D5) would be less than 2%. This would mean that only some of the most vulnerable households would suffer extensive damage or collapse, as it happened in 1923. The most affected sectors would be the old downtowns of Vielha and Casarilh (Val d'Aran) and some sectors of the historic center of Bagneres de Luchon. All these areas had been identified as having a significant ratio of buildings dating prior to 1950, so have a high percentage of traditional housing built with stone masonry. Severe damage (state D3) would be more important in the nuclei of Vielha, Gaussac and Casarilh (10 to 15% of the state park in D3). Other towns in Val d'Aran and also on the French side would have between 5 and 10% of buildings in this state. These areas coincide with centers with a most important percentage of construction prior to the 1950 and impacted with a seismic intensity of VII. The locations with intensities lower than VII presented severely damaged buildings percentages below 2%. The number of buildings in damage state D3 is significant to estimate the number of people without shelter which can reach several hundred of people. Moderate damages (D2 damage state) appear not only in old downtown but also in recent residential districts (it means, cracking on infill walls on RC structures).

The damage grade distribution for the probabilistic scenario is shown in Fig. 4.1b. The heaviest damages for this scenario are concentrated into the areas with a high site effect (of the valleys). The Val d'Aran globally shows lower mean damages. These results and differences between the two countries could be explained by 2 facts. Firstly, the French side has more vulnerable buildings (building type T1 is the main one) than Spanish side and secondly, the main villages, with the higher building concentration, on the French side are situated over zones with strong site effect. On the other side, in Val d'Aran, there is a high number of buildings over bedrock, near to the ski resort, so without amplification and consequently with a lower intensity.

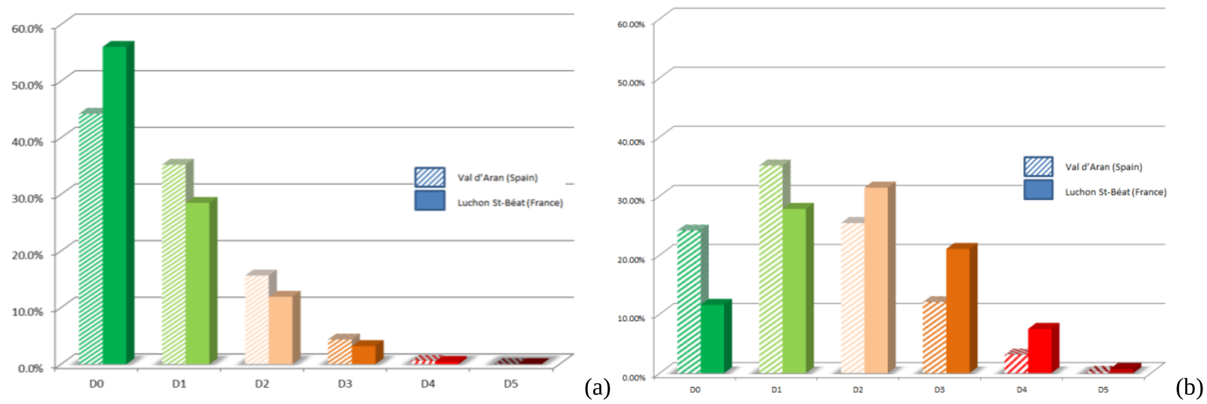

Figure 4.1. Damage grade distribution results for: (a) the deterministic scenario and (b) the probabilistic.

5. CONCLUSIONS

The major building types of the zone have been distinguished. The most vulnerable buildings are the traditional housing, with bear walls in stone masonry and wooden slabs. Traditional housing within the pilot zone on the two countries has the same structural system so vulnerability is quite similar because between the 2 countries there was a common technical know-how. Recent individual housing is also quite similar between the 2 countries (masonry bearing walls, RC composite slabs).

