THE OHIO STATE UNIVERSITY

Surrogate Model Selection in RAVEN for Seismic Dynamic PRA/PSA

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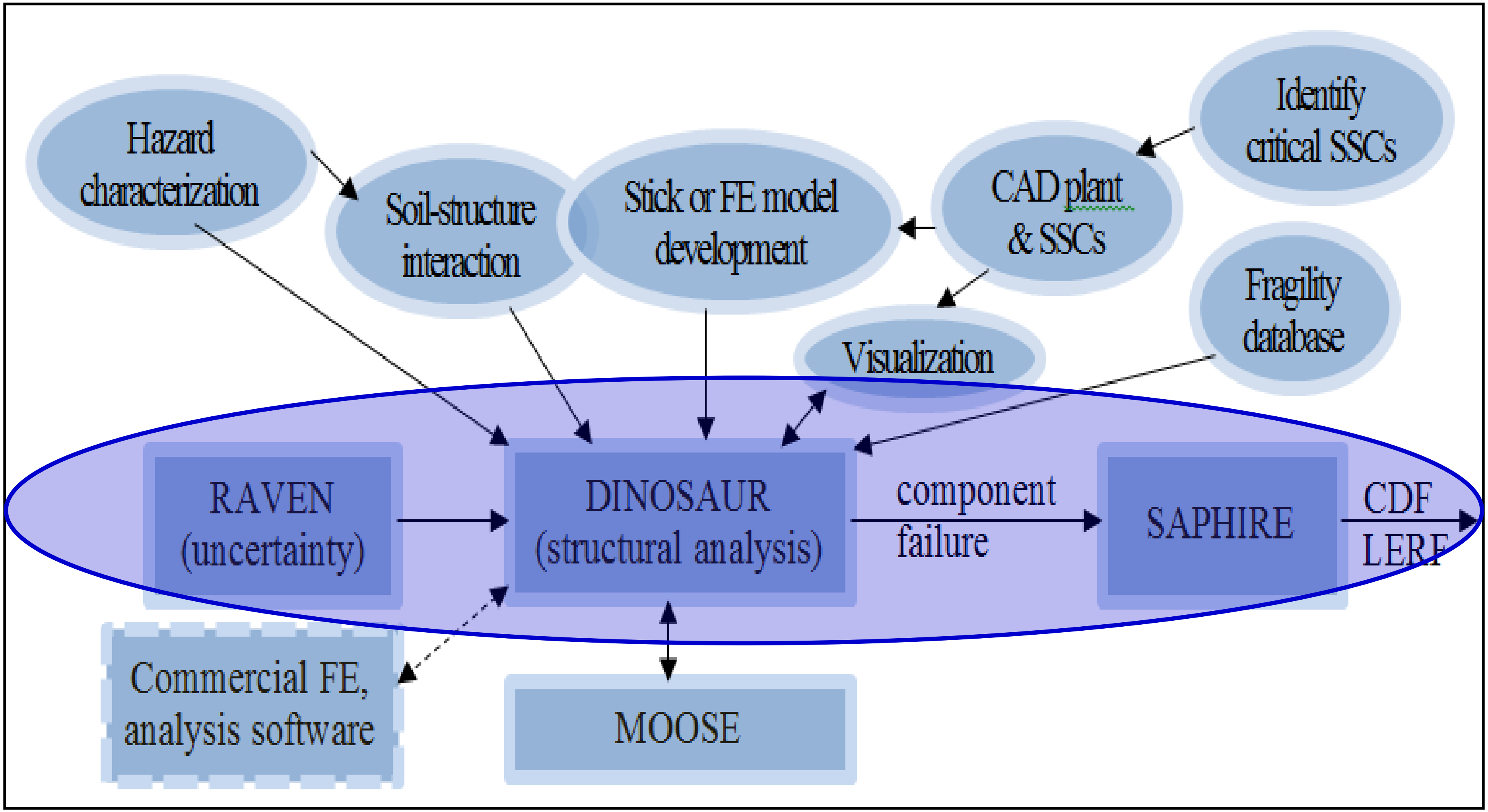
Background 1/2

- The Ohio State University is working to integrate external events analysis with probabilistic risk/safety assessment (PRA) as part of the US DOE Light Water Reactor Sustainability Program
  - The project includes development of advanced tools for uncertainty quantification
- The case study under investigation seeks to:
  - Use surrogate models to reduce the computational burden of uncertainty quantification in seismic PRA
  - Perform sensitivity analyses to determine the limits of applicability of surrogate models
  - Package the efforts within a common computational platform

