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SEISMIC RISK QUANTIFICATION IN FRANCE: PROBABILISTIC EVALUATION

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ABSTRACT

.A simple and efficient calculation line has been developed for the quantification of seismic risk and the presumption of buildings conformity. The seismic risk assessment is performed in a probabilistic way. The hazard is taken into account through median hazard curves and associated percentiles 15 and 85, in intensity. Building vulnerability is characterised by a vulnerability index from Risk-UE (2003, Lagomarsino et al. 2006). Human losses are calculated according to Coburn et al. (2002) method involving the calculation of a mortality rate. Economic losses are taken into account as a cost curve. The probabilistic calculation of seismic risk then allowed determining its representative's values: annual probability of individual mortality, probable number of casualties per year, annual probability to exceed one casualty and probable economic losses per year. In order to assess the conformity of a building toward Eurocode 8, a simple calculation method using vulnerability index from Risk-UE have been suggested. Drawing an abacus linking acceleration, damage probability and vulnerability index then allows determining the largest Risk-UE vulnerability index for conformity.

INTRODUCTION

In France, reinforcement of the whole buildings designed without taking into account the seismic actions cannot be planned for obvious economic reasons. In this way, the AFPS (French Association of Seismic Engineering) studies and formalises methods for the optimisation of technical and economic performance of reinforcement. In these terms, a method of classification of buildings for priorities of reinforcement is suggested

In a social context of aspiration to risk mitigation, earthquakes are among the most unpredictable and potentially devastating. The measures taken by authorities in France since the nineties impose rules and requirements for new buildings undergoing seismic actions. However, what about the buildings constructed before the application of these standards? Given the amount of risk-exposed buildings, a complete reinforcement of all these buildings is not economically reasonable. Since 2012, new European requirements and national authorities decrees, it is possible to partially reinforce an existing building [EC8-3]. The implementation of priorities would be a starting point to optimize technical and economic performances of this reinforcement. Therefore, there is a need to determine an effective method to quantify the seismic risk and evaluate the compliance of buildings; the aim of this study.

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Also, uncertainties are very present in seismic risk presumption so they have been estimated. The introduction of vulnerability and losses uncertainties in the previous calculation line allowed to highlight their effects on seismic risk results and to assess the proportion of each. In the literature, Switzer guidelines SIA 20118 (OFEG 2005) suggests a representation of seismic risk which highlights reinforcement priorities for buildings inside a building estate. The aim is to suggest a similar representation that could be used for France. The seismic risk values previously calculated have been considered as criterions and representations of those have been suggested for a priority classification. Those values can then be compared to define reinforcement priorities for buildings inside a building estate.

The first part of this paper recalls le probabilistic seismic risk quantification. In the second part, the seismic risk's representative values in metropolitan France is proposed to assess rough estimates. These have been calculated for representatives 40 cities (Figure 1). Then, section presents the ranking process of building according to the seismic risk. Fictive and characteristic data on vulnerability and losses allowed assessing seismic risk for a wide building stock. The compliance approaches of these building and the reinforcement decision are obtained in the last section.

PROBABILISTIC SEISMIC RISK QUANTIFICATION

Seismic risk is the convolution of seismic hazard, vulnerability and economic or social issues. They have to be apprehended and quantified together in order to mitigate the loss probability.

Hazard representation

The evaluation of the probabilistic seismic local hazard is made by the definition of annual rates of occurrence of ground motion parameters. Three steps are needed to calculate the probabilistic seismic hazard (Martin *et al.*, 2008):

- the identification of source areas in the studied region which are mapped on seismotectonic zoning;
- the modeling of a hazard curve by considering the earthquake catalogue (which list seism that occurred in that area) for each source a rea. The hazard curve defines magnitudes and annual rates of occurrence.

The selection of reduction laws are adjusted to the study area. Those laws may be linear or not, they determine a density probability function of the acceleration induced by a given magnitude and source to site distance. Assuming that the intensities are distributed according to a normal distribution, the curve's dispersal is calculated by random draw of values in accordance with this law. After the calculation of the annual rates of exceeding a series of given accelerations, annual rates according the seismic motion can be drawn. The seismic motion could be characterized by the ground acceleration or the EMS-98 seismic intensity (Grunthal *et al.*, 2001). A curve may be drawn for each source area that influences the studied site. Due to the amount of data usually obtained, it may be easier to use the median values and the 15^{th} & 85^{th} centiles as hazard curves.

