THE OHIO STATE UNIVERSITY

Convergence of Varied Surrogate Models for Seismic Dynamic PRA/PSA

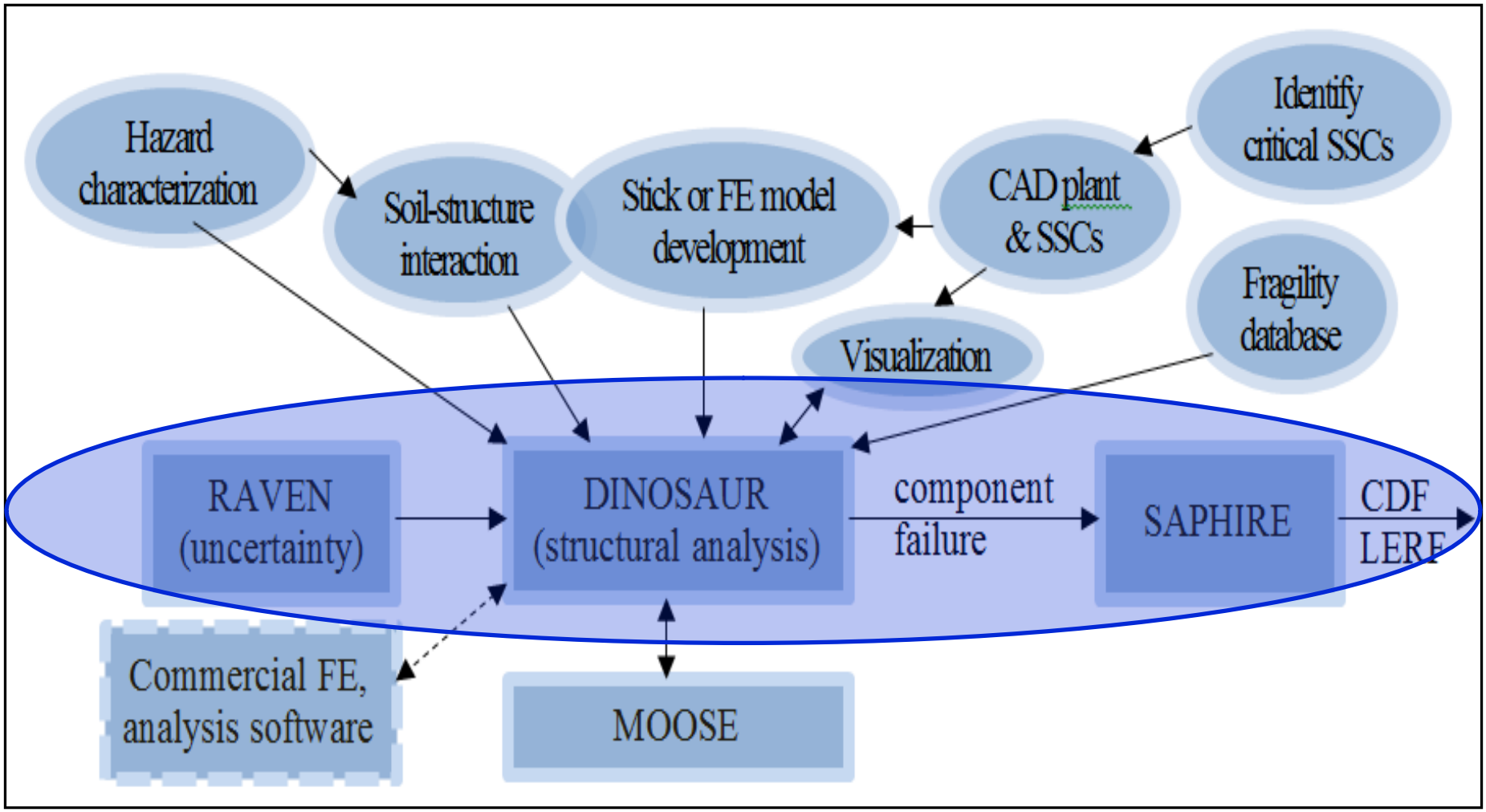
Brian Cohn, Jieun Hur, Richard Denning,
Tunc Aldemir, Halil Sezen

