Advanced Mechanistic 3D Spatial Modeling and Analysis Methods to Accurately Represent Nuclear Facility External Event Scenarios

Project Overview

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NEUP Nuclear Energy University Programs
U.S. Department of Energy
INL Idaho National Laboratory

Project Team

- Two OSU departments
  - Civil, Env. and Geod. Engineering, **H. Sezen** (PI)
    - **J. Hur**, Jr. Faculty
    - ***M. Kose****, Visiting Professor for one year (12/2014 to 12/2015)*
    - ***S. Uwizeramana****, MS (graduated 12/2015)*
    - **E. Althoff**, MS candidate
    - **J. Fan**, PhD candidate
  - Mechanical and Aerospace Engineering (Nuclear Program), **T. Aldemir**
    - **Z. Jankovsky**, PhD candidate
    - **B. Cohn**, PhD candidate (will receive MS degree soon)
    - ***A. Guler*** *(Yigitoglu), PhD, ORNL (graduated 12/2015)*
  - Consultant, **R. Denning**
- Structural engineering contractor –RIZZO Associates
  - **F. Alemdar** and **N. Vaidya** (co-PI)
- INL interface – **C. Smith, J. Coleman**

Program Rationale

The current industry methodology and tools (largely developed with EPRI support) have a number of strengths:

- Treatment of both aleatory and epistemic uncertainties.
- Well supported by training and procedures.
- Widely reviewed – Satisfies needs of ASME PRA standard and regulatory guides for PRA.
- Efficient treatment of fragilities.
- Use of common methodology among utilities simplifies regulatory review.

Potential Limitations of Existing Methods (1/2)

Limitations are identified not to be critical of the methods but to recognize areas of vulnerability as technical and regulatory issues arise.

- A stylized treatment of component fragility, which includes considerable expert judgment.
- A multiple factors approach to the combination of uncertainties using log normal distributions that is approximate but probably conservative.
- Limited ability to perform detailed uncertainty analyses because of the computational cost of detailed finite element (FE) analysis.

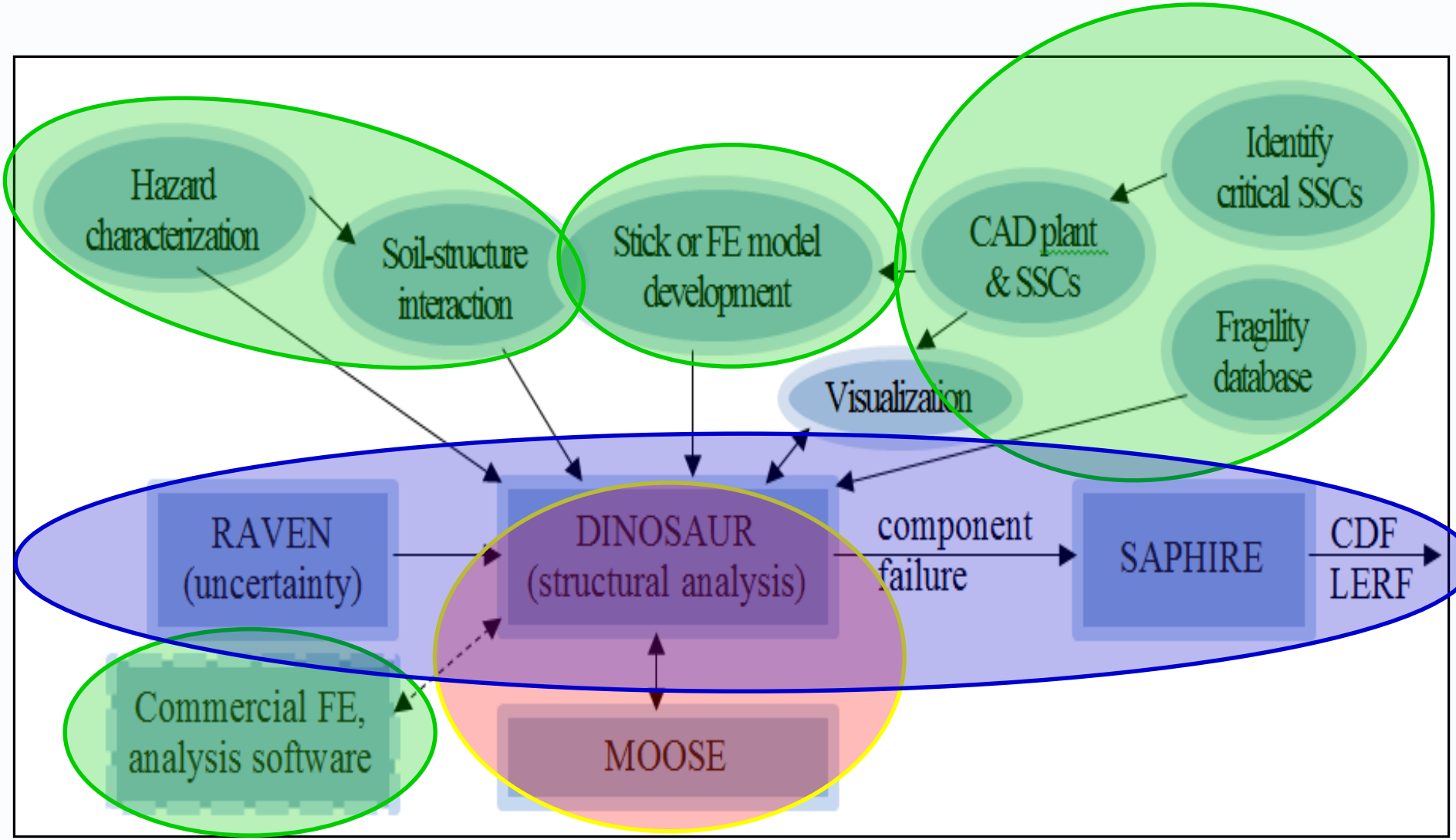
Potential Limitations of Existing Methods (2/2)

