METIS

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Report from Peer review group meetings

Authors : Vinicius ALVES FERNANDES (EDF)

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Project officer: Katerina PTACKOVA

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Summary

This document summarizes the main technical and organizational aspects of the peer-review of the METIS case-study, which is composed of a hybrid NPP structure-site combination: the Ukrainian Zaporizhzhia NPP located at a site in central Italy, facing the Tyrrhenian Sea. This hybrid case-study allowed the METIS consortium to rely on real data throughout the whole case-study, although it is not a real NPP structure-site combination. Therefore, this case-study is intended to provide basis for comparison of different methodologies developed by METIS, but it does not represent a real PSA for a real NPP. The peer-review was organized around technical meetings between the peer-review group and METIS WPL to review the different METIS reports associated with the case-study and to provide general remarks and feedback concerning the integrated METIS methodology and PSA. The peer-review group was composed of members from EAB, IAB and some participants of the EUG. The METIS project gratefully acknowledges their implication and participation in the peer-review group. This document also summarizes main accomplishments and limitations from the METIS case-study. Main remarks and recommendations from the peer-review are summarized in METIS Deliverable D3.3.

Approval

Date	By
2025-05-14 09:23:18	Vinicius ALVES FERNANDES (EDF)
2025-05-14 17:55:38	Irmela ZENTNER (EDF)

METIS

Seismic Risk Assessment
for Nuclear Safety

Research & Innovation Action

NFRP-2019-2020

Peer-review of METIS case-study: technical and organizational points

Deliverable D3.2

Version N°1

Author:

Vinicius Alves-Fernandes (EDF)

Disclaimer

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Abbreviations and Acronyms

Acronym	Description
AvgSa	Average value of spectral acceleration between two selected periods
CMS	Conditional Mean Spectrum
EAB	External Advisory Board
EPRI	Earthquake Pacific Research Institute
EUG	End-Users Group
IAB	Internal Advisory Board
IM	Intensity Measure
GM	Ground motion
NPP	Nuclear Power Plant
PGA	Peak Ground Acceleration
PSA	Probabilistic Safety Assessment
PSHA	Probabilistic Seismic Hazard Assessment
rotD50	Median of response spectra of the two horizontal components projected onto all nonredundant azimuths
Sa	Spectral acceleration
SSC	Structures, Systems and Components
SSI	Soil Structure Interaction
Vp	Pressure wave velocity
Vs	Shear wave velocity
WP	Work Package
WPL	Work Package Leader
ZNPP	Zaporizhzhia Nuclear Power Plant

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Keywords

METIS case-study, Probabilistic seismic hazard assessment, Fragility curves, Seismic Probabilistic safety assessment

1. Introduction

The objective of the METIS case-study was to set up a test case sufficiently realistic and yet simple enough for partners to test different methodologies developed during the METIS project. Deliverable D3.1 [1] describes the decision process conducting to the choice of a hybrid case-study:

- The chosen site is in central Italy, facing the Tyrrhenian Sea (Figure 1). This choice is motivated by different factors, mainly: (i) higher and better characterization of the region seismicity (i.e., time histories from the region available in Italian databases, adapted GMPEs for the Italian territory), although being one of the lowest seismicity regions in Italy; (ii) the site beneficiates from previously conducted geophysical and geotechnical data, so the site response could also rely on real data.