Background 1/2

- The Ohio State University recently completed a project to integrate external events analysis with probabilistic risk/safety assessment (PRA) as part of the US DOE Light Water Reactor Sustainability Program
  - The project included development of advanced tools for uncertainty quantification
- The case study under investigation sought 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

Background 2/2

DINOSAUR Module Structure

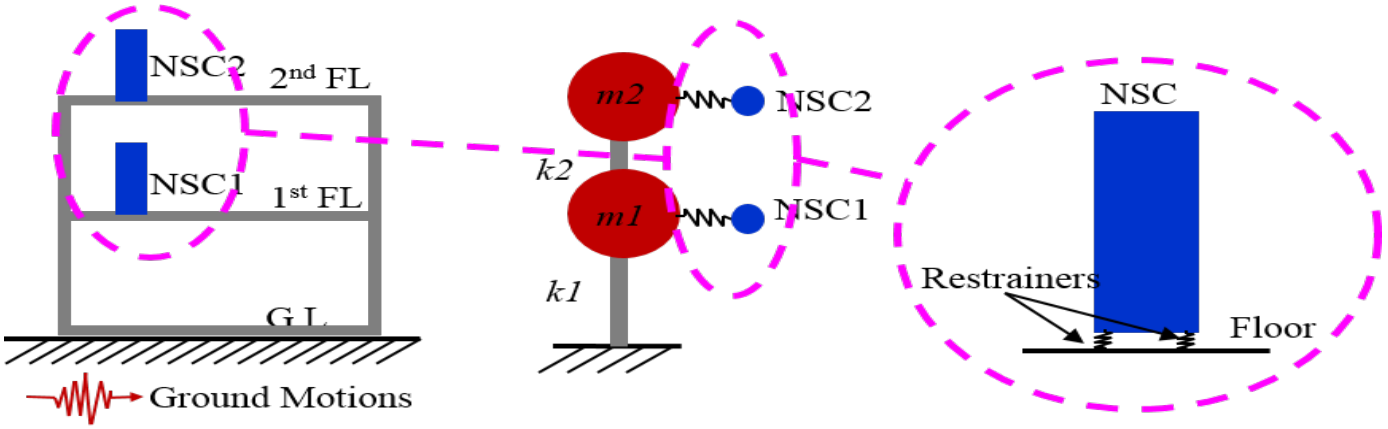


Motivation

- Surrogate models (SGs) can reduce the computer resources necessary for uncertainty quantification.
- The accuracy of surrogate models varies wildly based on the surrogate model and scenario.
- The objective of this study is to demonstrate a process of selecting appropriate surrogate models for a scenario without detailed analysis.
- The study is performed using a stick model to demonstrate the approach.

Previous Work

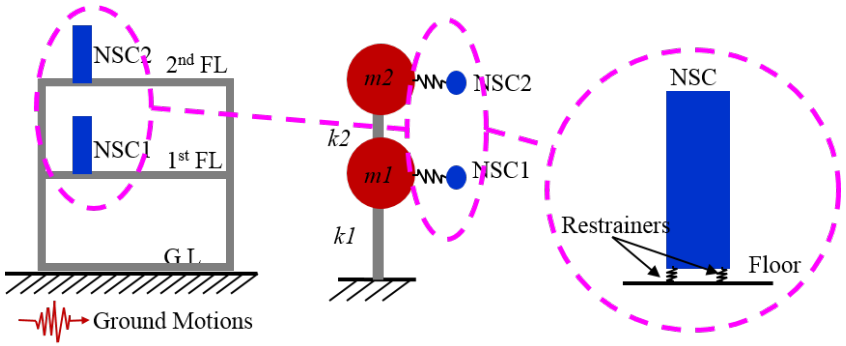
- Earlier work in this project generated finite element and stick models of auxiliary building
- Previous work demonstrated the possibility of using few runs to determine accurate models



Development of auxiliary building models

Scenario Description

- Both floors have mass and stiffness drawn from same normal distributions
- Process is divided into the Analyst Set and Full Set
  - Full Set represents data for conformation of research
  - Analyst Set consists of a limited amount of information
- Goal is to represent real state of knowledge