DINOSAUR Module Structure

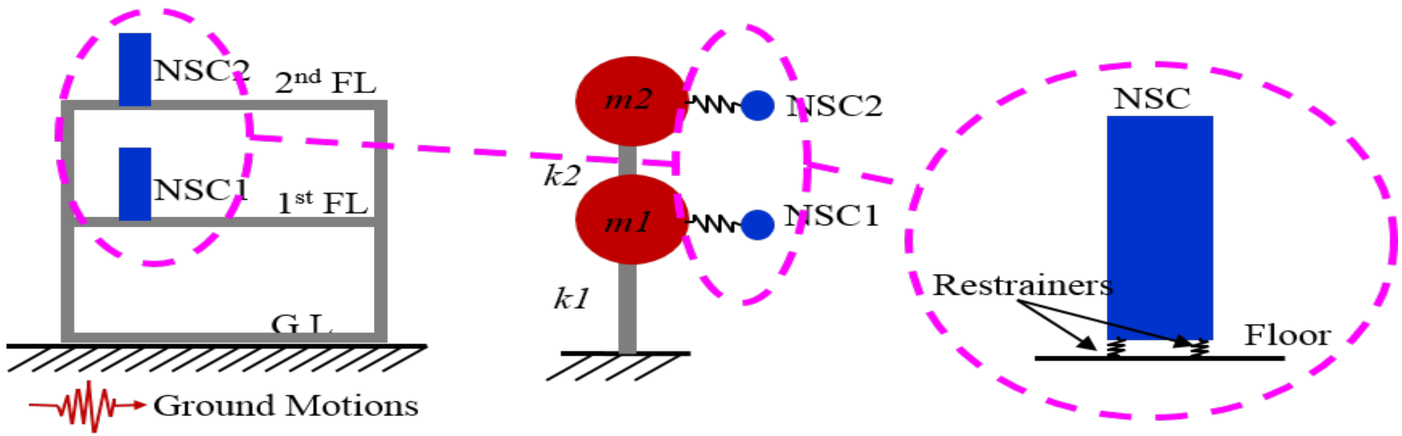


Motivation and Objective

- Surrogate models have been found to reduce the computer resources necessary for uncertainty quantification.
- The accuracy of surrogate models can vary wildly based on the surrogate model chosen and the scenario.
- The objective of this study is to demonstrate a method to select appropriate surrogate models for a scenario without detailed analysis of the surrogate's construction.
- The study is performed using a stick model to demonstrate the approach.

Previous Work

- Earlier work in this project generated finite element and stick models of auxiliary building
- The seismic response of the stick model was tuned to match the finite element structure in a previous case study (Case Study 1)



Development of auxiliary building models

Previous Case Study (1/2)

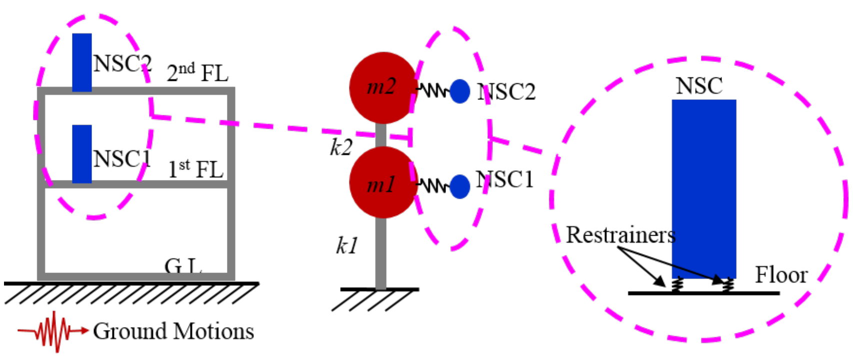
- The objective of Case Study 1 was to perform uncertainty quantification for a typical SPRA configuration.
- The stick model was constructed to approximate the response of an auxiliary building and non-structural components (NSCs) at a nuclear power plant (NPP) at different locations in the auxiliary building.
  - A stick model consists of each floor’s mass lumped together in single points, while being joined together by massless sticks with a stiffness equal to that floor’s structural stiffness

Previous Case Study (2/2)

- Uncertain parameters considered were mass, stiffness and failure acceleration of NSCs.
  - Three subcases involved using a single draw for both floors, a draw per floor from identical distributions or draws from non-identical distributions
- Failure probabilities (including the joint failure probability) were determined for two essentially identical NSCs at two floors of the building.
- A followup analysis determined that training surrogate models could reduce the calculation time.
- Improperly selected surrogate models have a large error.

