SimCenter Tools for Next Generation Regional Natural Hazard Engineering

Sanjay Govindjee
UC Berkeley

NSF award: CMMI 1612843
SimCenter Mandate

To produce Extensible Software that Researchers in Natural Hazards Engineering can use in their research

- Develop an **open-source computational framework** for **building workflow applications** to support decision-making to enhance community resilience to natural hazards **in the face of uncertainty**;
- **Design a framework** that is sufficiently **flexible, extensible, and scalable** so that any component of it can be enhanced to improve the analysis and thereby better meet the needs of the community;
- **Seed the framework** with enough **data** and **interfaces to existing simulation tools** so that it can be employed in the near-term;
- **Release tools/applications built using this framework** that meets the computational needs of researchers in natural hazards engineering;
- **Provide an ecosystem** that fosters collaboration between scientists, engineers, urban planners, public officials, and others who seek to improve community resilience to natural hazards.
NHERI SimCenter

“Transforming the nation’s ability to understand and mitigate adverse effects of natural hazards on the built environment through computational simulation”

- Cloud-enabled research tools, scalable to run on HPC
- Emphasis on uncertainty quantification
- Educational resources

SimCenter’s Application Framework

- rWhale
- BRAILS
- Pelicun
quoFEM (v2.0)

 quoFEM (Quantified Uncertainty with Optimization for the Finite Element Method) is a tool that combines finite element applications with uncertainty quantification (UQ) applications behind a simple user interface (UI).

**Capabilities**

1. **Forward problem:** Monte Carlo (MC), Space filling (LHS) Variance Reduction, Importance Sampling Variance reduction, MC using surrogate models - Gaussian Processes (GP) or Polynomial Chaos Expansion (PCE), density approximation using samples
2. **Inverse Problem:** Parameter Estimation (MLE/MAP) and simulation of samples from posterior using Metropolis-Hastings (MH) variants (MH with delayed-rejection, adaptive MH)
3. **Reliability Analysis:** FORM and SORM adopting local or global search schemes for most probable point (MPP) and further leveraging surrogate models for efficient MPP identification
4. **Global Sensitivity Analysis:** MC or PCE based estimation

**Year 4 updates will incorporate:**

1. Online parameter estimation
2. Integration of hierarchical models and coupled with Multi-fidelity Monte Carlo simulation
3. Design under uncertainty problems (RBDO)
4. Extension of interface to allow easy integration of algorithms beyond DAKOTA capabilities (⇒)
5. High efficiency techniques for global sensitivity analysis
6. Design of Experiments for global surrogate modeling
7. Rare event MC-based reliability analysis
Wind Engineering with Uncertainty Quantification (WE-UQ) is an application to determine the response of a structure to wind loading. The tool focuses on providing different wind loading options (including options to integrate with CFD simulations), structural model generators, and UQ methods. It allows users to run computations on HPC resources.

**Capabilities**

**Loading options:** (1) stochastic wind load generation; (2) database-enabled options utilizing Vortex-Winds; (3) uncoupled CFD simulations incorporating TlnF option for inflow; (4) Tokyo Polytechnic University’s (TPU’s) low-rise wind tunnel datasets; and (5) user-provided wind tunnel test data for rectangular buildings.

**UQ methods:** Forward Problem methods from quoFEM

**Model Generators:** Nonlinear (NL) shear models and detailed OpenSees building models

**Year 4 updates will incorporate:**

(1) Coupling of CFD-FEM simulations.
(2) Surrogate Modeling options.
(3) Additional Low Rise Roof Shapes and TPU datasets.
(4) New UQ features made available through quoFEM, including Sensitivity and Reliability Options.
(5) Model Generators including Expert System.
Earthquake Engineering with Uncertainty Quantification (WE-UQ) is an application to determine the response of a structure to earthquake loading. The tool focuses on providing different earthquake loading options, structural model generators, and UQ methods. It allows users to run computations on HPC resources.

**Capabilities**

Loading options: (1) Stochastically generated motions Vlachos et al. and Dabaghi & Der Kiureghian; (2) PEER .AT2 files; (3) interaction with PEER NGA WEST database; (4) Site Response (soil column: Elastic, PM4Sand/Silt, PDMY02, etc.)