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

Mathematical Basis

- SGs are trained using:

$$\sigma(\zeta)$$

- 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

Surrogate Models

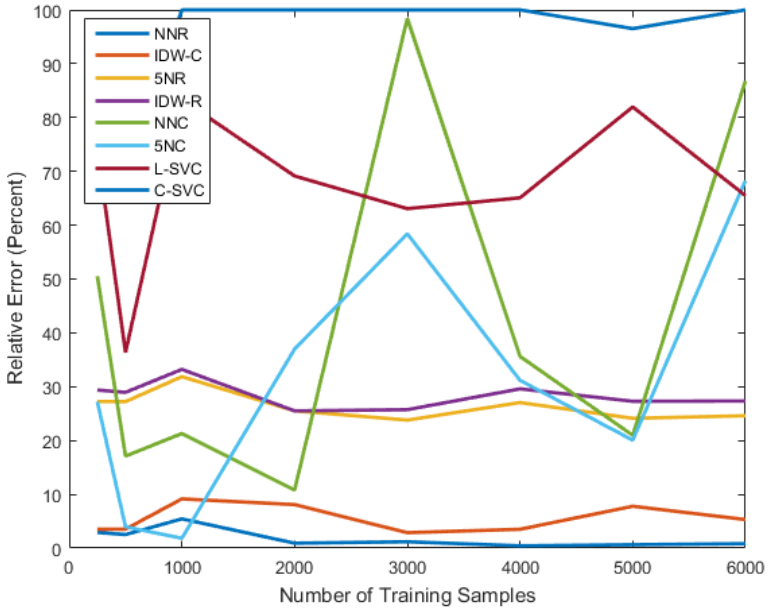
- Eight SGs

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.

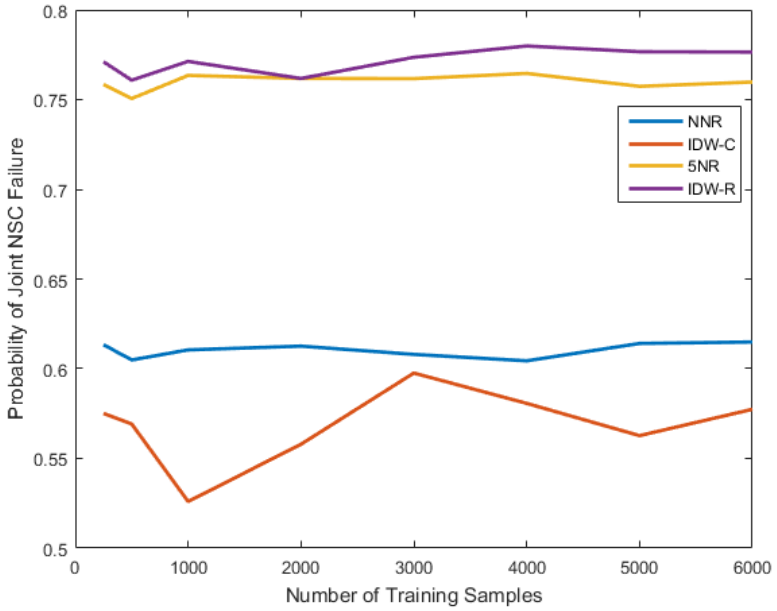
Analyst Set Results

- Increasing number of training points
- Error is relative to the most thorough training data



