SITE-SPECIFIC PSHA: COMPARISON BETWEEN TWO FULLY PROBABILISTIC METHODS, THE EUROSEISTEST CASE.

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INTRODUCTION

The integration of site effects into Probabilistic Seismic Hazard Assessment (PSHA) is a constant subject of discussion within the seismic hazard community due to its high impact on hazard estimates. To include this effect on a PSHA, several different methods have been developed by different authors varying from hybrid (deterministic – probabilistic) approaches to fully probabilistic approaches. **The aim of this research is to compare the hazard curves on a highly non-linear soil site obtained with two different fully probabilistic site specific seismic hazard methods**: **1) The Full Convolution Analytical Method (AM) proposed by Bazurro and Cornell 2004a and 2) what we call the Full Probabilistic Stochastic Method (SM).** The AM computes the site-specific hazard on soil by convolving the site-specific hazard curve at the bedrock level, Sar(f), with the probability distribution of the amplification function, AF(f) at a given site, while the SM, is nothing else that the hazard curve built from stochastic time histories on soil.

THE EUROSEISTEST

"The EUROSEISTEST is a multidisciplinary European experimental site for integrated studies in earthquake engineering, engineering seismology, seismology and soil dynamics. It is the longest running valley-instrumentation project worldwide". (Pitilakis et al., 2013).

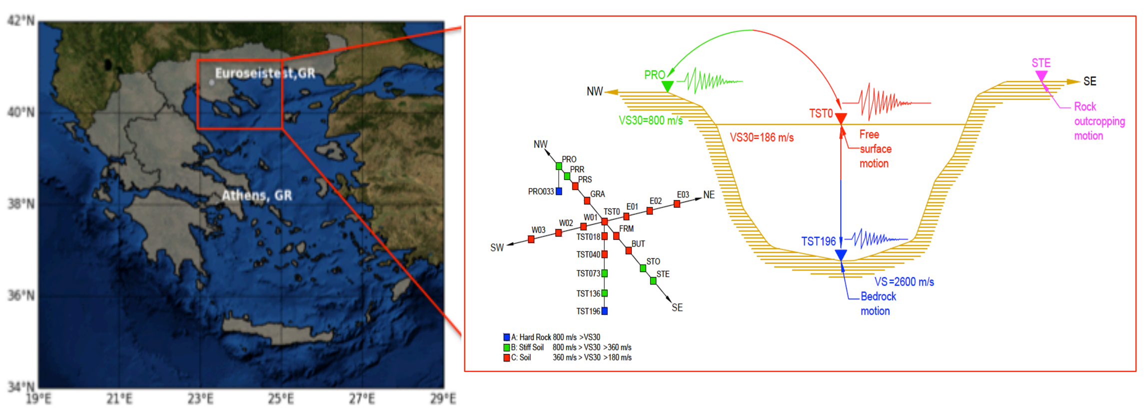

Figure 1: Euroseistest Location - Greece   Figure 2: Euroseistest Seismic Array and basin scheme.

"The EUROSEISTEST is located in the Mygdonian basin in North-Eastern Greece, 30 km ENE of Thessaloniki, at the epicentral area of the magnitude 6.5 event that took place in 1978". (Pitilakis et al., 2013).\

The EUROSEISTEST was selected because it has been:

- Extensively investigated.
- Densely instrumented.
- Soil profile (Jongmans et al. 1998; aptakis et al. 2000).
- Degradation curves (Hollender).
- Amplification Functions (Raptakis et al.1998, Ktenidou et al. 2015).
- Fundamental Frequency.
- Single Station Sigma Analysis (Ktenidou et al., 2015).

