Site-specific seismic hazard assessment for nuclear and hydropower facilities in France

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Outline

- Introduction
- Why OQ Engine?
- « How has it been used? »
  - PSHA at the national scale
  - Site-specific PSHA at EDF nuclear and hydro power facilities
  - Engineering applications
- Perspectives
Energy operators are responsible for Seismic Hazard Assessment of their facilities (with Safety Authority, who guarantees compliance with the regulation + technical support)

Nuclear regulation in France calls for Deterministic SHA approach, but international standards and guides (WENRA, IAEA) call for application of probabilistic approaches

Dam regulation allows performing either, deterministic or probabilistic approach for SHA

Critical facilities located all over the territory → variety of geological, seismotectonic, attenuation contexts

Need to perform PSHA at both, national and « site » scales

N.B. Ordinary building code, as well as “special risk facilities” based on probabilistic SHA
Why GEM and the OQ Engine?

EDF selected GEM’s Openquake Engine for the implementation of their PSHA calculations, based on:

- Numerous features for SHA
- Open-source code
- Continuous development and active maintenance of the source code
- Code-testing on a daily basis
- Resources for support and toolkits
- GEM’s active participation in long-term R&D (academic & private) projects
National scale hazard maps
OQ Developments and model comparisons in France

- Implementation in OQ Engine of new GMM useful in the French context
- Model Comparison with existing seismic hazard maps for France → implementation of the Drouet et al. (2020, 475 yrs RP) model (Seister in-house code)
  - Complex SSC models built under same assumptions
  - Same multiple GM models
- Conclusion: Agreement between software can only be achieved when a substantial amount of detail about the model and the processes in the underlying software are provided.

European model: ESMH20

Recent European Hazard Map ESHM20 (Danciu et al. 2021)
http://www.efehr.org/earthquake-hazard/

Implemented using OQ Engine → possibility to perform
- Transparent model comparisons over the French territory
- Sensitivity Studies

Overall all this ensures transparency and robustness in Seismic hazard assessment!!

Next release of seismic hazard maps

- Pre-existing seismic hazard maps for France (regulatory map developed in the early 2000 and Drouet et al. 2020 – 475 ys RP implemented using Seister’s in-house PSHA code)

- Motivations for new release:
  - Moving towards GMC back-bone partially non-ergodic model, based on the Kotha et al. (2020-2022) GMM.
  - New source models (zoneless, faults, area sources)
  - Implementation using the OQ Engine
  - Delivery expected 2024-2025
  - Expanded capabilities for Epistemic Uncertainty Propagation recently developed in OQ

**Fig. 20** Hazard map for median PGA at 475 years return period (10% probability of exceedance within 50 years). Blue triangles denote points where comparison with PSHA results from other studies are performed.
Partially non-ergodic GMM

ESHM20 model based on a partially non-ergodic GMM, developed using the pan-European Engineering Strong-Motion (ESM) dataset, applicable for earthquakes of $3 < Mw < 7.4$

Ongoing Bayesian update of the Kotha et al (2020, 2022) partially NE model using French data (EDF-ISTerre collaboration)

Next release of seismic hazard maps for France

Weatherill et al., 2018, 2020a,b, Kotha et al 2020
Optimized implementation of partially non-ergodic GMM in OQ

➢ Partially non-ergodic GMM → take into account regional and/or site, source or path differences in ground motion scaling (classically neglected when the ergodic assumption was used). Significant impact on predictions and on standard deviation.

➢ In OQ : optimized implementation of partially non-ergodic GMM (regional scaling effects associated to the source and the site location)

→ automatic selection of the regional adjustments depending on the location of the source and of the site:
   • Default: full Kotha 20-22 GMM (vs the simplified version already implemented for the ESHM20 computations).
   • User-defined geo-database, providing attenuation regionalization polygons, source location polygons, associated adjustments and standard errors

➢ Ongoing work in the framework of the next release of seismic hazard maps in France.

Chandrasekhar et al 2022
Site-Specific PSHA at critical facilities
Site-specific PSHA at critical facilities

- Developments in OQ Engine: fully non-ergodic GMM implementation and methods, ongoing HAZ45 code implementation comparisons

Prototype of Non-ergodic GMM for France

Traversa et al. (2020), Buscetti et al. (in prep.)
Engineering needs
Needs for the engineers

- Standard (scalar) PSHA provide annual probability of exceedance of each selected IM → hazard curves, UHS (representation of all SA having the same APE, taken individually) →
  - Return Period associated to an UHS taken as a whole is larger than the target RP
  - no one-to-one link of the PSHA results with an earthquake of well defined characteristics

- But, for site response and structural dynamic calculations, waveforms related to a seismic scenarios are needed → Recent developments in OQ Engine:
  - V-PSHA
  - Conditional Spectrum

→ Link with risk evaluations

Joint mean rate density of two IMs
Collaborations and Perspectives

Working group on the use of OQ Engine for PSHA at nuclear and hydro power facilities in France

- Participants: EDF, CEA, GEM: collaborations, uniformisation of practices, feedback on the use of OQ for site-specific applications at nuclear sites (complex logic trees, long return periods...) → 1 annual meeting per year
- Training on the OQ Engine use in 2019 provided by GEM

Perspectives

- Pursuing the implementation of non-ergodic methods and models in OQ Engine
- Site-specific PSHA combining results of different site response assessment approaches → sound epistemic uncertainty propagation
- « Scenario approaches », pursuing the developments on CS and V-PSHA
- ...

GEM Conference - Bergamo - June 13-14, 2023
Thank you !
Energy production in France

- Nuclear electrical power: ~70% of the total production.
- Hydroelectric power: 12% of the total production, 53% of renewable energy production.

Source: EDF (https://www.edf.fr/groupe-edf/espaces-dedies/l-energie-de-a-a-z/tout-surl-energie/produire-de-l-electricite)
Regulatory seismic map for ordinary buildings

Carte du zonage sismique de la France métropolitaine établi en 1991
• Zone 0 : sismicité négligeable, mais non nulle.
• Zone 1a : sismicité très faible.
• Zone Ib : sismicité faible
• Zone II : sismicité moyenne.
• Zone III : sismicité forte (aux Antilles).

Carte du zonage sismique de la France métropolitaine en vigueur depuis le 1er mai 2011
• Zone 1 : aléa très faible.
• Zone 2 : aléa faible.
• Zone 3 : aléa modéré.
• Zone 4 : aléa moyen.
• Zone 5 : aléa fort (aux Antilles).

Source: IRSN (https://www.irsn.fr/savoir-comprendre/surete/zonage-sismique-france)