Concerning modern collective housing buildings, special attention should be done to residential buildings built after 1970, especially in Val d'Aran. Many have been built using structures in RC frames and infill walls. These buildings show generally a large number of irregularities (soft storeys, irregular forms, cantilevers). For this kind of buildings non-structural elements could be dangerous even for moderate intensity earthquakes as it has been shown by the earthquake of Lorca in 2011.

The most important differences between the two sides of the frontier appear on residential buildings. These differences come even from the respective seismic codes, the acceleration values within the zone are 0.16g on France side and 0.04g in Spain side. Consequently the structural types and the constructive solutions are different. On French side recent residential buildings have been built using RC shear walls. On Spanish side the main structure is RC frame and infill walls.

Expected damages on the present current building stock were simulated with the interpreted intensity of the earthquake of Vielha 1923 all over the pilot zone (intensity VIII in Vielha and VII in Bagneres de Luchon). The damage would minor (damage states D1 and no damages), ie would have an impact on the buildings without affecting the structural stability of buildings. Only about 4% of the total stock of buildings suffers damage degree 3 (important cracking), i.e. about 250 buildings on Saint-Béat Luchon and 125 in Val d'Aran. Non-structural damages in infill walls are more important all over the zone, even in recent residential districts.

Probabilistic scenario shows the differences between the two countries, being lower the damages on the Val d'Aran. When comparing sectors with a similar intensity, the damage will tend to be higher in urban areas with a higher proportion of vulnerable buildings (types T1 and T1') that correspond to the traditional construction of the area. New residential neighborhoods built from the 1970's in general have a lower medium damage.

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REFERENCES

Giovinazzi, S. and Lagomarsino, S. (2002). WP04: Guidelines for the implementation of the I level methodology for the vulnerability assessment of current buildings. Genoa, Italy.

González, M. (2010). "Evaluación del riesgo sísmico en el Principado de Andorra". Tesis doctoral del Departamento d' Enginyeria del terreny, cartográfica i geofísica de la Universitat Politècnica de Catalunya. (Disponible en: -www.tdx.cat/TDX-0618110-122408.)

Goula, X. and the ISARD team. (2007). Proyecto ISARD: Información Sísmica Automática Regional de Daños. *3er Congreso Nacional de Ingeniería Sísmica*. 1513-1526.

Grünthal, G. (1998). European Macroseismic Scale 1998. *Centre Européen de Géodynamique et de Séismologie,* Luxemburg.

INE. Spanish Stat Data Institute. Avalaible on www.ine.es. Las visited on november 2010.

INSEE. French Stat Data Institute. Avalaible on www.insee.fr. Last visited on october 2010.

ISARD (2006). "Información *Sísmica Automática Regional de Daños"*, Interreg IIIA France Spain 2000–2006 programme, Avalaible in: http://isard.brgm.fr/encyclopedique.php3?lang=fr&id_article=33

Irizarry J., P. Roussillon, M. González, B. Colas, O. Sedan, y T. Susagna (2007) Escenarios Transfronterizos de Riesgo Sísmico en el Pirineo Oriental. 3r Congreso Nacional de Ingeniería Sísmica, Girona, Spain.

Lantada N., Irizarry, J., Barbat H.A., Goula, X., Roca, A., Susagna, T. and Pujades L.G. (2010). Seismic hazard and risk scenarios for Barcelona, Spain, using the Risk-UE vulnerability index method. *Bulletin of earthquake engineering*, **8 (2)** p. 201-229.

Le Midi Socialiste, (1923). Paper editions from November 21, 1923

La Vanguardia, (1923). Paper editions from November 21-22, 1923. Avalaible in www.lavanguardia.es. Last visited on august 2010.

Lungu, D., Aldea, A., Arion, A., Vacareanu, R., Petrescu, F. and Cornea, T. (2001). P1 Report European distinctive features, inventory database and typology. Risk UE Project. 58 pp.

Macau, A. (2008). Microzonación sísmica. Contribución a los estudios de peligrosidad sísmica a escala local en zonas rurales y urbanas. *PhD Thesis*. Universidad Politécnica de Catalunya. Barcelona, 328pp.