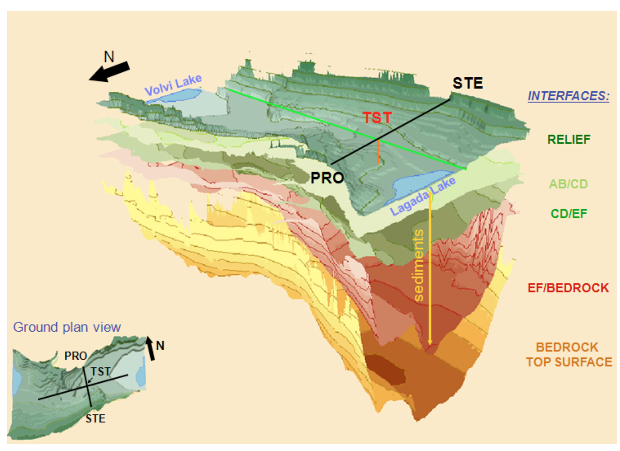

Figure 3: 3D model of the Mygdonia basin geological structure (Manakou et al., 2010)

RESULTS

Comparison Between Methods

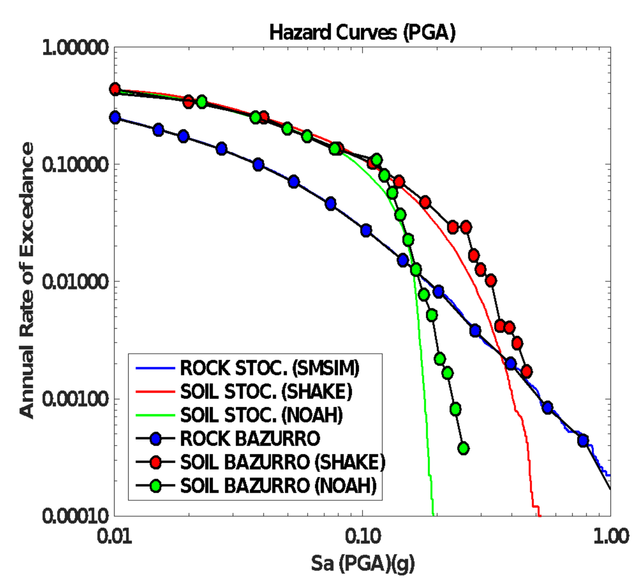

Figure =17: Comparison between the AM and SM for three different spectral periods (PGA, Sa=0.2s and 1.0s).

After comparing both methods, the AM and the SM, a good resemblance at low return periods its observed (Figure 17), however it starts to distance oneself as the return period increases. This differences specially at large level of acceleration can be explained due to the limitations of the simplified approximation of the AM method, also acknowledged by the authors, where a piecewise-linear regression issued to fit the *AF(f)* as a function of the acceleration level on rock *Sar(f)*.

Nevertheless, and despite the mentioned limitations that the AM method can present, Bazurro and Cornell method is a quick and easy way to include in a fully probabilistic way the site effects at an specific site, however special attention needs to be take when strong non linearity of the soil is observed such ad the exposed case at the Euroseistest, or as the authors said, when the correction factor takes on values greater than 10.

Comparison With Real Local Data

Some available records are available at the WUROSEISTEST webpage, however most of them correspond to the weak motion. Figure 18, shows the Sa Rock Vs. Sa Soil plot for the two soil models (L-SHAKE, NL-NOAH) and for the few available real data. It is interesting to discuss that the real points are all located within the σ of our models, suggesting that the considered input models are consistent with real data at the linear domain. However, and as we currently face, there is no real strong motion data, to say the same for the NL part, or to suggest that the linear or nonlinear model resembles better to real data.

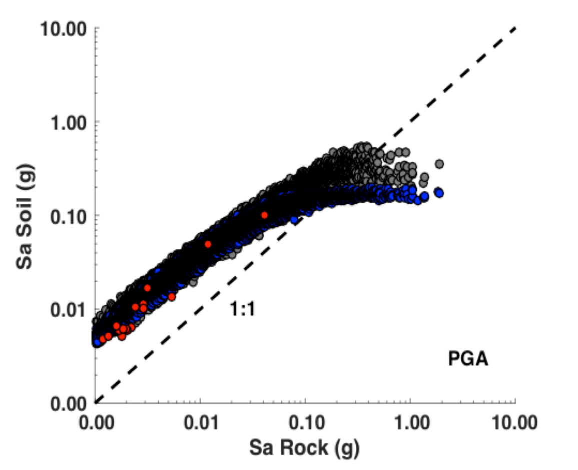

Figure =18: Sa Rock Vs. Sa Soil for L-SHAKE Vs NL-NOAH models and real data.

