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Abbreviations and Acronyms

Acronym	Description
CCF	Common Cause Failure
CDF	Core Damage Frequency
CMS	Conditional Mean Spectrum
DOE	Department of Energy
DoE	Design of Experiments
EDP	Engineering Demand Parameter
FE	Finite Element
HCLPF	High confidence of low probability of failure
HRA	Human Reliability Analysis
HVAC	Heating, Ventilation and Air-Conditioning
IDA	Incremental dynamic analysis
LHS	Latin Hypercube Sampling
PSA	Probabilistic Safety Analysis
PSHA	Probabilistic Seismic Hazard Analysis
SEL	Seismic Equipment List
SPSA	Seismic PSA
SSC	System Structure and Components
SSI	Soil Structure Interaction
TSO	Technical Support Organization
WP	Work Package
WYSIWYG	What You See Is What You Get

Summary

METIS Users group gathers seismic PSA practitioners who will likely be using outputs of METIS project in the future. A survey has been conducted in the frame of METIS WP2 in order to gather the expectations of the Users group members regarding METIS project. This report summarizes the answers provided by the METIS Users group members to the survey.

The survey has been answered by 17 respondents. The respondents are individuals from among the project members and the 12 entities (including 8 companies) in the Users group, covering a large spectrum of future users of the outputs of METIS project, both in terms of organization type and size, and of area of expertise.

The respondents have presented the workflow, the methodologies and software they use for performing a seismic PSA, with their weak points needing improvements. They also presented their expectations regarding future software tools. To summarize, the members of the User Group want software that is well validated, with a clear documentation, largely spread in professional community in the world, if possible with a strong support for maintenance. The want to be able to use it easily and efficiently, with reasonable calculation time, through an ergonomic/graphical interface, and to be able to interface it easily with existing tools and calculation chains. Source code availability would be appreciated, as well as some additional features for concurrent developments and uncertainty management for example.

The respondents also have strong expectations in terms of training, about generic SPSA methodology as well as about specific steps of SPSA, in order to help training more experienced professionals in seismic PSA, well aware of the current state of the art.

Keywords

Users group, survey, expectations, codes, methodologies, software, PSA

Introduction

This report summarizes the answers provided by the METIS Users group members and project partners to the survey conducted in the frame of WP2 regarding the expectations of the Users group members regarding METIS project.

The content and website for the survey have been prepared by partner UKC with support from IRSN and EDF.

1. Survey respondents

1.1. Survey respondents panorama

The survey has been answered by 17 respondents, coming from the project partners and the 12 members of the Users group.

The sharing of the respondents is the following:

- About 1/3 from industrial organizations, 1/3 from regulators and TSOs, ¼ from consultancy organizations and only 1 respondent from a research organization
- Most of the respondents are based in European continent, including 7 from France (others from Spain, UK, Germany, Bulgaria, Belgium, Slovenia, Switzerland). Only one respondent is not Europe-based (USA)
- About half work in big organization (>1000 employees), while the other half work in small companies (more than 40% in companies with less than 100 employees)
- The role of the respondents in their companies is well balanced between research (30% of the respondents), management (30%) and engineering (40%)
- About half (60%) are well experienced (>10 years) while the other half is made of people with less than 5 years of experience

1.2. Survey respondents area of expertise

All areas of expertise covered by METIS project are almost equally represented among the respondents to the survey: almost all fields (PSA, Hazard, structural engineering, fragility) are in the area of expertise of around 50% of the respondent. Geotechnical engineering is the only technical field of METIS with a lower coverage among the respondents (only 4 respondents = 23%). When asked more precisely about their main topic of interest in METIS, 1/3 of the respondent focus on fragility analysis, ¼ on PSA and 10-15% on the other topics (PSHA, uncertainties, site response and ground motion).

Some respondent are very specialized in a single step of the whole SPSA process (accelerogram selection, fragility curve determination…) while others have activities covering a wider spectrum, sometimes even in non-nuclear activities.

2. Seismic PSA workflow

Respondents have been asked to describe the workflow they use for performing a seismic PSA. Here is a summary of the most interesting answers provided.

<u>PSHA/Seismic hazard + site response workflow for seismic design:</u>

1. PSHA (for bedrock)

2. site-response calculation (free field motion and/or motion at depth)
3. SSI (floor response spectra)
4. Seismic design

Fragility analysis workflow:

inputs : structural model + Seismic design calculations/qualification reports/stress reports + probabilised seismic solicitations (floor response spectra (ideally: probabilistic floor response spectra)

Possibility to re-assess fragility from scratch or based on original stress reports to determine margins.