Vulnerability representation – Risk-UE method

The Risk-UE method (Milutinovic et al., 2003) uses the damage scale and the intensity scale of the EMS98. Then, the vulnerability assessment is based on the attribution of a global vulnerability index considering building typology and vulnerability factors. The mean damage grade μ_D, with the macroseismic intensity, are then correlated to global vulnerability index. The fragility curve is the representation of the mean damage grade according to the EMS98 intensity. To estimate the damages that could occur to a building during an earthquake of a given intensity, their occurrence probability has to be calculated. For each damage level, the determination of the damage probability considering a discrete probability distribution is performed with a discrete binomial distribution.

Losses representation

Human losses can be evaluated by the amount of casualties; a mortality rate is determined for each class of buildings. This mortality rate is defined as the ratio between the number of casualties and the number of occupants present in the collapsed building. It may be estimated by using M parameters described hereafter (Coburn *et al.*, 2002):

- M1 represents the number of occupants in the building;
- M2 represents the mean hourly occupancy of the building. It is the ratio between the mean number of hours of occupation during a year and the amount of hours in a year;
- M3 represents the rate of occupants trapped in the collapsed building and depends on the intensity and the vulnerability index;
- M4 represents the percentage of casualties in the collapsing;
- M5 represents the rate of survivors trapped in the collapsed building and who died before help arrives.

The individual mortality rate may be used to evaluate the individual probability of dying, and is calculated without considering the M1 parameter. By multiplying this individual mortality rate by the damage probability, individual and annual probability of mortality is obtained. Annual possible number of casualties can be calculated with a binomial law (used as a sum of independent Bernoulli random variables).

Economic losses of buildings are considered by a reference value. This reference value could be represented by either the insurance value of the building, the cost of its refurbishment or the cost of its destruction and reconstruction. The building owner chooses the reference range for an economical study, considering his resources. The cost curve is performed in a statistic way and set forth repair costs generated for a damage level. To this end, a percentage of the reference value (which identifies the repair cost) is related with every damage level.

Risk evaluation: convolution of hazard/vulnerability/losses

Finally, the seismic risk is calculated by convolution of hazard, vulnerability and losses. Then, the probability of occurrence of an earthquake of which the damages would result in more than N casualties over a period of time T can be obtained. In the same way, the annual probable economic losses are obtained by the convolution of cost curve and probabilities of damage.

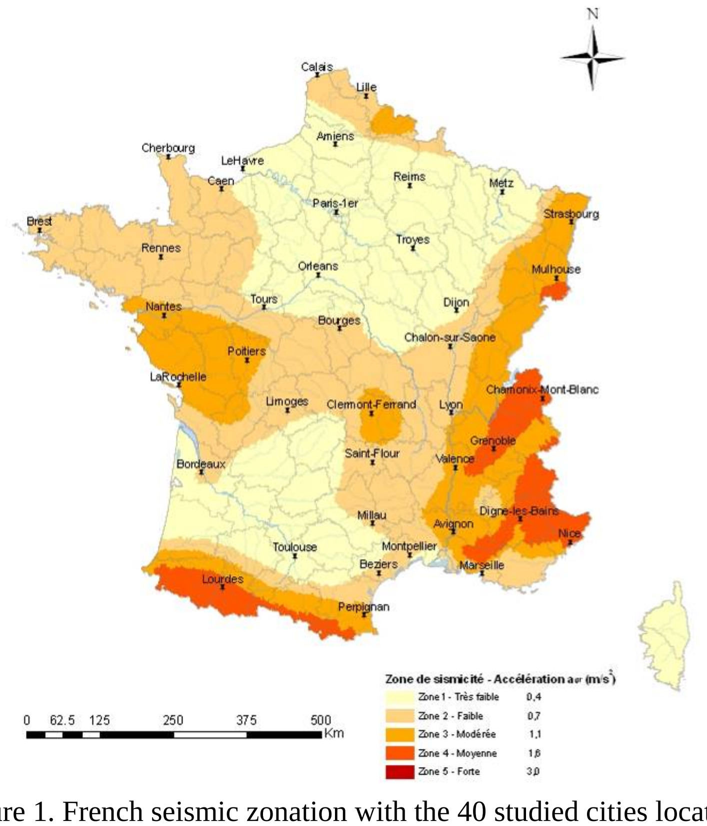

Figure 1. French seismic zonation with the 40 studied cities location.