METHODOLOGY

On this work we will **explore two different fully probabilistic procedures** to account for linear and nonlinear soil response in PSHA. The objective is to estimate the hazard curve on soil at the Euroseistest derived with the **Full Probabilistic Stochastic Method (SM)** as well as we have called the **Full Convolution Analytic Method (AM)**.

Stochastic Earthquake Catalog

Area Source Zones Impact on Hazard

Evaluate the impact on hazard estimates of the different areas source zones in the vicinity of the Euroseistest. (Figure 4 and Figure 5).

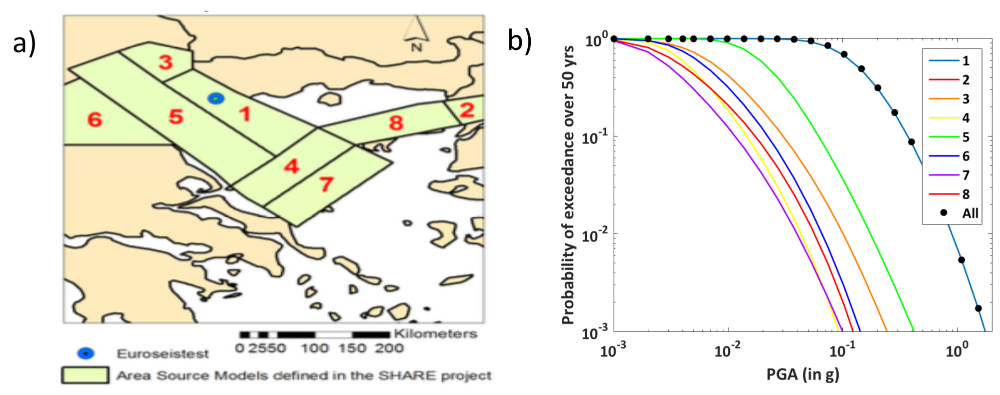

Figure 4: a) SHARE Area Sources at the EUROSEISTEST. b) Area Source Contribution to Hazard

Catalogue Length

Define the required catalogue length by comparing the stochastic catalogue hazard curve with the one generated using the classical method. (Figure 6)

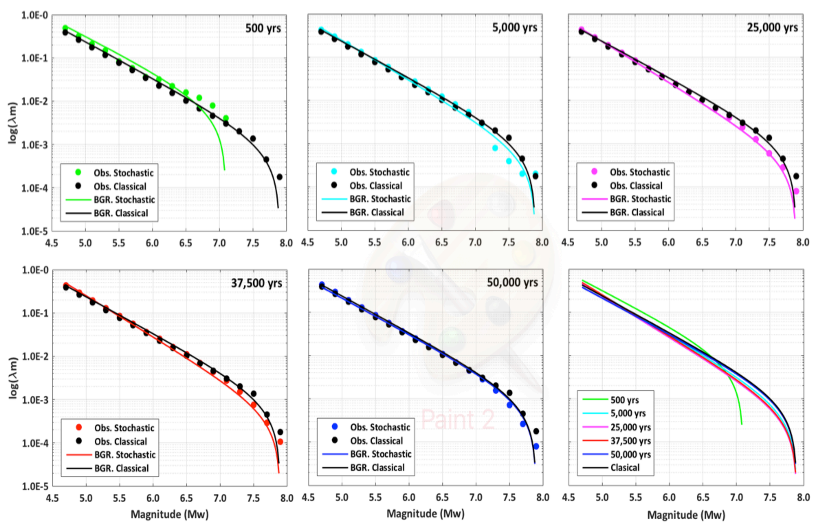

Figure 6: Bounded Guttenberg Richter Curve derived using the five different stochastic catalogues compared with the recurrence law proposed on the SHARE model.

