A method for comparison of recent PSHA on the French territory with experimental feedback

N. Humbert[1] and E. Viallet[2]

[1] *Engineer, EDF SEPTEN, Dept. of Dynamics & Earthquake Engineering, Lyon France*
[2] *Team Manager Dept. Of Dynamics & Earthquake Engineering, EDF SEPTEN, Lyon France*
Email: nicolas.humbert@edf.fr, emmanuel.viallet@edf.fr

ABSTRACT :

Recent Probabilistic Seismic Hazards Assessments (PSHA) studies on the French metropolitan territory exhibit very different seismic level. The two PSHAs considered in this paper are the study published by the MEDD (French ministry of environment and sustainable development) in 2002 and the study conducted by a working group of AFPS (French association of earthquake engineering) in 2006. These two studies are clearly not consistent in term of median values: we observe ratios of approximately 2 in term of PGA for a given return period and ratios of 10 between return periods for a given PGA. These discrepancies are a real serious problem for French Earthquake engineering.
The purpose of this study is to compare PSHA of the French territory with experimental feedback and gives an objective point of view of the confidence on probabilistic models of seismic hazard based on observations. The PSHA considered is compared with seismic experience feedback provided by the survey system of EDF sites and by the RAP (French seismograph network).
This paper develops a methodology based on a probabilistic approach. A statistic methodology of determination of soil-structure interaction (SSI), and specific soil effect is developed for each site where feedback is collected. These probabilistic models developed for each SSI and soil effect allows us to compare PSHA with feedback by a integration of both epistemic and random variability at each step of the methodology.

KEYWORDS: PSHA, Experimental Feedback, Confidence

1. INTRODUTION

Recent PSHA studies developed on the French metropolitan territory put the light on the importance of working hypothesis defined prior to any hazard integration. This point is not surprising because we know that epistemic uncertainties increase in low to moderate seismicity context. The French metropolitan territory has a relatively low seismicity and have to be subjected to particular care for epistemic uncertainties treatment.
To confront this difficulty the common practice for engineering is to compare the hazard evaluations of PSHA with experimental feedback making certain the consistency. This paper present a statistical approach which takes inspiration from this common practice. It is illustrated by two practical applications on:
– The PSHA published by French ministry of environment and sustainable development (MEDD) in 2002 (Martin et al. 2002) and the study published by a working group of AFPS in 2006 (Martin et al. 2005).
– The seismic experience feedback provided by the survey system of EDF power plants (19 stations) and by the French seismograph network (RAP) (set of 20 sites based on rock). (figure 1)
This comparison can be done in several dimensions (one dimension for each station). But in order to look at this study a little more clearly, we reduce these dimensions to one: the total number of “events” observed on all the stations (an “event” is an exceeding of a Peak Ground Acceleration (PGA) of 10 gal).

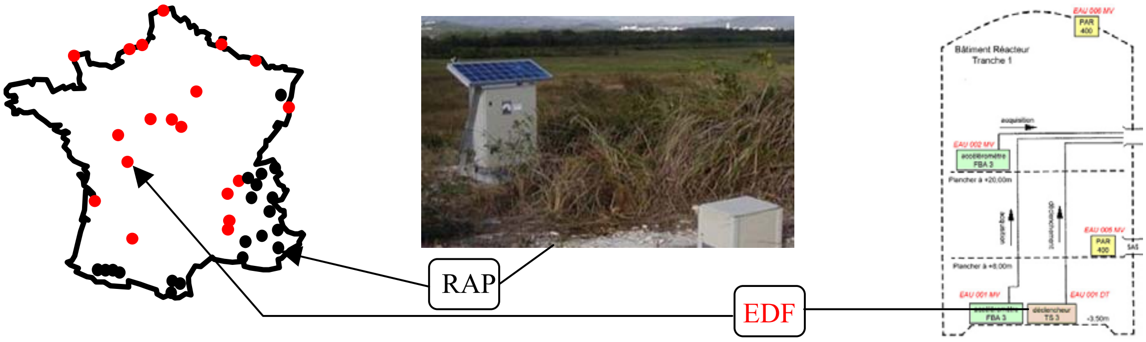

Figure 1 Survey system of EDF power plants and a selection of the French seismograph network (RAP)

2. DATA PROCESSING OF THE HAZARD: SOIL-STRUCTURE INTERACTION + SITE EFFECT

The PSHA gives a hazard consistent with rock (hard soil) and with free field seismic motion (without any building). This is fully consistent with the RAP experience feedback. But the accelerometers of the French power plants are based in the bottom slab of the reactor building and on various soil condition (rock or soft/sedimentary soil).