SEISMIC RISK CALCULATION FOR 40 CITIES in FRANCE

The previous method is now applied to quantify the seismic risk in 40 cities in France in order to evaluate orders of magnitude of risk. Seismic hazard curves of cities, that represent French seismic activity (Figure 1), are available and 4 vulnerability indices between 0.3 (low vulnerability) and 0.9 (extreme vulnerability. Then, a synthesis of the risk can be reached for each area of seismicity (e.g. human risk – Figure 2) and show that annual probability of exceeding 1 casualty is ranking from 10-8 for low seismicity zone to 10-4 for high seismicity zone.

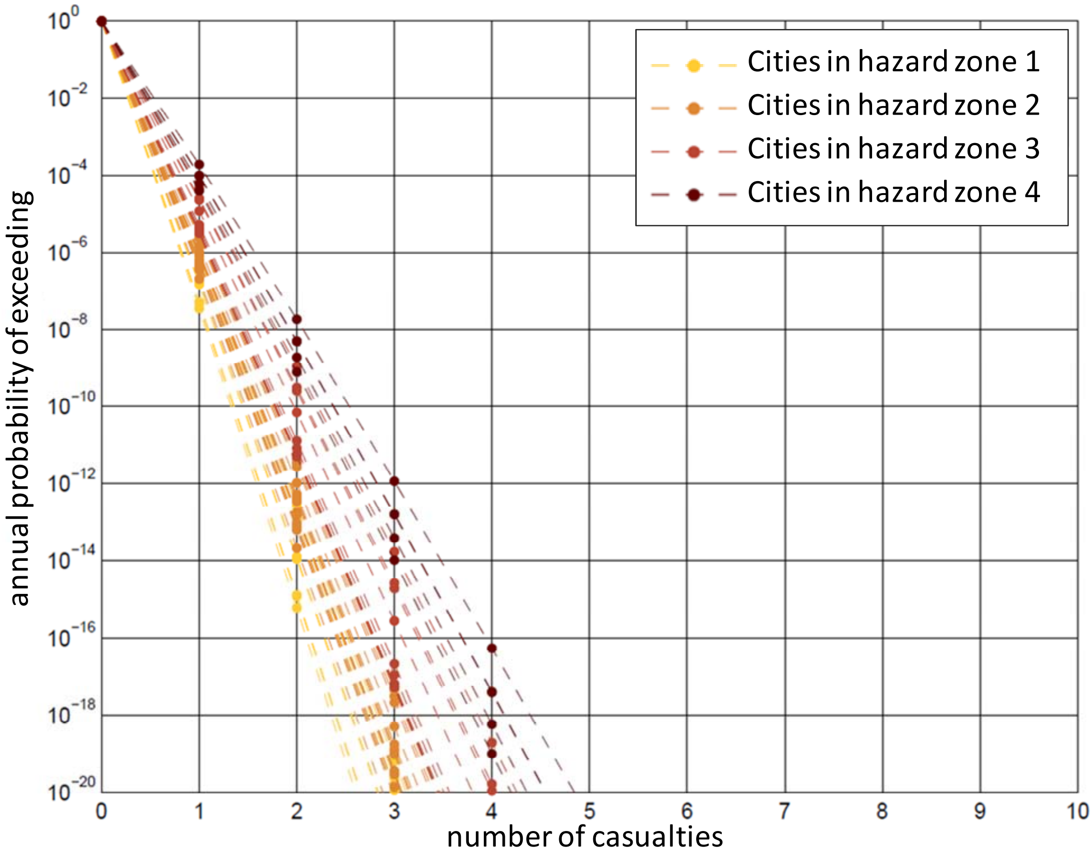

Figure 2. Curves of annual probabilities of exceeding N casualties in non-residential buildings occupied by 100 people.

RANKING PROCESS OF BUILDINGS IN A PRIORITY ORDER

A seismic risk plot method is now proposed in order to provide decision making about priority buildings for possible strengthening actions. In this way, the SIA Standard 2018 of the Federal Office for the Environment promotes simple reinforcement decision-making procedures. A similar representation, outcome from the Swiss guide, is also studied and their representations are suggested by using the seismic risk quantification method discussed above.

Priority rankings according seismic risk data and calculation assumptions

Keeping with the first step of the Swiss guide (Duvernay 1, 2005), different lists of priority are implemented considering a certain range of hazard, vulnerability and losses by using the probabilistic risk assessment method.