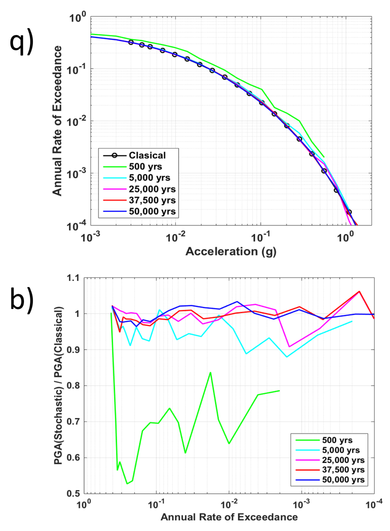

Figure 7: a) Different Catalogue length Hazard curves. b) Catalogue length error.

Host-to-target Adjustments

Adjusting ground motion prediction equations from their host conditions to the target conditions, In this case we use Laurendeau et al. 2017 for VS=800 m.s and VS=2600 m/s, and calculate the HTT Factors as the ratio between both hazard curves.

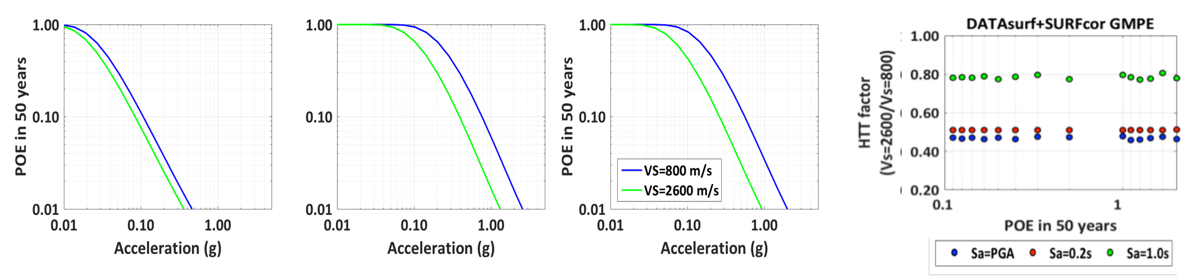

Figure 8: a) HTT adjustment factors derived from LA17. b) LA17 Euroseistest HC.

Synthetic Time Histories on Rock

We generate stochastic time histories on rock using the Ground Motion Simulation Stochastic Method proposed by Boore 2003, and posteriorly we scale them on the Fourier domain to make the stochastic hazard curves compatible with the classical hazard curve on rock, in this case AA14.

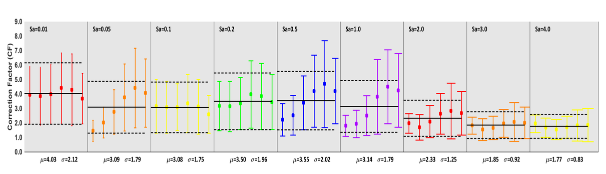

Figure 9: Scaling Factors as a Function of the Magnitude and the period.

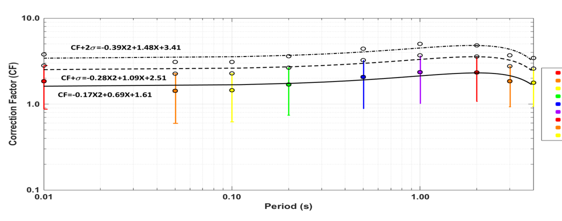

Figure 10: Scaling Factors continuous forms regression.