Scenario Description (1/2)

- Scenario under consideration for this study uses same model as Case Study 1
- Both floors have mass and stiffness drawn from same normal distributions
- Several surrogate models (SGs) are trained on few runs. The errors are then compared to the same SGs trained on a large number of runs.



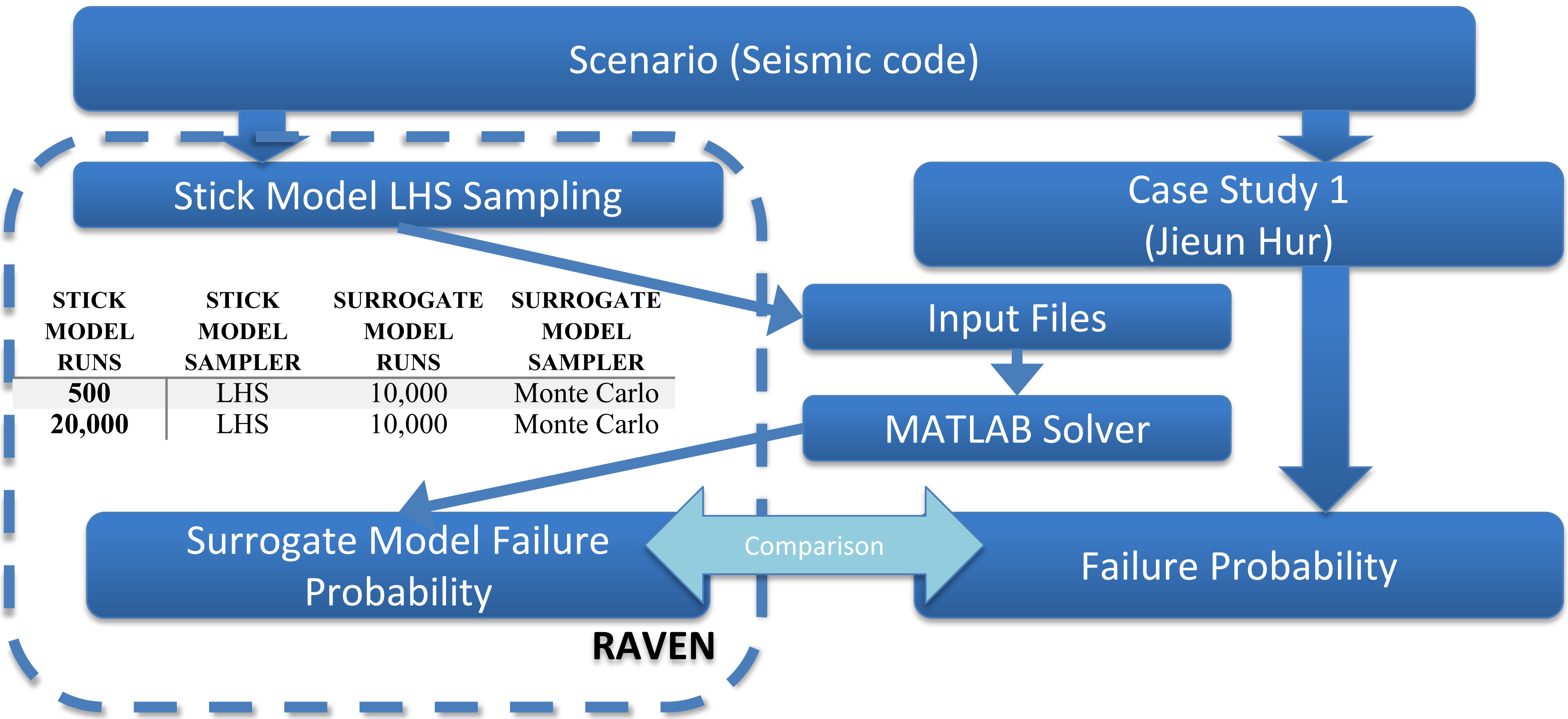
Seismic stick model description

	DISTRIBUTION	MEAN	ST. DEV.
Each floor mass m_1 and m_2 (ton)	Normal	25	2.5
Each floor stiffness k_1 and k_2 (kN/m)	Normal	150,000	15,000
Failure Acceleration (g)	Log-normal	1.01	0.69