To be the most thorough, this study must consider as many contingencies as possible. In that way, hazard data of 40 cities, 4 risk-UE vulnerability index: low (IV=0.3), average (IV=0.5), high (IV=0.7), extreme (IV=0.9) and 6 typical buildings with different characteristics which represent current building typologies are taken into account (Table 1). A set of 960 buildings is defined by different hazards, vulnerabilities and losses.

Table 1. Characteristics of 6 typical and representative buildings.

type of building	number of occupants	buliding area (m²)	unit price (k€/m²)	global price (M€)	mean occupancy	mean ratio of loss
individual housing	3	120	1.5	0.18	0.45	0.22
collective dewellings	30	1000	1.5	1.50	0.65	0.32
office block	60	1000	1.3	1.30	0.40	0.20
industrial building	10	10000	1.0	10.0	0.15	0.07
public establishement	300	1000	2.0	2.00	0.35	0.17
hospital	500	10000	3.0	30.0	1.00	0.49

Seismic risk representation for priority classification

Several seismic risk representations are proposed in order to inform decision making about prioritizing buildings on possible strengthening actions to be taken. Then, any result of the seismic risk calculation can be used as criteria to classify buildings. For each of the studied buildings, the representation may be:

- individual and annual probability of mortality (Figure 3);
- annual probable economic losses;
- annual heavy damage (D4 + D5) probability;
- annual exceeding probability of 1 casualty.

However, the risk criterion and priority limits are chosen by the building owner considering its investment in reinforcing its property assets.

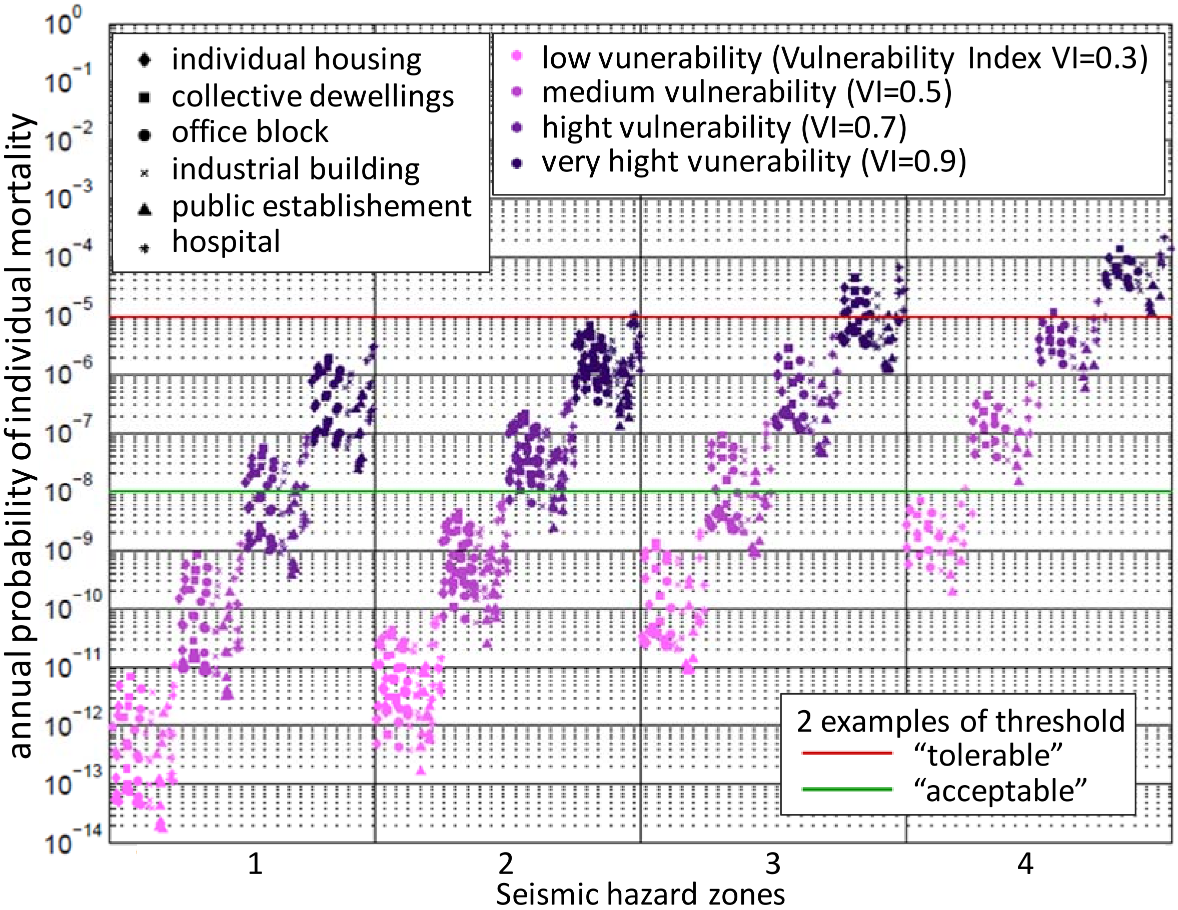

Figure 3. Distribution of annual and individual probabilities of mortality for each studied buildings.