UQ methods: Forward Problem methods from quoFEM

Model Generators: Nonlinear (NL) shear models and detailed OpenSees building models

**Year 4 updates will incorporate:**

1. Random Fields in Site Response
2. Incorporate Domain Reduction Method
3. Coupling with NGA East
4. Surrogate Modeling options
5. Incorporate Reliability and Sensitivity from quoFEM
6. Hierarchical models and multi-fidelity MC
7. Model Generators including Expert System
The Performance Based Engineering (PBE) Application is an extensible workflow application to perform PBE computations for various hazards. The current release provides researchers a tool to assess the performance of a building in an earthquake scenario. The application focuses on quantifying building performance through decision variables.

**Capabilities**

- **UQ methods**: As per EE-UQ
- **Event-loading options**: As per EE-UQ
- **Damage and loss (D&L) assessment**: FEMA P58 and HAZUS D&L functions
- **User configuration options**: Define D&L models

Year 4 updates will incorporate:

1. An extension to include wind events **(HAZUS D&L)**
PELICUN stands for Probabilistic Estimation of Losses, Injuries, and Community resilience Under Natural disasters. The HAZUS and FEMA P58 methods in PELICUN provide multi-hazard and multi-fidelity damage and loss modeling capabilities.

**Capabilities**
FEMA P58 and HAZUS-based methods to estimate damage and losses under earthquake and hurricane wind.
(1) uncertainty in structural response;
(2) time-based assessments;
(3) user friendly input and output
(4) auto-population feature for regional simulations

**Year 4 updates will incorporate:**
(1) Methods and configuration data for damage and loss assessment in storm surge and tsunami events.
(2) Higher fidelity models for lifeline damage and loss assessment.
(3) Enhanced auto-population methods for damage and loss models.
(4) Efficient structural response estimation without simulation.
Tools to Study Effects of Regional Hazard

Emphasis in 2020 is on **RDT**, rWhale, PELICUN, BRAILS to allow researchers to study Effect of Natural Hazards on the Regional Scale

- **SimCenter Research Tools**
  - **RDT**
  - **rWhale**

- **SimCenter**
  - Cloud-enabled research tools, emphasis UQ, scalable to run on HPC

- **BRAILS**

- **Back-end**
  - Building Information Models

- **Back-end**
  - rWhale

- **DesignSAFE-CI**
  - NHERI: A Natural Hazards Engineering Research Infrastructure

- **SimCenter’s Application Framework**
  - Asset Description
  - Hazard Description
  - Asset & Hazard Modeling
  - Response Estimation
  - Regional Recovery Simulation

- **Data storage and HPC access**
Buildings Inventory Development using Web Automation

- Tax Assessor’s website
- Web Automation Framework
- Parcel Tax Records
- Parcel Processor

Building Information Models

SimCenter NHERI
The Building Recognition using AI at Large Scale (BRAILS) is a new AI-enabled tool to assist regional-scale simulations. BRAILS utilizes machine learning (ML) and deep learning (DL) to create enhanced building inventory databases of cities.
Earthquake Scenario Simulator (EQSS)

- Prototype for Scenario-based Regional Seismic Hazard Analysis and Ground Motion Records Selection/Scaling
Regional Simulations Testbeds to Verify the Software

San Francisco Bay Area Testbed
- 3D ground motion simulation (M7.0)
  - 141,400 red-tagged buildings
  - 5.6% net buildings loss ratio

Anchorage, Alaska Testbed
- Parcel level damage
  - 3,828 red-tagged buildings
  - 14.5% net buildings loss ratio

Atlantic City, NJ Storm Testbed

Memphis, TN Lifelines Testbed
Anchorage Testbed: Workflow Configurations

- Two different rWHALE configurations to characterize ground motions

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Hazard</th>
<th>Modeling</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scraped BIM</td>
<td>GM (Recorded)</td>
<td>MDOF NL</td>
<td>FEMA P58</td>
</tr>
<tr>
<td>Scraped BIM</td>
<td>GM (Simulated)</td>
<td>MDOF NL</td>
<td>FEMA P58</td>
</tr>
</tbody>
</table>

Recorded Ground Motions

Simulated Ground Motions
Anchorage Testbed: Results: Validation

- Estimated Losses

<table>
<thead>
<tr>
<th></th>
<th>Recorded GM</th>
<th>Simulated GM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair Cost [$Billion]</td>
<td>7.5</td>
<td>7.3</td>
</tr>
<tr>
<td>Red Tags</td>
<td>3800</td>
<td>626</td>
</tr>
<tr>
<td>Loss Ratio [%]</td>
<td>14.5</td>
<td>12.5</td>
</tr>
</tbody>
</table>

- City of Anchorage identified more than 750 homes and buildings that suffered substantial damage
- Research opportunities to calibrate, verify and validate computational models
Anchorage Testbed: Results: a Story Map

- Documents the input data, results and process

On November 30th 2018, a magnitude 7.1 earthquake occurred near Anchorage, Alaska. Originally the earthquake was estimated to be a magnitude 7.0, but was later revised to magnitude 7.1. The epicenter of the earthquake was 10 miles away from the Anchorage metro area and the depth of the earthquake was 29 miles.