2.1. ISS

The first step of the study is an ISS evaluation for each site. This evaluation is done with the same spirit as a Seismic Probabilistic Risk Analysis (SPRA), but with very low values of distortion: so we do not reach the same non-linearity in soil and in structures as SPRA.
In these 19 ISS studies we develop a « best estimate » model accounting for epistemic uncertainties of parameters. The computation is performed using an axisymetric stickmodel of the reactor building (accounting for specificities of each French Reactor Building). The median Young's modulus of the concrete comes to 41900 Mpa and the soil is represented by series of layers: with shearing waves velocity (Vs) fitted on cross hole reports. The uncertainties on seismic motion, soil conditions and building physical parameters are integrated in the computation (~600 runs : 19 buildings x 30 computations).
A conversion coefficient K_{ISS} between the free field and the bottom slab of reactor buildings is defined for each site (equation (2.1)). This coefficient is a statistical variable with a distribution specific for each site.

$$K_{ISS}=\frac{FreeFieldMotion}{BR\_Slab} \tag{2.1}$$

The figure 2 gives an overall view of the finite element model and shows the median value for KISS with a desegregation on Vs30: the average velocity of shearing waves in the 30 first meters.

2.2. Soil amplification (KSOL)

The ratio proposed to represent soil amplification K_{ISS} (equation (2.2)) published in literature are not estimated as « best estimate » values but as fixed and conservative coefficient (for instance the Eurocode 8 coefficients). Moreover some studies (e. g. Drouet S. 2007) take a new look at the « rock » reference of attenuation relationship and PSHA. To avoid this in-depth debate this study decided to have a "deterministic" hypothesis for this step : KISS=1 (with no uncertainty). In this study this hypothesis is the most restrictive one.

$$K_{SOL} = \frac{FreeField + SiteEffect}{FreeField + Rock} \qquad (2.2)$$

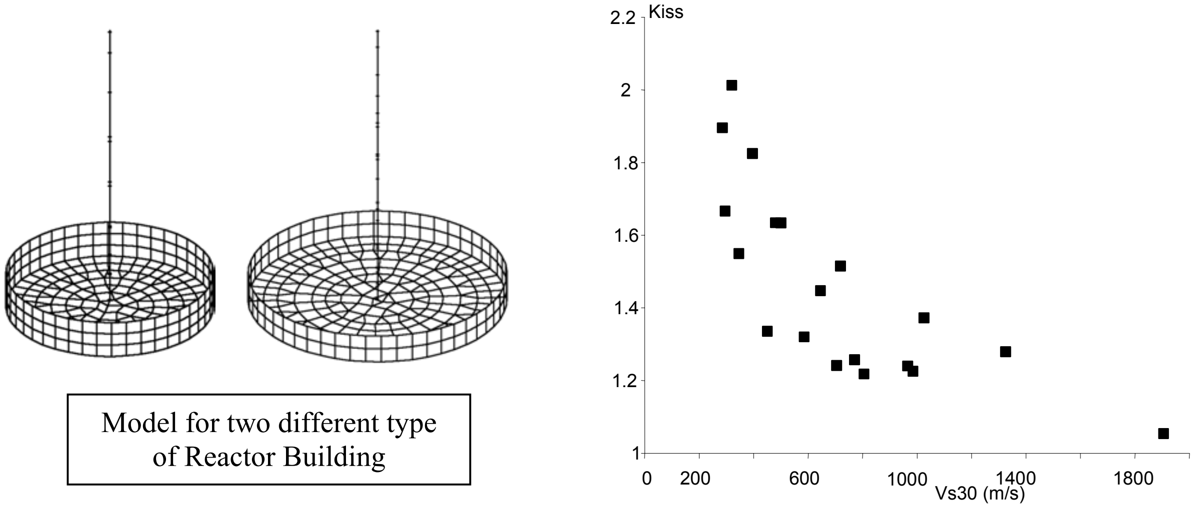

Figure 2 Model and median results for K_{ISS} estimation.