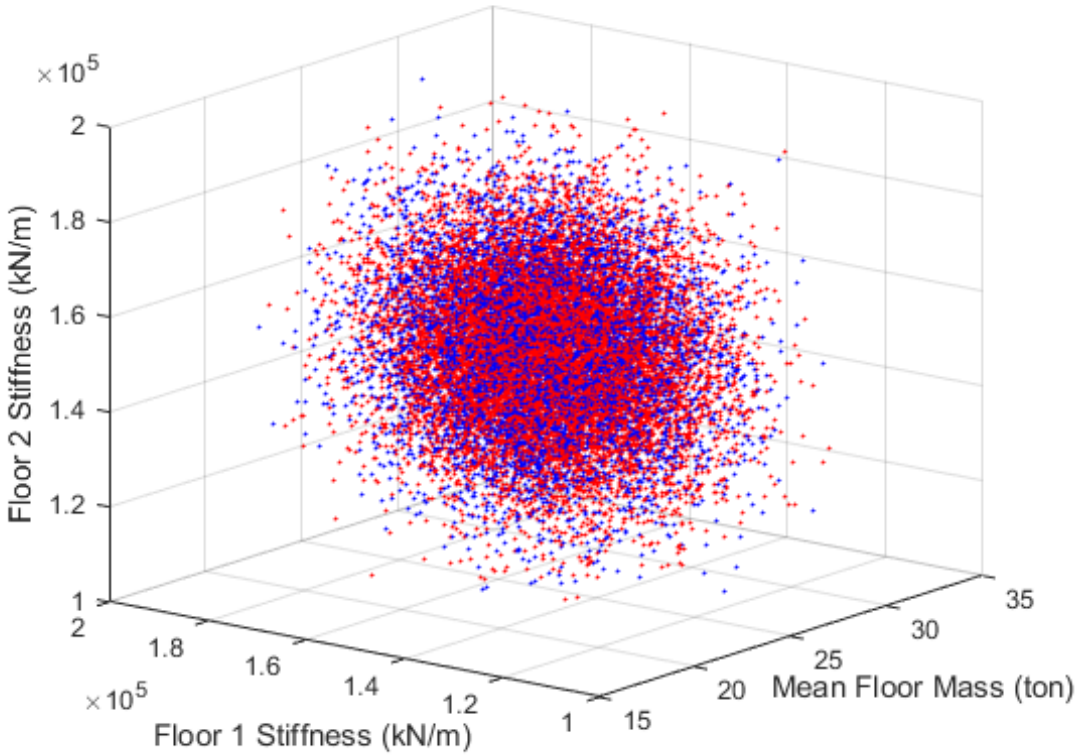
Analyst Set Results

- Small relative error is necessary
- To determine convergence, it is necessary to examine NSC failure probability directly



Full Set Data

- Full Set data consists of 20,000 data points



Full Set Data Comparison

- Full Set probabilities of NSC failure

F_{P1} (NSC_1 | GM_S)	F_{P2} (NSC_2 | GM_S)	F_{PJ} ($NSC_1 \cap NSC_2$ | GM_S)
0.6109	0.7094	0.6109

- Good agreement with Analyst Set results

Compared to	IDW-R	NNR	5NR	IDW-C	NNC	5NC	L-SVC	C-SVC
F_{PJ}	27.91%	0.08%	24.00%	4.57%	12.56%	16.65%	62.45%	88.71%
ROM trained using 20,000 run FS data	0.63%	0.57%	0.30%	0.96%	88.29%	72.86%	8.28%	100%

Conclusions

- SGs require careful selection to avoid model bias

- SGs which are accurate with few training points remain accurate as training points increase

- The analyst set of information provides justification of the SG accuracy, as confirmed by the full set comparison

Thank you!

Questions?