1. identifying and generating DoE for the uncertain parameters
2. performing the calculus (structure and equipment) to obtain the scatter of the response
3. using the scatter to produce the fragility curve with a statistical analysis

Output : the fragility curves/fragility parameters (median capacity, beta_r, beta_U, HCLPF)

Seismic PSA workflow:

input : seismic hazard curves + uniform hazard spectra (UHS) + fragility curves + HRA + internal events PSA models and equipment database/lists (including room information, seismic classification).

1. seismic equipment list (SEL)
2. walkdown (for existing plants)
3. PSA modelling (extension of L1 PSA model)
4. fragility analysis (SEL SSC)
5. risk quantification
6. documentation/discussion

Output = SEL + extended PSA model + quantification results (core damage frequency and risk contributors; minimum cutsets, importance measures, e.g. Fussel-Vesely) + plant damage states for PSA L2

SMA workflow:

SMA (PSA-based): same as Seismic PSA, but no hazard curve

SMA (success path based): same as Seismic PSA, but no hazard curve and no PSA model

3. Codes, guidance and methodologies

3.1. Codes and methodologies panorama

A lot of respondents follow EPRI guidelines for seismic PSA:

- EPRI 3002000709 "Seismic Probabilistic Risk Assessment Implementation Guide"

- EPRI-3002012994 Seismic Fragility and Seismic Margin Guidance for Seismic Probabilistic Risk Assessments
- EPRI- 3002012980
- EPRI 3002008093 (December 2016) An Approach to Human Reliability Analysis for External Events with a Focus on Seismic"
- EPRI TR-103959
- TR-1019200 (fragility)
- EPRI NP-6041
- EPRI NP-60541-SL, "A Methodology for Assessment of Nuclear Plant Seismic Margin, Revision 1", 1991

The following codes have also been cited by the respondents:

- ASCE 4-16 Seismic Analysis of Safety-Related Nuclear Structures
- ASME PRA-Standard RA-S-2008 Addenda 2009
- Seismic re-evaluations:
  - ENSI AN-8567 (Swiss methodology document for seismic re-evaluation)
  - KTA 2201 (German nuclear standard)
  - RCC-CW, annexes DA (Seismic), DI (HCLPF), DM (design extension)
  - SQUG GIP (Generic Implementation Procedure)
- IAEA SSG-9, SSR-2

3.2. Codes and methodologies weak points and needed improvements

The following issues are the most cited by the respondent as the weak points or the points needing improvement of existing codes and methodologies currently being used for seismic PSA:

- A list of up-to-date references applicable per technical area would be needed. Methods and reference documents are not easily available (not public)
- The uncertainties which are accounted for at each step of the calculation chain are not clearly stated: there is a risk of double counting
- It is hard to introduce and use new (maybe better) methods, as it costs more time and money to convince the regulator that it is at least as good as the old and known methodology
- Fragility analysis :
  - Analysis of failure modes preceded by strongly non-linear behaviour (sliding, buckling, contact): the separation-of-variables method assumes linearity and the applicability of the individual parameters provided in the EPRI guidance (e.g. beta for random phasing) is questionable

   - Data for sliding coefficients (e.g. for non-anchored components) and contact stiffnesses are not given in guidance documents
   - Analysis of functional failure modes is often based on shaking-table testing, i.e. on the respective qualification reports:
     - Epistemic uncertainty is quite significant: the sample size is limited,
     - For cabinet testing it is a challenge to demonstrate the applicability to cabinets with (slightly) different occupation,
     - Capacity beyond the tested level is hard to quantify/justify.
   - There is often confusion about whether peak-to-valley variability (with respect to the target (UHS) in the response spectra used for design) is already covered by the UHS
   - conditional mean spectrum is generally elaborated for horizontal components, on a combined quantity expressing mean or maxima
   - improvements would be needed in order to allow/facilitate a wider use of advanced structural analysis for development of fragility functions similarly to the current non-nuclear state-of-the-art, eg., use of IDA, cloud analysis, etc. to derive EDPs to feed the fragility analysis

- Ground motion should be hazard consistent, site specific and design adequate
- Uncertainty propagation in L1 and L2 PSA
- There is a need of standardization of the methodologies for seismic PSA based on international practice and state of the art
- Lack of training material

4. Software and tools

4.1. Software panorama

Most respondent (70%) use commercial codes, in combination with in-house and/or open-source tools.