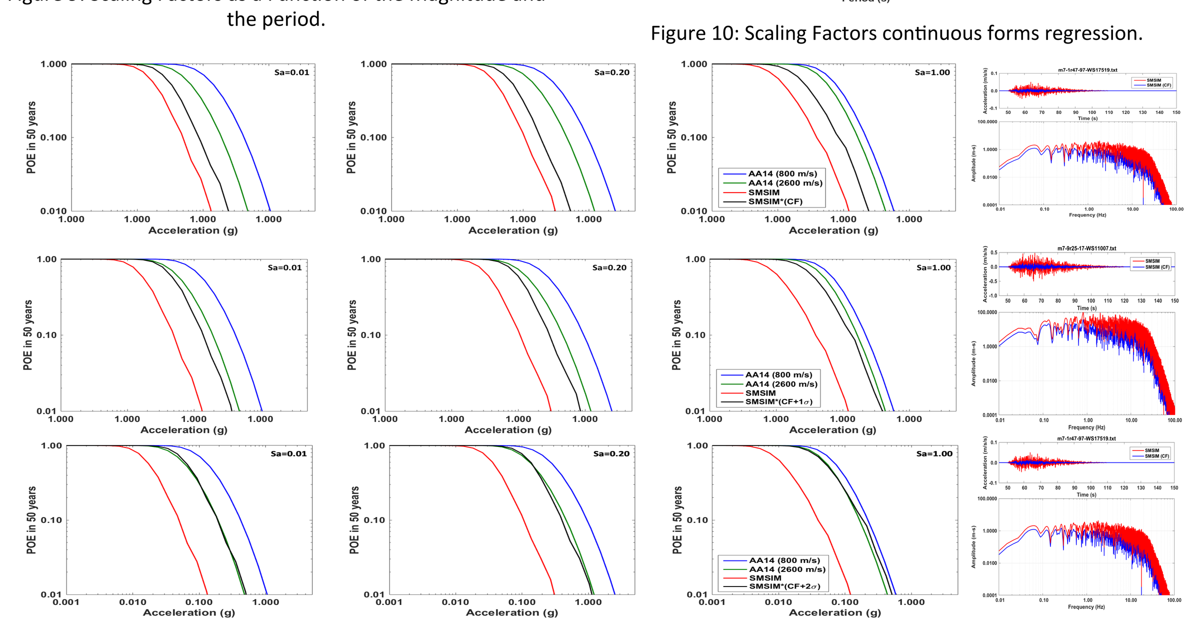

Figure 11: Hazard curve using stochastic time histories and scaling factors.

Figure 12 Shows the ratio between AA17 classical hazard curve on hard rock and the stochastic hazard curve., where it is possible to observe the important gain in accuracy, with a ratio ~1.0 at the three different periods and and all return periods. The CF+2σ provided the best fitting.

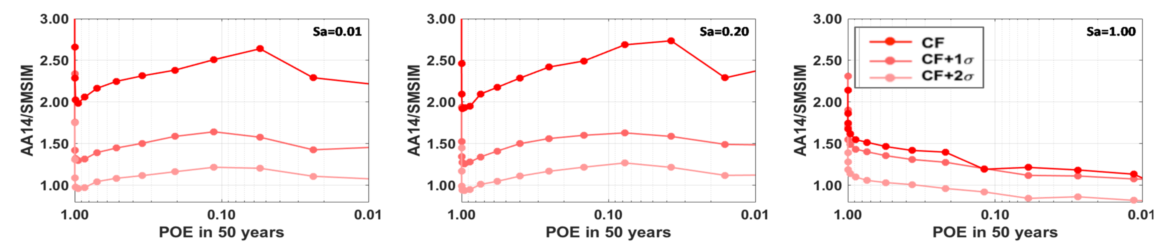

Figure 12: AA14*HTT Classic Hazard Curve on Rock (VS=2600) to Stochastic SMSIM Time Series Hazard (VS=2600) Curve Ratio.

Soil Site Response Analysis:

Once the hazard curve on rock has properly been established as well as the acceleration records on rock, we proceed to perform the linear and nonlinear calculations using SHAKE91 and NOAH respectively. Figure 13 shows the soil profile and the degradation curves used on this example.