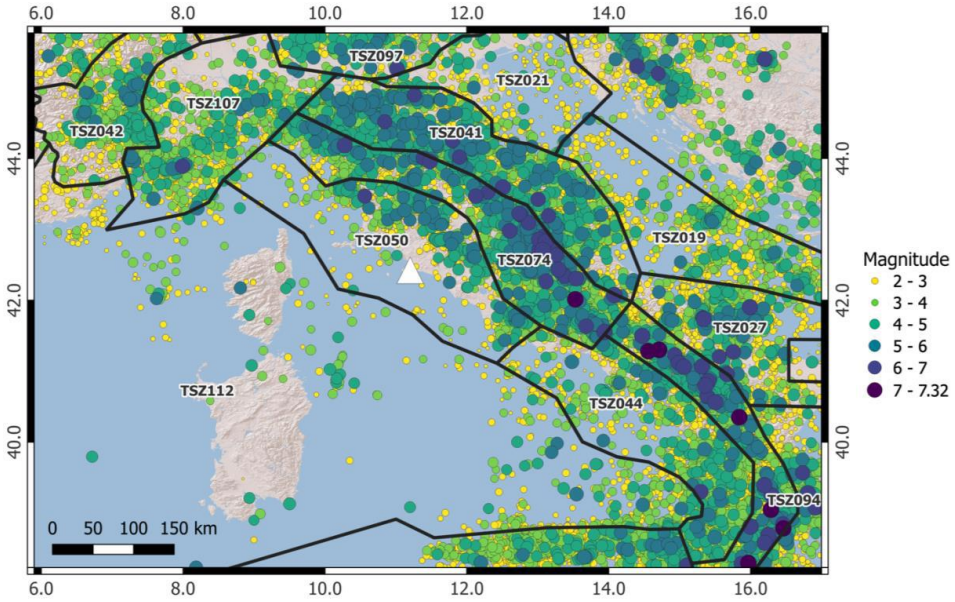

Figure 1: Location of the METIS case-study site in central Italy.

- The chosen structure is Unit 1 from Zaporizhzhia Nuclear Power Plant (Figure 2), for which partner SSTC made available structural plans from selected buildings and previously conducted PSA studies (fault-tree models).

Figure 2: Zaporizhzhia nuclear power plant, Ukraine.

This hybrid case-study allowed to rely on real data for key points of the PSA methodology developed by the METIS project, although it is not a real NPP structure-site combination. **Therefore, this case study is intended to provide the basis for the comparison of different methodologies, but it does not represent a real PSA for a real NPP.**

This report is organized as follows:

- Section 2 presents a synthetic overview of the METIS case-study, methodological contribution from the different WP and produced datasets,
- Section 3 reviews accomplishments and limitations from METIS case-study,
- Section 4 focus on main organizational points of the peer-review.

2. Overview of METIS case-study

The different steps of the PSA for the METIS case-study were implemented by contributions from tasks in WP 4 to 7. A synthetic view of the contribution from the different WP is given in Figure 3. In a summary:

- WP4 performed a probabilistic seismic hazard analysis (PSHA) for standard rock (Vs=1000m/s) near the site. This study provided hazard curves and conditional spectra (CS) for different intensity measures selected by the project. Deliverable D4.6 describes the hypotheses and different steps of the PSHA.
- WP5 was responsible for (i) selecting 3-component accelerograms in accordance to the hazard at rock, for different return periods and different conditioning IMs and (ii) conducting site-specific studies in order to obtain 3-component accelerograms at the site surface for SSI studies. Deliverable D5.4 describes these different steps and main results.
- WP6 was responsible for fragility curves estimation for main structures and components, previously defined at Task 3.1 (D3.1). The following SSC were selected for numerical modelling, both based on data from ZNPP but also EPRI documents: Reactor Building, Diesel Generator Building, Filter Containment Venting System, Transformer 6kV-380V, Control Monitor Cabinet and Service Water Pump. Deliverable D6.8 provides a comprehensive description of the components and fragilities.
- WP7 was responsible for the PSA of METIS case-study, based on available fault-tree modelling of the ZNPP, seismic hazard at rock at the chosen Italian site and specific fragility curves for SSCs modelled by WP6 (all other components kept their originally estimated fragility curve). Deliverable D7.9 thoroughly describes the probabilistic safety model considered and main results.