2.3. Equivalent Exceeding Level determination

For each accelerometer we evaluate the Equivalent Exceeding Level : this equivalent level is determined by equation (2.3). It depends on K_{ISS} and K_{SOL} so this coefficient is a statistical variable with a specific distribution for each site.

$$\frac{K_{SOL}}{K_{ISS}} = \frac{BR\_Slab\_Motion}{FreeField + Rock\_Motion} \qquad (2.3)$$

3. ASSESSMENT OF THE EXPECTED CUMULATED FEEDBACK WITH A PSHA STUDY

The objective is not to assess a second time seismic hazard by using experimental feedback: some studies prove this is practically impossible (Beauval et al, 2007). This paper uses the model developed in PSHA to predict the experimental feedback of the last years: this probability is conditional: P(Feedback/Model) which means “what could have been observed if the model is true”. This conditional probability includes the occurrence random variability due to the finite observation window so there is no question of “sufficiency” of feedback. The confrontation always is possible, however its conclusions can be interesting or not. That is why this study introduces a real discussion on consistency of PSHA with accelerometers feedback.

3.1. Estimation for one site

PSHA studies give an expectation of λ, the annual exceeding frequency for a PGA value (all this site by site). PSHA studies formulate the hypothesis that earthquake occurrence is a Poisson process. So the number of exceeding for one site follows a Poisson distribution (equation 3.1).

$$P(n,t) = \frac{e^{\lambda t \frac{K_{SOL}}{K_{ISS}}} (\lambda t \frac{K_{SOL}}{K_{ISS}})^n}{n!} \qquad (3.1)$$

P(n,t) is the probability recording n « events » during t years. We notice that the uncertainty of this distribution depends on $(1/t)^{0.5}$: so the longer is the time of feedback, the more precise the evaluation becomes. We don't need to check sufficiency of time of feedback, the occurrence model do it automatically.

3.2. Estimation for all the sites (cumulated feedback)

If we formulate the hypothesis that sites are independent in term of seismic hazard, the total number of exceeding for the N sites follows a Poisson distribution too (equation 3.2).

$$P(n,t) = \frac{e^{A}(A)^{n}}{n!} \quad \text{with} \quad A = \sum_{i \in sites} \lambda_i t_i \frac{K_{SOL}}{K_{ISS}} \tag{3.2}$$

We don't formulate this independence hypothesis because the model developed in PSHA is able to account for this hazard dependence. The hazard dependence has no effect on "A" (expectation of the distribution) but increases the standard deviation (SD): for a Poisson distribution the SD is "$A^{0.5}$" with the dependence hypothesis this SD becomes "$KA^{0.5}$", with K a parameter greater than 1. K is the average number of sites impacted by one earthquake.

For data post processing reasons, the assessment of the distribution for the cumulated feedback is estimated with a Monte-Carlo simulation instead of the continuous integration of activity expectation proposed by McGuire (1976). Using more than 100 000 simulations we estimate the cumulated feedback distribution: the negative binomial distribution (ie. Pòlya distribution) proposed by Woo G. (2000) fitted perfectly the Monte-Carlo simulation (validation on 5 SD) (figure 3 and equation 3.2).

The K parameter depends on all the PSHA parameters and depends on each branch of the logic tree. But K depends mainly on two hypothesis: the feedback (sites localization, number and time of recording) and the minimal magnitude for hazard integration (Mmin). So we have to estimate K for each PSHA and each type of experimental feedback.