COMPLIANCE OF THE BUILDINGS AND REINFORCEMENT DECISION

After the quantification of the seismic for the several buildings, the most vulnerable are selected to study their compliance according to the requirements currently in force (Eurocode 8). Different method can be used for this compliance approach.

Simplified method for the evaluation of a compliance factor

The compliance factor is the ratio between the actual capacity of the building and the basic regulatory capacity. The compliance factor calculation from the Risk-UE LM1 vulnerability index (Milutinovic et al., 2003) is based on the ground acceleration for which the level of damage reaches D4 level to represent the building's capacity. The intensity for which the building reaches this limit is calculated from the vulnerability index and the mean damage grade. In order to be compared to the regulatory acceleration, this intensity must be converted to ground acceleration. Finally, the compliance factor is the ratio between the acceleration for which the building is near collapse, and the regulatory acceleration.

Compliance estimation by monograph

In order to estimate maximum vulnerability indexes corresponding to the compliance factor, an abacus representing probabilities of heavy damage (D4+D5) for a given acceleration and for several vulnerability indexes (from 0.1 to 1) is proposed (Figure 4). As well, this monograph may be drawn in intensity to avoid uncertainties resulting from the conversion of intensities into accelerations. The limit accelerations for each seismic zone defined in the Eurocode 8 and the maximum probabilities of damage level allow estimating regulatory vulnerability indexes for each French seismic zone considering a given limit state of significant damages.