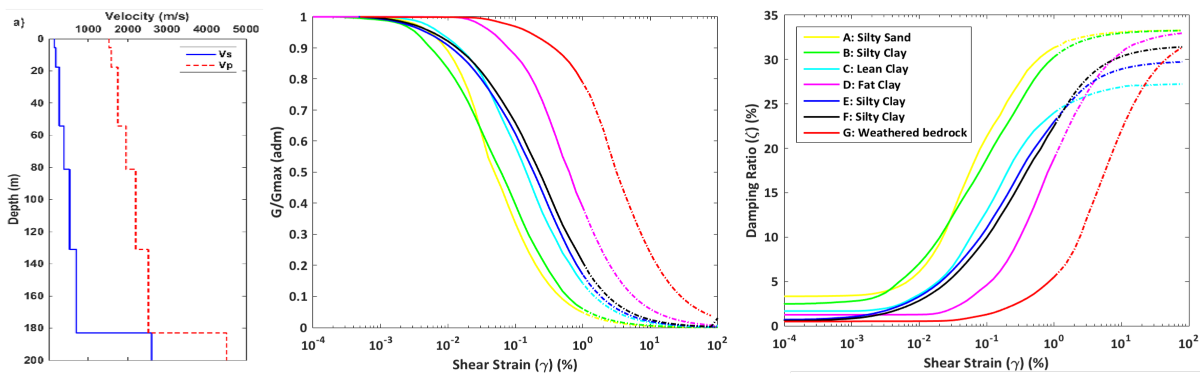

Figure 13: EUROSEISTEST a) Soil Profile. b)Degradation Curves (Hollander, 2014)

Full Convolution Analytical Method (AM):

The "Analytical Estimate of the Soil Hazard" method, is a simple, closed-form solution that appropriately modifies the hazard results at the rock level to finally obtain the hazard curve on rock (Bazurro and Cornell. 2004b).

$$AF(f) = \frac{Sa^s(f)}{Sa^r(f)} \qquad \ln \widehat{Sa^s} = C_0 + (C_1 + 1)\ln \widehat{Sa^r} \qquad G_z^{(z)} = H(S^r_{a,z})\, e^{\frac{1}{2}\frac{k_r^2\sigma^2}{(C_1+1)^2}}$$

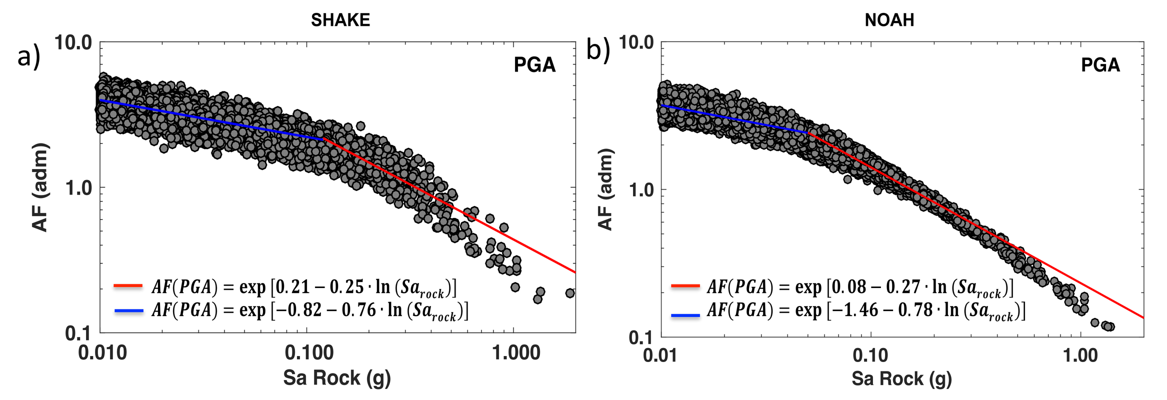

Figure 14: *Piecewise-linear regression models of AF(f) on Sar(f) at PGA spectral period. a) Surface acceleration time histories were calculated using SHAKE91. b) Surface acceleration values were calculated using NOAH.* .