- Use of fixed event trees - Aspects of seismic events might be better addressed with dynamic event trees:
  - Human performance in the recovery of safety functions (e.g. implementation of FLEX equipment).
  - Effects of aftershocks.
- Limited treatment of Common Cause Failure (CCF), typically using guidelines rather than through analysis.
- Limited capability to address seismically induced fires and floods.
- Verification of results usually not possible.

Program Objectives

- The goal of the program is to provide *advanced* methods of seismic PRA to be used in the *verification* of industry methods and to support potential industry needs in the resolution of seismic issues.
- Specific areas in which the tools under development in the Light Water Reactor Sustainability Program could be of benefit SPRA include:
  - Efficient performance of uncertainty analyses, including ability to perform high fidelity FE uncertainty analyses.
  - Assessment of CCF probability in a more rigorous manner.
  - Treatment of multi-physics issues on a common platform, including seismically induced flooding.
  - Performance of DET analysis to support assessment of recovery actions.
  - Verifiability of results.

Project Framework



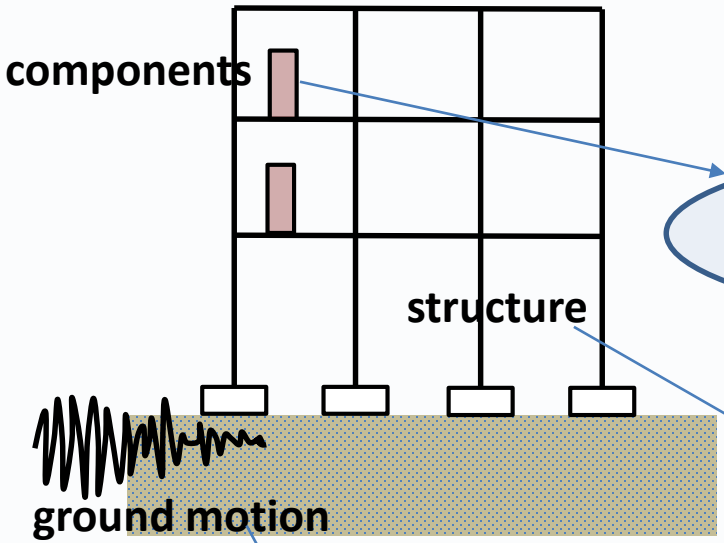
Major Activities

1. Input ground motion – site characterization
2. Identify SSCs for SPRA and fragility (case studies)
3. Finite element (FE) models of selected SSCs
4. FE and simplified analysis of SSCs: DINOSAUR/MOOSE, ANSYS, SAP2000
5. Development fragility parameters for SSCs
6. Failure probabilities (fragilities) of selected SSCs
7. Combined failure of SSCs with internal events

Duration: February 2014 to January 2017 (September 2017)