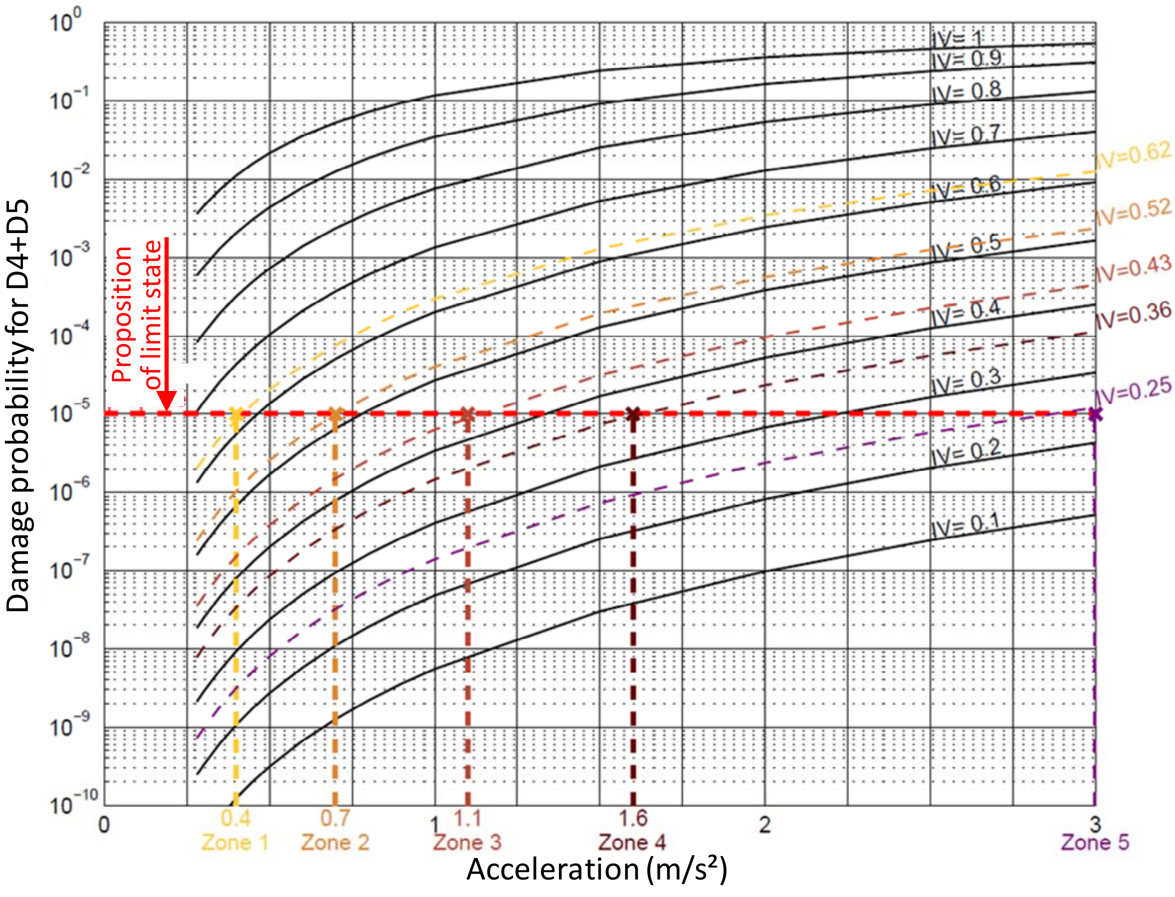

Figure 4. Shapes of heavy damage (D4+D5) probabilities for given accelerations and limit values of vulnerability index for each seismic zone considering a 10^{-5} probability of heavy damage (D4+D5).

Considering a limit state of significant damages corresponding to a 10^{-5} probability of reaching D4+D5 levels damage, limit values of vulnerability index are determined for each French seismic zone and compliance area (Table 2).

Table 2. Bounds of vulnerability index considering French seismic activity zoning and different compliance areas.

seismic hazard	agr (m/s²)	α = 1	α = 0.8	α = 0.25
1	0.4	0.62	0.68	0.92
2	0.7	0.52	0.55	0.81
3	1.1	0.43	0.48	0.70
4	1.6	0.36	0.41	0.62
5	3	0.25	0.28	0.50

CONCLUSION

In order to maximize the technical and economic performance of the reinforcement, a quantification of seismic risk is allowed by a probabilistic approach as illustrated in this study. It has been shown that it is possible to evaluate uncertainties resulting from calculation steps and input data. Then, orders of magnitude have been estimated for 40 cities in France. Furthermore, representations of seismic risk have been proposed for a wide range of buildings to define reinforcement priorities. Finally, a simplified method for the compliance factor calculation led us to determine maximum vulnerability indexes considering the compliance according to Eurocode 8 requirements.

Following this study, the acceptability of seismic risk has to be studied. The outcomes induced by values of priority bounds and limit state have to be calibrated. Besides, the choice of risk criteria to be considered is open to debate and may be the subject of a further study.

BIBLIOGRAPHY

COBURN A. and SPENCE R. (2002). Earthquake protection. Second edition, John Wiley & Sons, 420 p.

COMITE EUROPEEN DE NORMALISATION (2005). Eurocode 8 : Calcul des structures pour leur résistance aux séismes - Partie 3 : Evaluation et renforcement des bâtiments. Comité Européen de Normalisation, Norme Européenne, Projet définitif, n° pr EN 1998-3:2005 F, 67 p.

DEVAUX M., KOLLER M. (2009). Seismic vulnerability of the building stock in Basel – Lörrach – St-Louis area. *Rapport technique, Résonance Ingénieurs-conseils SA, 76 p.*

DUNAND F., BREMOND S. and GUEGUEN P. (2012) Analyse et validation des évaluations de la vulnérabilité sismique du bâti existant à partir des données INSEE – Application aux villes de Nice, Annecy et Lambesc. Rapport Final, Rapport GEOTER et ISTerre. 26p.

DUVERNAY B. (2005). Vérification de la sécurité parasismique des bâtiments existants : Concept et directive pour l'étape 1. 2ième édition : Office Fédéral des Eaux et de la Géologie, Directives de l'OFEG, 13 p., annexes

GRUNTHAL G. et LEVRET A. (2001). L'échelle macrosismique européenne 1998 (EMS-98). Ministère de la Culture, de l'Enseignement Supérieur et de la Recherche, Conseil de l'Europe, Cahiers du Centre Européen de Géodynamique et de Séismologie, Vol. 19, 103 p.

MARTIN C., SECANELL R., VIALLET E., HUMBERT N., « Consistency of PSHA Models in Acceleration and Intensity by Confrontation of Predictive Models to Available Observations in France », CSNI Workshop on "Recent Findings and Developments in PSHA Methodologies and Applications". Lyon, 7-9 April 2008.

NICOL J. (2013). Quantification Effective du Risque sismique. *Rapport technique GEOTER 87p.*