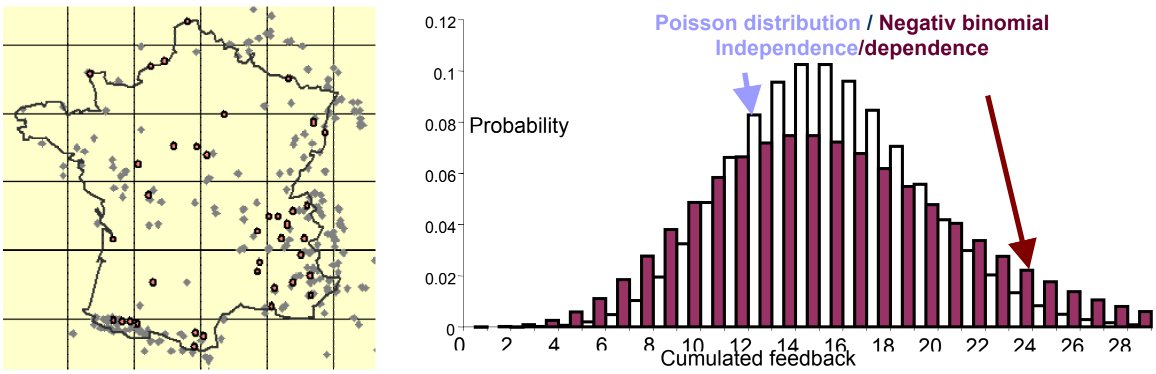

Figure 3 : Example of Monte-Carlo simulation and Poisson/NegativBinomial distributions comparison.

$$P(n,t) = \exp\left[\ln\Gamma\left(\frac{A}{K-1}+n\right) - \ln\Gamma\left(\frac{A}{K-1}\right) - \ln\Gamma(1+n)\right]\frac{1}{K}^{\frac{A}{k-1}}\left(1-\frac{1}{K}\right)^{n} \tag{3.2}$$

with lnΓ the logarithmic gamma function. The effect of the dependence hypothesis is a widening of the feedback estimate (Figure 3).

4. IMPLEMENTATION OF THE COMPARISON

In this part we implement the method presented in part 2 to 3 on both PSHA and both experimental feedbacks. Because it would be impossible to present all the possible comparisons in this paper we only present some results as illustrations. First we present both PSHA compared with feedback of power plants in term of median epistemic value. Then for the AFPS 2006 study we implement a desegregation on epistemic fractiles, which allows us to introduce some details about the likelihood function.

4.1. Median comparison with power plants feedback

Figure 4 presents the comparisons between the feedback distribution estimated by PSHA for French power plants an the real experimental feedback. There is only one event recorded on the 19 power plants taken into account, the Sierentz earthquake of 1980 with a PGA of 18 gal observed on Fessenheim nuclear power plant.