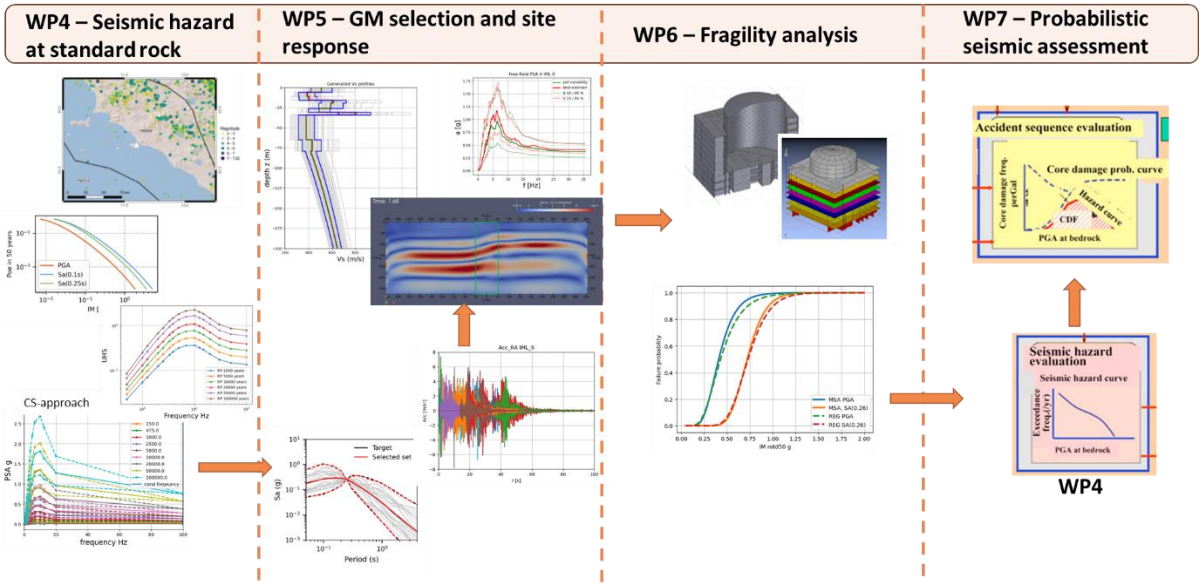

Figure 3: Synthetic view of METIS case-study with contribution from different WPs.

2.1 Produced datasets and data sharing

Datasets developed by partners in the scope of the METIS case-study were accessible during the project through different project internal repositories (SharePoint, Flexx platform). The main datasets produced for the METIS case-study were the following:

- OpenQuake file containing the hazard results (disaggregation results and conditional spectra) at standard rock for the selected Italian site, described in terms of rotD50 of the horizontal directions.

- Different sets of 3-component ground motions that are consistent with the rock hazard, for different IMs (PGA, Sa(0.1s), Sa(0.25s), AvgSa(0.1-0.4s)) and covering various return periods in the range 40 - 100.000 years,

- Different sets of 3-component accelerograms and equivalent soil properties obtained using 1D site response analysis, covering return periods of interest for structural analysis (2.500 – 50.000 years- return period) and fragility curves of SSCs and a reduced set of IMs (PGA, Sa(0.25s)),

- Finite element models for selected structures and components on OpenSees and code_aster numerical platforms,

- Datasets of fragility curves estimated from finite element models for geometrical mean of PGA and returns periods covered by the site response analysis.

Open access datasets produced during the project will be available for further use by the scientific community at OpenMETIS on Zenodo platform (https://zenodo.org/communities/openmetis).

3. Accomplishments and limitations of METIS case-study

The METIS case-study provided basis and datasets for different teams to confront existing and developed methodologies during the METIS project. This section summarizes the main accomplishments and limitations of this case-study exercise. The main accomplishments are the following:

- METIS case-study successfully constructed a hybrid site relying on real data for different steps of seismic PSA (seismic hazard, site response, structural and fragility estimation, safety assessment). The open datasets produced for the METIS case-study and available on OpenMETIS at Zenodo (https://zenodo.org/communities/openmetis) can be a vector for other research teams to test new methodologies and integrate them in the framework of the METIS case-study.
- Most teams built on the produced datasets to test and confront methodologies and tools developed during the project with established practices for different steps of PSA studies.
- Training sessions on PSA methodologies organized by the METIS project benefited from the case study as an example of the applicability and expected results of the developed methodologies. This educational characteristic of the case-study can be enforced after METIS, serving as the basis for further training sessions organized by project partners on seismic PSA.
- The case study allowed state-of-the-art methodologies to diffuse among project partners and served as a vector for sharing partners' knowledge in their specific scientific discipline within the METIS consortium.
- The case study also served as a vector for testing new developments motivated by the project on numerical platforms developed or tested by project partners (OpenQuake Engine, code_aster, Andromeda).