Seismic PRA Process/Framework

4) Internal events PRA, dynamic event trees



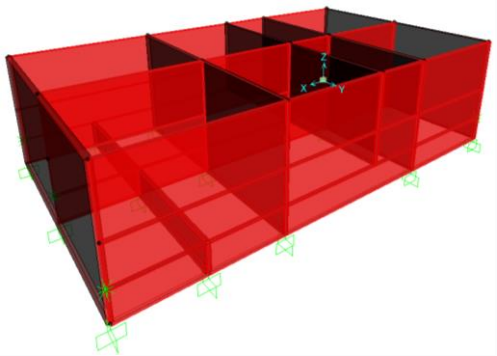
3) Fragility analysis:
- Accelerations and displacements
- Failure probabilities

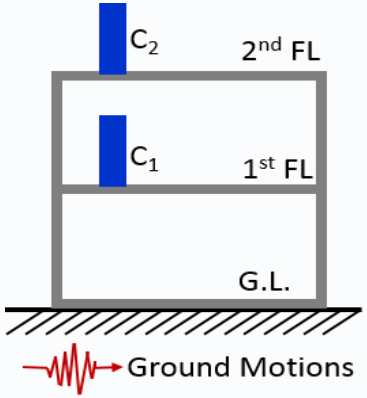
2) Structural models & analysis
- calculate accelerations
- displacements

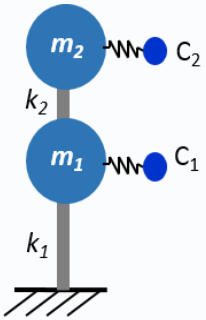
1) Hazard analysis
- maximum acceleration
- risk level

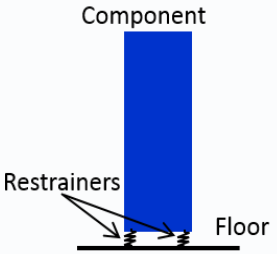
Three Case Studies

Case Study 1:

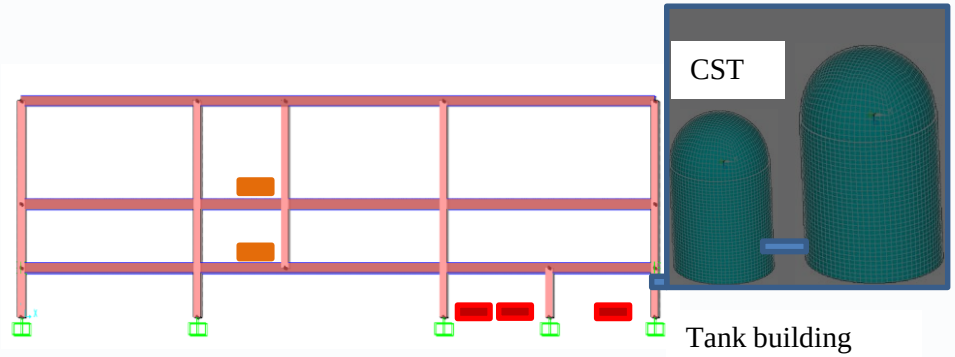




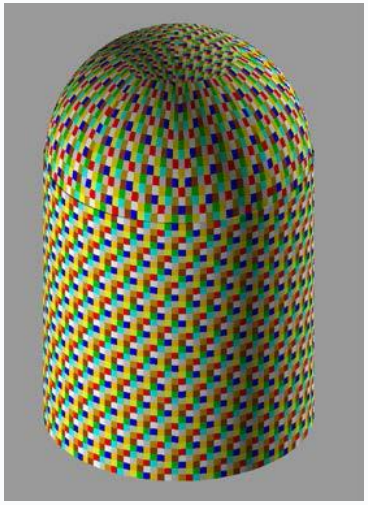


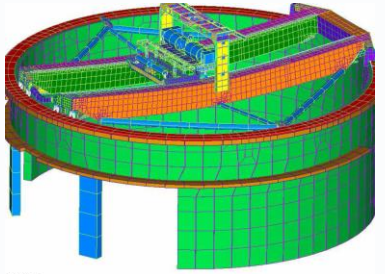


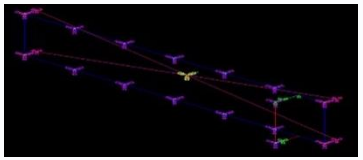
Case Study 2:



Case Study 3:







Publications (1/2)