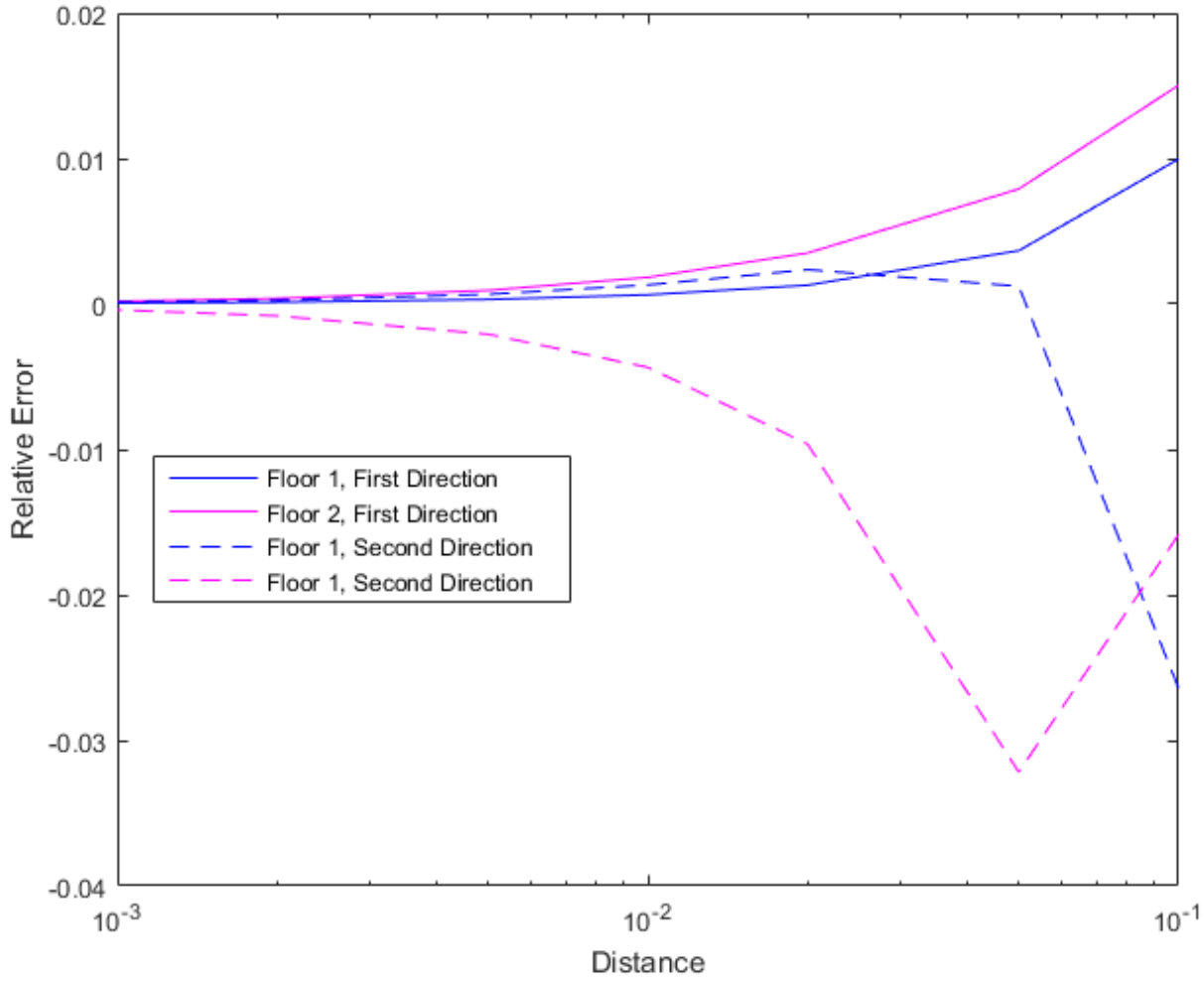
Acknowledgement

This research is being performed using funding received from the DOE Office of Nuclear Energy's Nuclear Energy University Programs. The support provided for the project NEUP 13-5132 is greatly acknowledged.

NEUP Nuclear Energy University Program

U.S. Department of Energy

Resonance Resolution



THE OHIO STATE UNIVERSITY

Analyst Set Data

TRAINING RUNS \ SURROGATE MODEL		IDW-R	NNR	5NR	IDW-C	NNC	5NC	L-SVC	C-SVC
250	0.5960	0.7711	0.6134	0.7584	0.5751	0.2948	0.7583	0.1543	1
		29.38%	2.919%	27.25%	3.507%	50.53%	27.23%	74.11%	67.79%
500	0.5900	0.7608	0.6049	0.7506	0.5692	0.6909	0.6134	0.3754	1
		28.95%	2.525%	27.22%	3.525%	17.10%	3.97%	36.37%	69.49%
1000	0.5790	0.7713	0.6105	0.7635	0.526	0.4557	0.5896	0.0963	0
		33.21%	5.440%	31.87%	9.154%	21.30%	1.83%	83.37%	100%
2000	0.6070	0.7618	0.6126	0.7618	0.5579	0.5414	0.3825	0.1873	0
		25.50%	0.922%	25.50%	8.09%	10.80%	36.99%	69.14%	100%
3000	0.6153	0.7736	0.608	0.7617	0.5976	0.0098	0.2559	0.2272	0
		25.72%	1.186%	23.79%	2.877%	98.41%	58.41%	63.07%	100%
4000	0.6018	0.7799	0.6044	0.7646	0.5807	0.8162	0.7894	0.2101	0
		29.59%	0.432%	27.05%	3.506%	35.63%	31.17%	65.09%	100%
5000	0.6102	0.7767	0.6141	0.7574	0.5627	0.4823	0.4878	0.1100	0.0212
		27.29%	0.639%	24.12%	7.78%	20.96%	20.05%	81.97%	96.53%
6000	0.6098	0.7765	0.6149	0.7598	0.5774	0.0805	0.1934	0.2104	0
		27.33%	0.836%	24.60%	5.31%	86.80%	68.28%	65.49%	100%