In the few weeks following the earthquake, the NHERI SimCenter team collected and processed building exposure data from public sources. The data was used to run a regional loss estimation for the 85,000 buildings in Anchorage and Eagle River.

Disclaimer
The presented simulation results are not representative of any individual building’s response. To understand the response of any individual building, please consult with a professional structural engineer. The presented tool does not assert the known condition of the building. Just as it cannot be used to predict the negative outcome of an individual building, prediction of safety or an undamaged state is not assured for an individual building.

Acknowledgment
This material is based upon work supported by the National Science Foundation under Grant No. 1612863. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

http://arcg.is/1X8DLu
SimCenter Memphis (TN) testbed
E. Month (SimCenter REU, Cornell); C. Lee, I. Tien (GeorgiaTech)

- use rWHALE for estimation of damage and repair times
- unprecedented fidelity in damage and loss estimates
- support Bayesian approach to describe interdependencies
- extended damage and loss models to support non-building assets
- extended rWHALE to preserve spatial correlation in lifeline performance estimates
SimCenter Memphis (TN) testbed
E. Month (SimCenter REU, Cornell); C. Lee, I. Tien (GeorgiaTech)

- use rWHALE for estimation of damage and repair times
- unprecedented fidelity in damage and loss estimates
- support Bayesian approach to describe interdependencies

- extended damage and loss models to support non-building assets
- extended rWHALE to preserve spatial correlation in lifeline performance estimates
SimCenter Memphis (TN) testbed
E. Month (SimCenter REU, Cornell); C. Lee, I. Tien (GeorgiaTech)

- use rWHALE for estimation of damage and repair times
- unprecedented fidelity in damage and loss estimates
- support Bayesian approach to describe interdependencies
- extended damage and loss models to support non-building assets
- extended rWHALE to preserve spatial correlation in lifeline performance estimates

Memphis Testbed: Potable Water Network
SimCenter Memphis (TN) testbed
E. Month (SimCenter REU, Cornell); C. Lee, I. Tien (GeorgiaTech)

- use rWHALE for estimation of
damage and repair times

- unprecedented fidelity in
damage and loss estimates

- support Bayesian approach
to describe interdependencies

- extended damage and loss models
to support non-building assets

- extended rWHALE to preserve
spatial correlation in lifeline
performance estimates
SimCenter Memphis (TN) testbed
E. Month (SimCenter REU, Cornell); C. Lee, I. Tien (GeorgiaTech)

- use rWHALE for estimation of damage and repair times
- unprecedented fidelity in damage and loss estimates
- support Bayesian approach to describe interdependencies

- extended damage and loss models to support non-building assets
- extended rWHALE to preserve spatial correlation in lifeline performance estimates
SimCenter Memphis (TN) testbed
E. Month (SimCenter REU, Cornell); C. Lee, I. Tien (GeorgiaTech)

- use rWHALE for estimation of damage and repair times
- unprecedented fidelity in damage and loss estimates
- support Bayesian approach to describe interdependencies
- extended damage and loss models to support non-building assets
- extended rWHALE to preserve spatial correlation in lifeline performance estimates
Summary

- Anchorage
- Bay Area
- Atlantic City
- Memphis

WATER NETWORK
BUILDINGS
EARTHQUAKE
HURRICANE

Fidelity
Efficiency
Leveraging past PEER projects to move into the future
  - Regional simulations
  - New hazards

All software is opensource – including building inventories
  - [http://SimCenter.DesignSafe-Cl.org](http://SimCenter.DesignSafe-Cl.org)
  - [http://github.com/NHERI-SimCenter](http://github.com/NHERI-SimCenter)

The Center is open for collaborations: Looking to facilitate research

Open job opportunities for postdocs interested in hazards and programming

Follow us on Twitter & Facebook. Subscribe to our newsletter. Come to our workshops. Attend our webinars. Most importantly contribute.