1. J. Hur, E. Althoff , H. Sezen, R. Denning, T. Aldemir, “Seismic Assessment and Performance of Nonstructural Components Affected by Structural Modeling”, *Nucl. Eng. Technol.*, **49**, 387-394 (January 2017)
2. H. Sezen, J. Hur, M. M. Kose, R. S. Denning, T. Aldemir, “Mechanistic and Probabilistic Seismic Assessment of Structures and Components In Nuclear Power Plants”, *SMiRT-23*, Paper ID 651**,** International Association for Structural Mechanics in Reactor Technology, Berlin, Germany (August 2015**)**
3. J. Hur, A. Guler, H. Sezen, T. Aldemir, R. Denning, “Assessment of Conservatism in the Separation of Variables Approach to Seismic Probabilistic Risk Assessment”, *ICAPP 2016*, 1152-1160, American Nuclear Society, LaGrange Park, IL (April 2016)
4. A. Guler, J. Hur, Z. Jankovsky, H. Sezen, T. Aldemir, R. Denning, “A Dynamic Treatment of Common Cause Failure in Seismic Events*”, ICAPP 2016*, 1161-1169, American Nuclear Society, LaGrange Park, IL (April 2016)
5. S. Uwizerimana, M. M. Kose, J. Hur, H. Sezen, R. Denning, T. Aldemir, “Computational Simulation of Dynamic Response and Failure Of Structures In Seismic Events”, *ICAPP 2016*, 1170-1177, American Nuclear Society, LaGrange Park, IL (April 2016)
6. J Hur, J. Fan, E. Althoff, H. Sezen, R Denning, T. Aldemir, “Development of Structural Models Of a Condensate Storage Tank in Nuclear Power Plants”, *Proc. PSAM 13*, Paper A-187, International Association for Probabilistic Safety Assessment and Management, California (October 2016)
7. Z. Jankovsky, R. Denning, T. Aldemir, H. Sezen, J. Hur, “Application of Dynamic Probabilistic Risk Assessment to A Seismically-Induced Internal Flood Event”, *Proc. PSAM 13*, Paper A-250, International Association for Probabilistic Safety Assessment and Management, California (October 2016)
8. J Hur, E. Althoff, H. Sezen, R Denning, T. Aldemir, “Seismic Assessment and Performance of Nonstructural Components Affected by Structural Modeling”, *Proc. PSAM 13*, Paper A-253, International Association for Probabilistic Safety Assessment and Management, California (October 2016)

Publications (2/2)

10. B. Cohn, R. Denning, T. Aldemir, J. Hur, H. Sezen, "Implementation of Surrogate Models within RAVEN to Support SPRA Uncertainty Quantification", *Safety and Reliability – Theory and Applications*, M. Cepin & R. Briš (Eds), 2865-2871, Taylor & Francis Group, London (June 2017)
11. H. Sezen , T. Aldemir, R. S. Denning, J. Hur, F. Alemdar, N. Vaidya, C. Smith C. "Uncertainty Quantification in Seismic Probabilistic Risk Assessment Using Detailed and Surrogate Models", *Trans. SMIRT-24*c, CD_ROM, International Association for Structural Mechanics in Reactor Technology (https://www.iasmirt.org/) (August 2017)
12. E. Althoff., J. Hur, H. Sezen, R. S. Denning, T. Aldemir, "Evaluation of Seismic Reduced Order Models for Auxiliary Buildings", *Trans. SMIRT-24*c, CD_ROM, International Association for Structural Mechanics in Reactor Technology (https://www.iasmirt.org/) (August 2017)
13. J. Fan, H. Sezen, J. Hur, R.S. Denning,, T. Aldemir, "Structural Modeling and Seismic Analysis of Condensate Storage Tanks", *Trans. SMIRT-24*c, CD_ROM, International Association for Structural Mechanics in Reactor Technology (https://www.iasmirt.org/) (August 2017)
14. B. Cohn, R. Denning, T. Aldemir, J. Hur, H. Sezen "Surrogate Model Selection in RAVEN for Seismic Dynamic PRA/PSA", *Proc. PSA 2017*, 132-139, American Nuclear Society, LaGrange Park, IL (September 2017)
15. J. Hur, E. Althoff, H. Sezen, T. Aldemir, R. Denning, "Seismic Evaluation of Auxiliary Buildings And Effects of 3D Locational Dynamic Response in SPRA, *Proc. PSA 2017*, 211-218, American Nuclear Society, LaGrange Park, IL (September 2017)