Macau, A., Figueras S., Roullé A., Kingne L., Bellmunt F. and Meneses C. (2012). Seismic microzonation in two Pyrenean Valleys : Val d'Aran and Luchonnais. 15 WCEE Lisbon.

Milutinovic, Z. V. and Trendafiloski, G. S. (2003). WP04. Vulnerability of current buildings. RISK UE project: An advanced approach to earthquake risk scenarios with applications to different European towns. *Institute of Earthquake Engineering and Engineering Seismology (IZIIS)*, Skopje. 109 pp.

Mouroux, P. and Lebrun, B. (2006). RISK-UE project: an advanced approach to earthquake risk scenarios with application to different european towns in: C. S. Oliveira, A. Roca and X. Goula, (Editors), *Assessing and Managing Earthquake Risk*, Springer, 479 - 508.

NCSE (2002). Normativa de Construcción Sismorresistente Española. Comisión Permanente de Normas Sismorresistentes, Real Decreto 997/2002. Boletín Oficial del Estado No. 244 del 11 de octubre de 2002, España.

Olivera, C., Riera, A., Lambert, J., Banda, E. and Alexandre, P. (1994a). Els terratrèmols de l'any 1373 al Pirineu: efectes a Espanya i França". *Servei Geològic de Catalunya. Generalitat de Catalunya. Monografíes,* **vol. 3**, 220p.

Olivera, C., Riera A., Melis A., Martínez B. and Roca A. (1994b). Revision of the 1427 earthquakes in the Eastern Pyrenees. Delimitation of the epicentral area and intensity assessment for the March 15 and May 15 events. In: Albini, P. and Moroni, A. (editors): *Historical investigation of european earthquakes. CNR, Milan,* **vol. 2**, 169-179.

Plan séisme, (2012). Zonage sismique de la France (http://www.planseisme.fr/Zonage-sismique-de-la-France.html). Last visited on march 2012.
Risk-UE (2003). An advanced approach to earthquake RISK scenarios with applications to different European towns". European Commission 5FP - City of Tomorrow and Cultural Heritage. CEC Contract Number: EVK4 CT 2000 00014. Duration: 44 Months (15/01/2001-30/09/2004).
Roullé, A., Macau A., Figueras S., Monfort D., Lantada N., Susagna T. and Irizarry J. (2012) Performing seismic scenario in the Luchon - Val d'Aran area, Central Pyrenees. Eurogeo 2012, Bolonia.
Rousillon, P., Irizarry, J., González, M., Delmotte, P., Sedan, O., and T. Susagna (2006). Cross-border seismic risk scenarios (Eastern Pyrenees), *First European Conference on Earthquake Engineering and Seismology*. Geneva, Switzerland, 3-8 September, Paper ID 902.
Sedan, O., Terrier, M., Negulescu, C., Winter, T., Roullé, A., Douglas, J., Rohmer, J., Bes-de-Berc, S., de Martin, F., Arnal, C., Dewez, T. and Fontaine, M. (2008). Scénario départemental de risque sismique- Méthodologie et processus de réalisation. *Rapport BRGM/RP-55415-FR*, 459p.
SisGeoInRisk (2010). Contribuciones sismológicas, geofísicas y de ingeniería a la predicción y prevención del riesgo sísmico. Proyecto de investigación del Ministerio de Educación y Ciencia 2009-2011(CGL2008 00869/BTE)
SisFrance, (2012). Sismicité de la France. Histoire et caractéristiques des séismes ressentis en France. (www.sisfrance.fr) Last visited on december 2011 .
Susagna, T., Roca A., Goula, X and Batlló, J. (1994). Analysis of macroseismic and instrumental data for the study of the November 19, 1923 earthquake in the Aran Valley (Central Pyrenees). *Natural Hazards*. **10**:7-17.