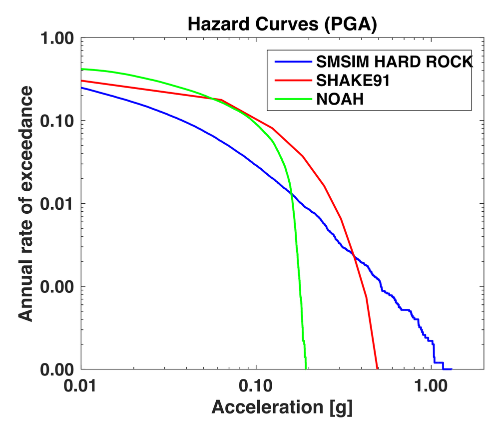

Figure 15: Hazard curve on Soil calculated using the AM

When the soil presents strong non linearity such as the Euroseistest case, special attention with the C1 term of the linear regression at high acceleration levels, since the slope of this line is close to one, hence the exponential correction factor that multiplies the hazard curve on rock tends to infinity, fixing a numerical limitation to this method, and in a certain way, a restriction to the maximum amount of non-linearity that can be considered in the model. Also, the standard deviation (σ) of the AF(f) that is used as a parameter on the correction factor, and have similar effect than the C1 slope.

Full Probabilistic Stochastic Method (SM)

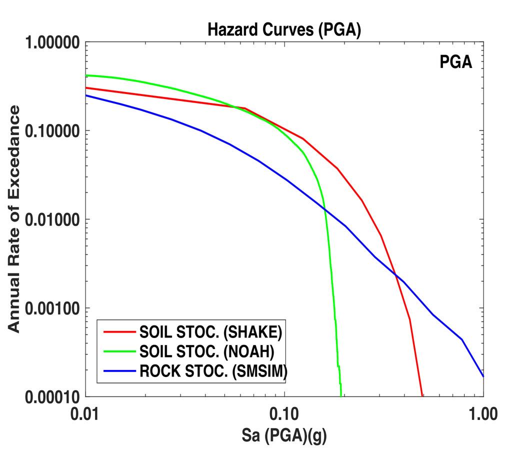

Figure 16: Hazard curve on Soil calculated using the SM

What we call here the full probabilistic stochastic method (SM) is nothing else that the hazard curve built from stochastic time histories on soil based on the two different event set of earthquakes propagated using the two site response codes (SHAKE91 and NOAH). To build the hazard curves on soil we calculate the annual rate of exceedance of a certain ground motion level (X) as follows:

$$\lambda(x \geq X) = \frac{N_{events}(x \geq X)}{Catalogue\ Length}$$

CONCLUSIONS

- A Rock to Hard Rock host-to-target adjustment factors were proposed using Laurendeau et al. 2017 GMPE, and posteriorly applied to our selected GMPE Akkar et al. 2014 in order to obtain the hazard on hard rock (Vs=2600 m/s).
- A simple method to fit stochastic time histories to target hazard curves has been exposed, an important tool for engineering purposes and especially for stochastic numerical simulations.
- A comparison between two fully probabilistic seismic hazard methods to include site effects was exposed, with the following **advantages and limitations:**

Full Convolution Analytical Method (AM):

- Simple and quick way to convolve the hazard curve on rock and the amplification functions.
- Limited amount of calculations.
- Numerical limitations (C1 and σ), specially when strong nonlinearity such as the Euroseistest case or any other place with expected soil site effects.

Full Probabilistic Stochastic Method (SM)

- More complex and time demanding method, however currently possible to achieve within a critical facility project.
- No need to convolve the hazard on rock with the amplification function, then no numerical limitation.

- Good agreement between both methods (AM and SM), specially at low return period. M
- Most of the uncertainty is related to the soil site response model rather than the method-to-method.

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