Compared to PSA studies conducted on real projects, the case-study also presents some limits related to inevitable simplifications. The main ones identified are as follows:

- The computed seismic hazard on rock didn't consider possible active faults, as consequence of lack of specific fault characterization data for the region It would be expected for high return periods to consider rare, low-probability events coming from capable faults.
- The METIS methodology relies on better estimation of uncertainties in seismic hazard by explicitly characterizing epistemic uncertainties on site response. However, GMMs used for the hazard model present similar uncertainties for either rock or soil sites, therefore not explicitly rewarding epistemic uncertainty quantification and propagation for site response. This drawback recalls that more research is necessary in constructing specific GMMs for rock sites.
- Although state-of-the-art methodologies for site response and SSI modeling were explored during the project, the datasets produced for the METIS case study relied on state of the practice methodologies. This practical choice was primarily motivated by (i) the enforced link between site response and SSI as part of the METIS strategy to avoid uncertainties related to double counting for soil and (ii) the capabilities of the numerical tools selected by project partners to build and run the numerical models. The datasets related to site response time histories present a large variability for vertical motions, as (i) the time-histories selection procedure consistent with rock hazard for the horizontal component didn't apply any constraint in the vertical motion, and (ii) vertical motion from 1D site response considered soil elastic properties. Within Linear Equivalent approach, methodologies increasing Poisson ratio exist to calculate Vp properties linked to Vs reduction, however presenting limitations for strong motions. This second point recalls that more research is necessary to establish methodologies for site response to vertical ground motions.
- The PSA calculations relied both on fragility curves estimated from specific datasets from the Italian site and already established fragility curves from ZNNP PSA conduct previously to METIS. This consequence of the hybrid characteristic of the case-study enforces that NPP-site

combinations are unique and different seismic PSA results can be obtained for identical structures on different sites.

4. Organizational points for the peer-review

The main objectives of the peer-review process conducted for the METIS case-study were the following:

- To assess the technical quality of the different steps of the final seismic PSA study, based on the technical reports produced by the project and discussions between the peer-review group and project members.
- To assess the feasibility of PSA implemented on METIS for real NPP applications.

The peer-review was expected to focus on assumed hypotheses and interfaces between different steps of PSA calculation performed by the METIS project: definition of hazard at rock, GM selection, site response, SSI, fragility analysis and safety assessment.

The peer-review process was organized as follows: a kick-off meeting was held in November 2024, and then 4 technical meetings were executed during the period January-February 2025. The peer-review group was composed of members from EAB, IAB and some participants of the EUG. The nominative list of participants for each technical meeting is available at the minutes of meetings on Appendix A. The METIS project gratefully acknowledges their implication and participation in the peer-review group.

They were invited to review to following deliverables from WP4-7 linked to the METIS case-study:

- D4.6 "Preparation of the METIS case-study (WP4) and application" [2]
- D5.4 "Hazard consistent surface ground motion time histories for METIS case-study" [3]
- D6.8 "Fragility computations for METIS case-study" [4]
- D7.9 "Application to METIS study-case (WP7)" [5]

Deliverable D4.7 "Summary of WP4 activities and insights" [6] was also provided for the peer-review group.

The peer-review group was invited to fill their comments and remarks in a specific power-point file per WP previously to the meetings. This document was stored in a specific SharePoint created for the peer-review process, which allowed the peer-review group to add their comments and remarks in a collaborative form. These documents were enriched by additional comments and remarks made during the meetings. The peer-review group provided a technical review on the deliverables as well as feedback and general remarks on the case-study. The minutes of the technical meetings are available in Appendix A of this document.

Although the project faced delays in producing some of the expected deliverables for the METIS case-study, the peer-review group had access to either already published document or a finalized draft version of deliverables (D6.8 and D7.9), which allowed the peer-review to be finalized as initially planned.

5. Bibliography

[1] METIS D3.1 – Case study for implementation and application of METIS results. Author: Senfaute, G. (2021).

[2] METIS D4.6 – Preparation of the METIS study case (WP4) and application. Authors: Chartier, T., Rood, A. (2023).

[3] METIS D5.4 – Hazard-consistent surface ground motion time histories for METIS case study. Authors: Garcia de Quevedo, P. et al. (2024).

[4] METIS D6.8 – Fragility computation for METIS case-study. Authors: Zouatine, M., et al. (2025).

[5] METIS D7.9 – Application to the METIS study case (WP7). Authors: Sevbo, O., et al. (2025).

[6] METIS D4.7 – Summary of WP4 activities and insights. Authors: Pagani, M., et al. (2024)