Uncertain parameters for analysis

Scenario Description (2/2)

- SGs are then sampled using previous uncertainty distributions to determine failure probabilities



STICK MODEL RUNS	STICK MODEL SAMPLER	SURROGATE MODEL RUNS	SURROGATE MODEL SAMPLER
500	LHS	10,000	Monte Carlo
20,000	LHS	10,000	Monte Carlo

Mathematical Basis

- SGs are trained using:

$$\Theta\left(\overline{\theta}_s\right) \approx \overline{H}\left(\overline{\theta}_i\right)$$

- Two types of SGs: Classifiers and Regressors
  - Regressors: Predict the precise figure of merit
  - Classifiers: Convert the figure of merit to success or failures for prediction

$$C_{NSC} = \begin{cases} 0 \; if \;\; a_{NSC} < f_{NSC} \\ 1 \; if \;\; a_{NSC} \geq f_{NSC} \end{cases}$$

Surrogate Models

- Eight total SGs were trained

SURROGATE MODEL	SURROGATE TYPE
NEAREST NEIGHBOR	Regressor Model
K=5 NEIGHBORS	Regressor Model
INVERSE DISTANCE WEIGHTING	Regressor Model
NEAREST NEIGHBOR	Classifier Model
K=5 NEIGHBORS	Classifier Model
INVERSE DISTANCE WEIGHTING	Classifier Model
LINEAR SUPPORT VECTOR CLASSIFIER	Classifier Model
C-SUPPORT VECTOR CLASSIFIER	Classifier Model

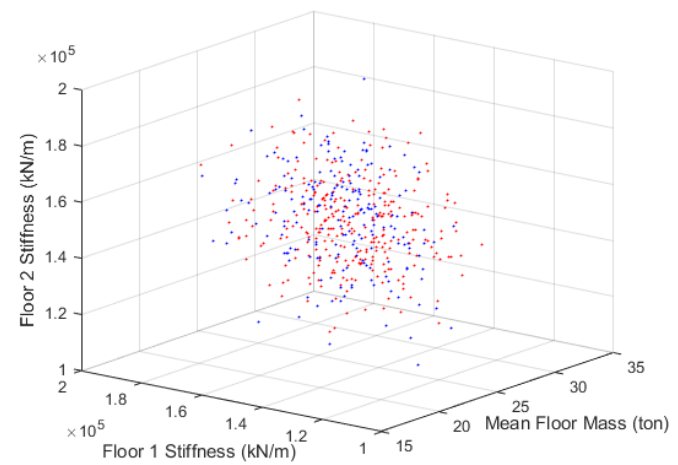
- Nearest Neighbor models poll the nearest K points.
- Inverse Distance Weighting models determine a weighted average.
- Support Vector Classifiers divide the input space into regions of success and failure.

Stick Model Results

- Stick model analysis shows success or failure cannot divide cleanly into regions of success and failure
- Seismic response is highly driven by structure resonances
- A high-fidelity run was also performed, with similar results

B_{P1} (NSC_1 | GM_S)	B_{P2} (NSC_2 | GM_S)	B_{PJ} ($NSC_1 \cap NSC_2$ | GM_S)
0.600	0.702	0.600

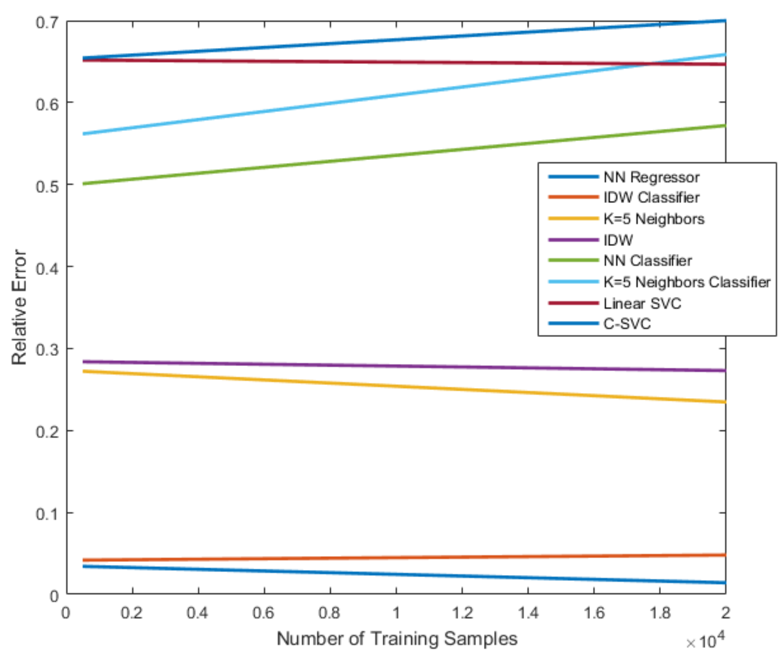
low fidelity model failure probabilities for NSC_1 and NSC_2.