The most cited software are (followed by the number of respondents using it in brackets):

- Seismic Hazard
  - Seismic source characterization : In house code + site investigation
  - Ground-motion characterization : HAZ45 (2) or hazardlib(GEM) + in-house
  - Seismic hazard computation: HAZ45 (2), OpenQuake(GEM) (3)
- site response/ground motion : Kerfract, Abaqus, Deepsoil, CMS, Rspmatch
  - Tools for 1-D site response : Strata (2), Pysra, Shake(2)
  - synthetic engineering ground motion computation : Simqke, Postquake or in-house codes
- Building models and fragility analysis :
  - to create the building models : ANSYS APDL (4), SAP2000 (4), LS-DYNA Pre/Post, SASSI (4), CAST3M (2), Sofistik, STAAD, R-fem, R-stab and other In-house software

- to build fragility curves : based on safety factor approach or statistical exploitation of scatter with Python, Excel + Scilab or Mathematica, Mathcad and other In-house software

- PSA : Riskspectrum and HazardLite module (6), KANT, FinPSA

Most of these software and tools run under windows (76%), some under Linux (24%).

4.2. Existing software – generic features[1]

4.2.1. Existing software strong points

The following features are the most cited by the respondent as the strongest points of existing software currently being used for seismic PSA (followed in brackets by the number of respondents citing it):

- widely accepted, used by a large community of users (8)
- easy to use and ergonomic, with a strong graphical interface (WYSIWYG) (6)
- reliable : software benefits from a strong V&V and it works as described in the documentation (6)
- availability of a strong support team for maintenance, bug fixing… (5)
- open source (4)
- flexible : software is general purpose, and very versatile, with the ability to handle large models (3)
- interfaces : software benefits from clear and easy input/output enabling automation and coupling with other codes (2)

The following strong points have also been cited at least once:

- speed of execution
- availability of Monte Carlo simulation
- possibility for several users to work simultaneously on the same project

4.2.2. Existing software weak points and needed improvements

The following features are the most cited by the respondent as the weak points or the points needing improvement of existing software currently being used for seismic PSA (followed in brackets by the number of respondents citing it):

- Lack of software documentation, including test cases (6)
- Lack of validation and associated documentation (5)
- Cost of commercial codes/software (4)
- Lack of community or support (4)

[1] In this section, each respondent indicated the strong points and weak points of the software he uses. Therefore the features cited by the respondents do not apply to all the software listed in §4.1

- Lack of graphic interface (especially for results post processing) and interface for integration in a calculation chain (5)
- The need for a strong expertise in using codes that can be tricky (3)
- No feature for concurrent development such as merge, conflicts solving, version management (3)
- Approximations in calculation (for example Binary Decision Diagram only applied in post-processing) (2)
- Lack of tools for uncertainty assessment and propagation (2)
- Source code unavailability of commercial software (2)

The following weak/to be improved points have also been cited at least once:

- High computation time
- Compiling issues with old software
- github sharing for developments
- computational limits of the software must be well defined and clear
- lack of debugging tools

4.3. Existing software – specialty related features

4.3.1. Seismic hazard modelling

The two answers concerning the main technical weak points of the existing software for seismic hazard modelling that should be improved in METIS software are:

- Lack of realistic modelling of focal depth, source to site distance and fault orientations, in particular at near field
- Need for an accelerogram selection tool

4.3.2. Site response and ground motion

Respondents only compute 1D site response. 2D or 3D site response is not computed by any respondent.

Uncertainties are propagated using logic trees.

Synthetic or natural ground motion is selected using available online databases.

4.3.3. Fragility analysis

In addition to the methodologies listed at § 3.1, the following methods are used specifically for fragility analysis:

- for Uncertainty propagation: LHS method, use of mean (composite) fragility curve for computing the point estimate of the CDF, Monte-Carlo sampling of the fragility basic events according to beta_U for computing the distribution of the CDF

The main technical weak points of the existing software for fragility analysis to be improved in METIS software are:

- Lack of automatic tool to take into account the impact of seismic hazard modification on fragility curves
- Non-linear seismic analysis
- Contact formulation, soil material laws
- SASSI: seismic input between layer may cause strange results (input better inside a layer and not at layer boarders)
- SASSI: calculation of large pile groups
- For certain type of structures, the lack of (geometrically) simpler (masses, springs and rigid links) surrogate nonlinear 3D FE models able to replace classical large 3D models (typically mainly shells and solids) for shorter calculation time.