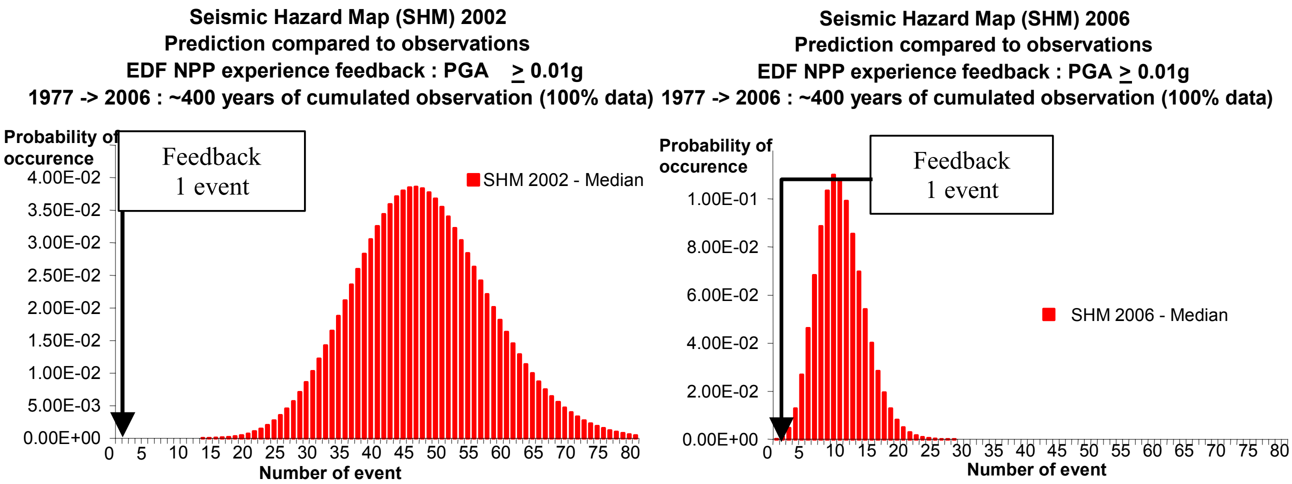

Figure 4 : Comparison of MEDD 2002 and AFPS 2006 (median) with feedback of French power plants.

We observe that MEDD 2002 PSHA estimates that only one observation is impossible: this PSHA is inconsistent with experimental feedback. The AFPS 2006 median study seems to be more consistent with experimental feedback in spite of the fact that it seems to overestimate the hazard too.

4.2. Comparison of "AFPS 2006" with both feedbacks: epistemic desegregation

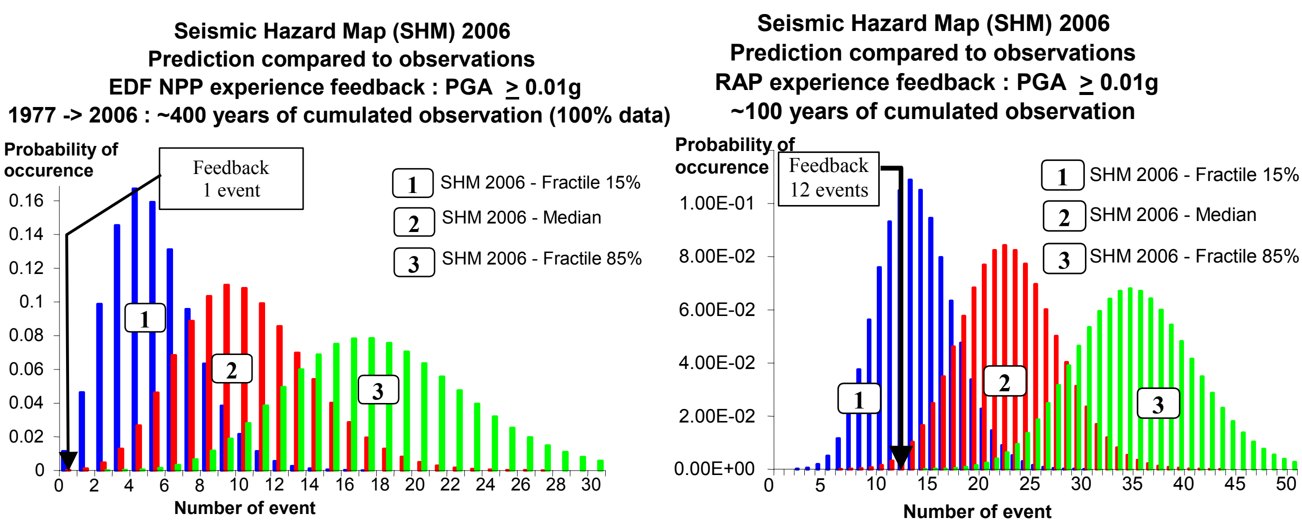

Figure 5 : Comparison of AFPS 2006 with feedback of French power plants and RAP stations.

PSHA are based on series of epistemic hypothesis, which could lead to large uncertainties. Comparison of PSHA with a desegregation on epistemic uncertainty could be a solution to limit these uncertainties. The Figure 5 presents this comparison for “AFPS 2006” with the experimental feedback of power plants an RAP. We notice that in both cases the situation is similar: the 15% fractile is the most consistent with experimental feedback.

4.3. Introduction to Bayesian methods on PSHA

In order to have a statistical result of this comparison we introduce the Bayes' theorem also known as "Bayes' rule" or "Bayes' formula". This equation is not describe here but based on the conditional probability P(Feedback/Model) assessed in previous parts this theorem defines a likelihood function which gives a “weight” for each branch considered functions of consistency with experimental data.
The figure 6 is identical as the figure 5 but formulated in term of likelihood.