Input values of the low fidelity seismic stick model and NSC response.

SG Results

- At both low- and high-fidelity, SGs had similar relative errors.
- Error size did not depend on model type.
- SGs which divide the input space into regions of success and failure had the largest errors.



Conclusions and Further Work

- Number of runs necessary for uncertainty quantification in SPRA can be large since seismic models with high fidelity have long run times.
- Reduced order SGs can greatly decrease the computing resources needed.
- Large errors may result from SGs if an inappropriate model for the problem under consideration is used.
- The appropriateness of SGs can be determined based on their errors at low fidelity without needing to understand the mathematical basis.

Thank you!

Questions?

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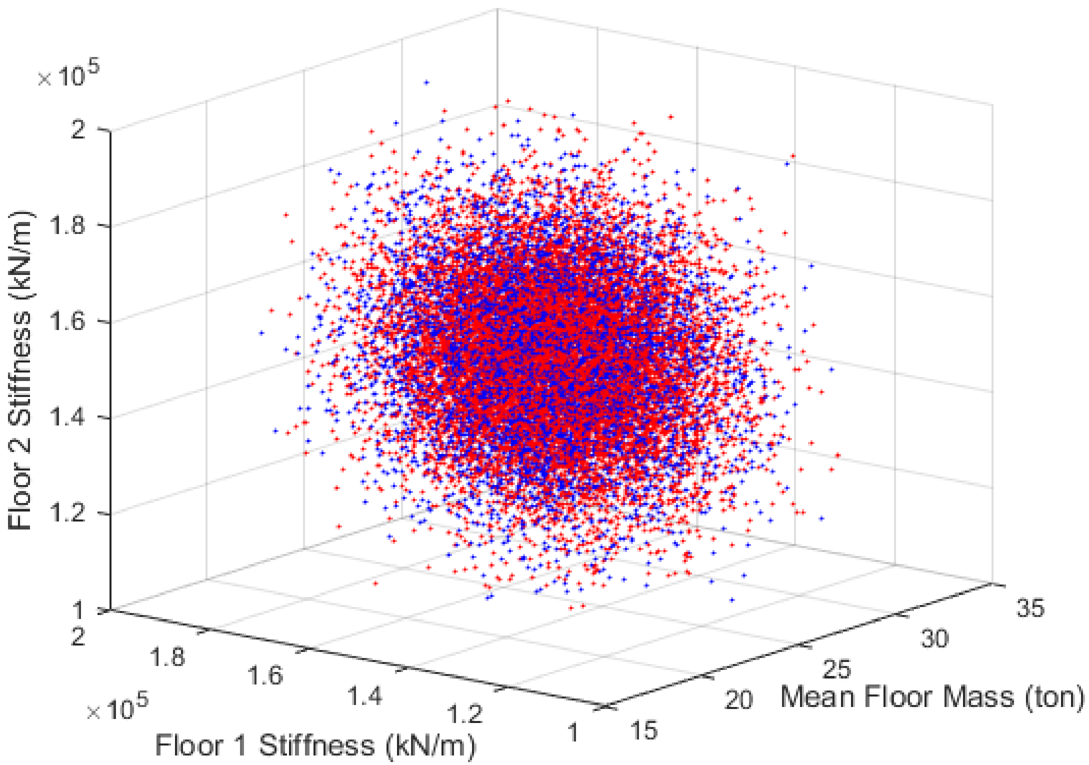
NEUP Nuclear Energy University Program

U.S. Department of Energy

High Fidelity Stick Model Results



Input values of the high fidelity seismic stick model and NSC response.