4.3.4. PSA

The main technical weak points of the existing software or methodologies for PSA modelling to be improved in METIS software are:

- Multi-unit approach including SFP by taking into account
  - shared resources between units,
  - impact on human factor,
  - correlations between site units.
- Aftershock consideration
- Internal hazards induced by earthquake
- Modelling and computation of models with high probabilities (>0.01)
- HRA
- Integration between PSA models and open databases
- Lack of exact solution computation
- Impact of relay chatter
- Lack of solution to deal with "mass items", i.e. equipment types with many representatives (valves, pipes, electrical cabinets and devices, sensors): little guidance on screening/grouping such items is available
- Modeling of distribution systems (piping, cable trays, HVAC ducting)
- Correlations between seismic failures and fragilities

Respondents have ranked by order of importance the following features of PSA software in the following order (mean rank in brackets):

- post processing of minimal cutsets (2,3)
- combination of models (3)
- ability to handle large models (3,3)

- ability to handle large CCF families (3,5)
- computation speed (4)
- solving logical loops (5)

4.4. Expectations for future software

Respondents declared that methods/tools aimed to be developed by METIS would likely be implemented at the project's scale in their organisation in the following fields:

- Uncertainty related methods and tools (72%)
- Fragility evaluation tools (53%)
- Ground motion simulation platform (53%)
- Ground motion selection methods (47%)
- New simplified approaches in seismic margin assessment (41%)
- PSHA testing tools (41%)

New PSA quantification algorithms are less likely to be implemented (only 23% of respondents interested).

Respondents expect from METIS tools a consistent seismic design chain, adapted to be applied to a large number of SSC and integrating the probabilistic structural response in the whole process.

Respondents expect future METIS tools/software to run on desktop computer (82%) and calculation clusters/clouds, rather internal to their organization (47%) than public (35%).

Respondents have ranked by order of importance the following software features in the following order (mean rank in brackets):

- V&V (2,4)
- Performance (2,5)
- Integration in simulation environment (3,1)
- Ergonomics (3,4)
- Source code availability (4,1)
- Easy to upgrade (5)

Only 35% of the respondents would be interested in using future METIS tools in a developmental stage.

To summarize, the members of the User Group want software that is well validated, with a clear documentation, largely spread in professional community in the world, if possible with a strong support for maintenance. The want to be able to use it easily and efficiently, with reasonable calculation time, through an ergonomic/graphical interface, and to be able to interface it easily with existing tools and calculation chains. Source code availability would be appreciated, as well as some additional features for concurrent developments and uncertainty management for example.

5. Skills development and training

The main expectations of the respondents in terms of skill developments are the following ones:

- We need additional experienced professionals in seismic PSA. METIS should help train young engineers/scientists to have a global comprehension of established methods in order to be recognized as expert in the domain and motivate them to find new, more efficient approaches where possible (4)
- METIS project shall gather all innovative developments and translate to industry the best of scientific production at current time (2)
- METIS should provide more flexible and open tools and help professionals develop skills allowing to implement and perform the international guidances and methodologies in an efficient and improved way
- For existing plants, METIS shall improve cost-effectiveness by using existing data / calculation reports, as much as possible
- For the licensing of new plants, it should facilitate a rapid review/approval by safety authorities, by standardization of methods

User Group members have expressed the following demands regarding trainings:

- both generic training about SPSA methodology and more specific trainings
- training on new tools
- training about the current state of the art on the more recent engineering practice
- training about historical evolution of the methodologies (seismic PSA, SMA, fragility) and of the method guidance / codes / standards
- training of intersection between seismologists and structural engineers
- Short online tutorials about key aspects of seismic PSA for newcomers to the subject, as a first introduction to seismic PSA before participating to usual trainings
- on-the-job trainings (short-time delegation of professionals in another organization performing seismic PSA)
- to have additional information about the results of other Seismic PSA from other countries

6. Feedback about the survey

Most of the respondents found the survey interesting. Some complained about redundant questions, about the length of the survey, much longer than announced, and the difficulty to answer properly some open questions without spending too much time on it.

7. Conclusion

The survey has been answered by 17 respondents, coming from the project members and the 12 members (including 8 companies) of the Users group, covering a large spectrum of future users of the outputs of METIS project, both in terms of organization type and size, and of area of expertise.

The respondents have presented the workflow, the methodologies and software they use for performing a seismic PSA, with their weak points needing improvements. They also presented their expectations regarding future software tools. To summarize, the members of the User Group want software that is well validated, with a clear documentation, largely spread in professional community in the world, if possible with a strong support for maintenance. They want to be able to use it easily and efficiently, with reasonable calculation time, through an ergonomic/graphical interface. They want to be able to interface it easily with existing tools and calculation chains. Source code availability would be appreciated, as well as some additional features for concurrent developments (merges, conflict solving, version management etc...) and uncertainty management for example.

The respondents also have strong expectations in terms of training, about generic SPSA methodology as well as about specific steps of SPSA, in order to help training more experienced professionals in seismic PSA, well aware of the current state of the art.