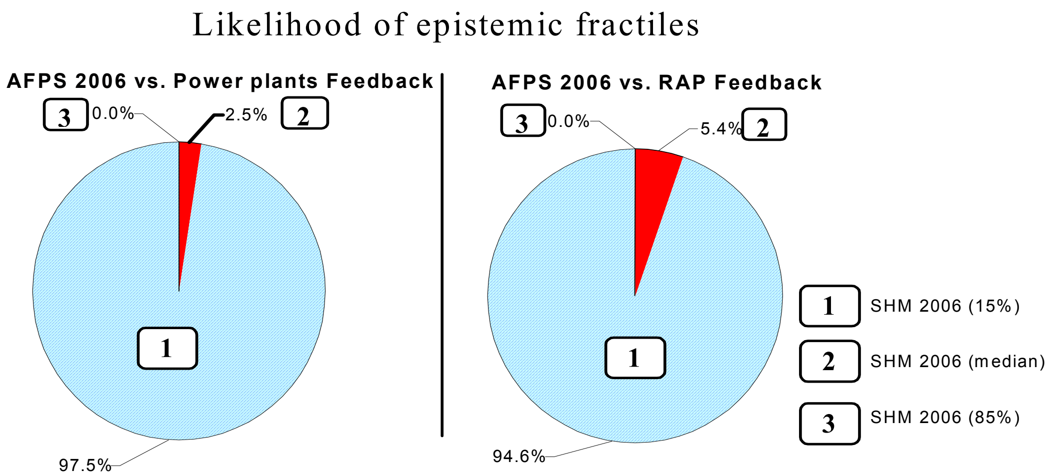

Figure 6 : Likelihood of epistemic fractiles on “AFPS 2006” compared both feedback

5. ROBUSTNESS OF THE METHOD

Comparison of PSHA with experimental feedback is not absurd because PSHA are completely based on experimental feedback. However this type of study is commonly criticize because of its potential instability. In order to answer this reservations, the robustness of the method is studied with three cases.

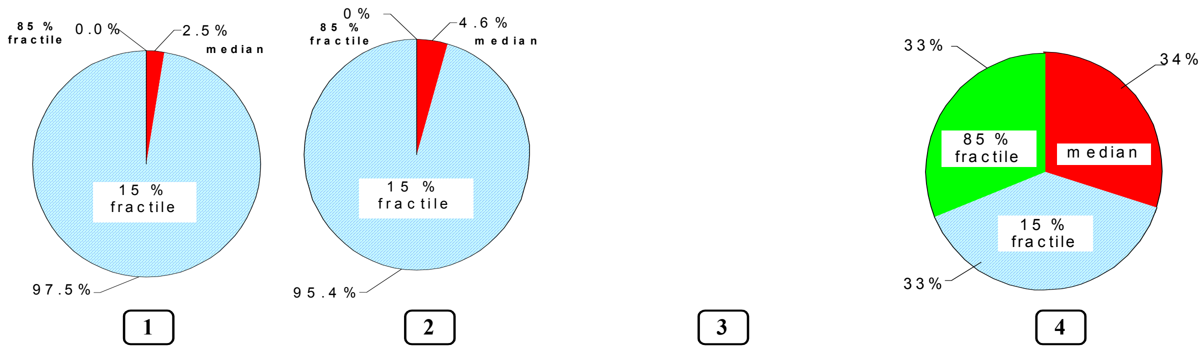

Figure 7 : Likelihood on fractiles of “AFPS 2006”: 4 robustness cases

5.1. Case 1: reference.

This is the result of the comparison of the AFPS 2006 PSHA with the experimental feedback of power plants formulated in term of likelihood. (Figure 6 and 7).

5.2. Case 2: What happens in case of a second event tomorrow.

This is the same comparison as “case 1” but with a second event observed on French power plants. We observe that the differences are hardly noticeable. There is no instability of the comparison on the randomness of seismic events because the randomness of earthquake’s occurrence is included in the comparison.

5.3. Case 3: Do we have enough information? (1/2)

In 1991 we had only a quarter of the experimental feedback. The “case 3” is the result we could have obtained in 1991 with this methodology. We observe the same tendency as “case 1” but less pronounced: because the cumulated time of observation is only 100 years, so the randomness of seismic occurrence plays a more important role making the likelihood less contrasting between epistemic fractiles.

5.4. Case 4: Do we have enough information? (2/2)

In 1980 when the only event ever recorded on the French power plants occurred (Sierentz) we could have used the same method: the “case 4” is the result of this comparison. We see that the likelihood gives no contrast between epistemic fractiles. Due to the lack of feedback the comparison is inefficient. In conclusion we do not need to study effectiveness of feedback to be compared with PSHA, the “effectiveness” is automatically represented because randomness of occurrence is included in the statistical comparison.

6. CONCLUSIONS

6.1. Development of the methodology

This paper develops a methodology based on a probabilistic approach which allows us to compare PSHA with experimental feedback. This methodology do “best estimate” evaluations at each step with a realistic integration of epistemic uncertainties and random variability:

1. Site Effect and Soil-Structure interaction are conceptualized as statistical variables with an epistemic distribution specific for each site.
2. The limits of experimental feedback are integrated: (i) the random variability of earthquake occurrence due to the limitations of observation period is accounted for and (ii) the seismic dependence between different sites of experimental feedback is accounted for by a Pòlya distribution.
3. There is no interpretation of PSHA, the hypothesis retained are exactly the same as those developed initially.

Finally the comparison is done in terms of conditional probability “P(Feedback/Model)” which means “what could have been observed if the model is true”.

6.2. Application for the context of the French metropolitan territory

The methodology is developed on two PSHA of the French metropolitan territory and on two experience feedback. The conclusions are:

1. The median PSHA is inconsistent with PSHA for one of the two studies (MEDD 2002) with an obvious overestimation of hazard.
2. The comparison with experimental feedback enable us to define a likelihood function. This function can distinguish between two epistemic choices and be accounted for in a Bayesian updating technique as presented by Viallet (2008).

6.3. Robustness

Finally robustness of the method of comparison is proved and the discussion on sufficiency of observation period solved.

REFERENCES

Fukushima Y., Tanaka T. (1990). A new attenuation relation for peak horizontal acceleration of strong earthquake ground motion in Japan. *BSSA*.

Beauval C. (2003). Analyse des incertitudes dans une estimation probabiliste de l'aléa sismique, exemple de la France. *Thèse de doctorat de l'université Joseph Fourier.*

Cornell C.A. (1968). Engineering seismic risk analysis. Bull. Seism. Soc. Am., *58(1), 1583–1606*.

Saporta G. (2006). Probabilités analyse des données et statistique, Technip.

Woo G. (2000). The mathematics of natural catastrophes, Imperial College Press.

Drouet S., Nicolas M., Hernandez B. (2007). Analyse de la base de données de mouvements forts Européenne: dans quelle mesure des effets de sites sont contenus dans cette base ? *AFPS 2007*.

Martin Ch., Combes Ph., Secanell R., Lignon G., Carbon, D., Fioravanti A., Grellet, B. (2002). Révision du zonage sismique de la France, Etude probabiliste. *GTR/MATE/0701-150.*

Martin Ch., Secanell R., Développement d’un modèle probabiliste d’aléa sismique calé sur le retour d’expérience, phase 1, AFPS, Groupe Zonage, document de travail, GTR/CEA/1205-279, décembre 2005.

Scotti O., Baize S., Baumont D., Beauval c., BergeThierry C., Bertil D., Bonilla F., Clement C., Cushing M., Volant P. (2003) Révision du zonage de la France métropolitaine, discussion des hypothèses et de leur impact sur l’aléa. *6ème colloque National de l’Association française de Génie Parasismique, Ecole Polytechnique.*

Viallet E., Humbert N., Martin C., Secanell R. (2008) On the Use of a Bayesian Updating Technique to Reduce Epistemic Uncertainties in PSHA. *The 14th World Conference on Earthquake Engineering, Beijing, China.*