An Overview of the NSF Natural Hazards Engineering Research Infrastructure (NHERI) SimCenter

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Co-Director  
Stanford University

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Goals

- Develop a computational framework that supports decision-making to enhance community resilience to natural hazards in the face of uncertainty;
- Design the framework to be sufficiently flexible, extensible, and scalable so that any component can be enhanced to improve the analysis and thereby meet the needs of a user group;
- Seed the framework with connectivity to existing simulation tools and data so it can be readily employed and improve as users identify new needs;
- Release tools/applications built using this framework that meet 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 Sites

DesignSafe-ci.org is a comprehensive cyberinfrastructure environment for research in natural hazards engineering.
- Data Storage and Sharing
- Access to HPC at TACC
- Cloud platform for running deployed applications

Experimental and RAPID facilities

SimCenter Application Framework

Cloud-enabled research applications
Scalable to run on HPC with emphasis on UQ
Leadership Group

Sanjay Govindjee
UC Berkeley

Ahsan Kareem
Notre Dame

Laura Lowes
U. Washington

Greg Deierlein
Stanford

Camille Crittenden
UC Berkeley

Frank McKenna
UC Berkeley

Matt Schoettler
UC Berkeley

Software Development Team

Peter (UW), Michael, Adam (Stanford), Frank, Chaofeng, Wael, Pedro (UW)
## Domain Experts

Additional experts in engineering, urban planning, social science, and computer and information science

<table>
<thead>
<tr>
<th>Iris Tien</th>
<th>George Deodatis</th>
<th>Patrick Lynette</th>
<th>Alex Taflanidis</th>
<th>Jack Baker</th>
<th>Ann-Margret Esnard</th>
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<tbody>
<tr>
<td>Joel Conte</td>
<td>Vesna Terzic</td>
<td>Jonathan Bray</td>
<td>Tracy Kijewski-Correa</td>
<td>Michael Motley</td>
<td>Paul Waddell</td>
</tr>
<tr>
<td>Filip Filippou</td>
<td>Ewa Deelman</td>
<td>Koncho Law</td>
<td>Ertugrul Taciroglu</td>
<td>Stella Yu</td>
<td>Eduardo Miranda</td>
</tr>
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## Strategy

Current software is often good, but:
- Regular software updating needed,
- Unable to scale to HPC,
- Difficult to interact with and move data from one app to another.

- Move to cloud-based HPC environment,
- Provide integrated “plug and play” capability to link multiple software apps together into workflows
API Facilitated Application of Applications

Desired Outcome
Performance-Based Engineering Framework

Simulation of Earthquake Events → Generate Site-Specific Ground Motions → Simulate Structural Response → Estimate Loss and Assess Regional Risk

- Earth Scientists
- Str/Geo Engineers
- Loss & System Modelers
- Social Scientists

Application Framework & Research Apps

Application Framework:
a collection of software connected by standardized interfaces

Focus on framework to connect simulation software

HPC resources & data storage at
**Application Framework & Research Apps**

- **Run in the cloud**
- **Run Locally**

**Application Framework & Research Apps**

- **Application Framework**
  - **Asset Description**
  - **Hazard Description**
  - **Asset & Hazard Modeling**
  - **Response Estimation**
  - **Damage and Loss Estimation**
  - **Regional Recovery Simulation**

**Supporting Databases**

**Uncertainty Quantification**

- **DesignSAFE-CI**
- **McDowell**
- **Penn State**

**Research Apps**

- **uqFEM Application**
  - **Integrates Simulation Applications with UQ Engine(s)**

**Application:**

- **Inputs:** FEM model, input uncertainty specification, UQ method & post-processing script
- **Outputs:** Depends on problem type and post-processing (e.g., Uncertainty measures of outputs)

**Release Dates:**

- **V1.0 (June 2018)** Connecting UQ engine DAKOTA with OpenSees and FEAP
- **V2.0 (2019)** – UQ Engines other than DAKOTA (e.g., UQpy)

**Research Opportunities:**

- Surrogate Modeling
- Model Calibration

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**Research Opportunities:**

- Surrogate Modeling
- Model Calibration
Wind (flow) Simulations

- DATA-DRIVEN SIMULATION TOOLS
- PARAMETRIC SIMULATION TOOLS
- USER-FRIENDLY CFD INTERFACES
- DIRECT ACCESS FOR CFD SIMULATION

EE-UQ Application

- Quantifies uncertainty in building response when subjected to an earthquake

**Application:**
- **Inputs:** Building information, earthquake event & uncertainty specification
- **Outputs:** Uncertainty measures of building response

**Release Dates:**
- V1.0 (2018) Uniform Excitation
- V2.0 (2019) Rock Outcrop motions + Expert System
- V3.0 (2020) Soil Box around Building + Machine Learning

**Research Opportunities:**
- Finite element modeling
- Hazard characterization
- UQ including surrogate model generation
- Datasets for model calibration
PBE Application

- Probabilistic damage & loss calculations of a building subjected to a natural hazard

**Application:**

- **Inputs:**
  - Building & structural information,
  - Hazard characterization,
  - Contents,
  - Damage & loss functions, e.g. PS8, HAZUS or user-defined.
- **Outputs:** Damage, loss, and consequences

**Release Dates:**

- V1.0 (Oct 2018) Earthquake
- V2.0 (2020) Other Hazards

**Research Opportunities:**

- Damage & loss calculations
- Validation of fragility and consequence functions

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Performance Based Engineering

- hazard regional site-specific ground motion
- losses model
- general info model response
damage model

PELICUN Toolbox

- **Probabilistic** Estimation of **Losses**, **Injuries** and **Community resilience** **Under** **Natural hazards**

- Hazard-agnostic loss-assessment library in **Python**

- Object-oriented and conceptually similar to what OpenSees is for FEM

- Open-source, transparent, cross-platform, easy to install and customize

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Regional Simulation (EQ)

Applications

The Application Framework provides applications with standard interfaces

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Hazard</th>
<th>Modeling</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic BIM</td>
<td>LLNL_SW4</td>
<td>MDOF_LU</td>
<td>FEMA PS8 LU</td>
</tr>
<tr>
<td>UrbanSIM</td>
<td>SNA-GM.py</td>
<td>Concrete Shear Walls</td>
<td>Pelicun</td>
</tr>
<tr>
<td>Document Database</td>
<td></td>
<td>Multiple Fidelity Modeling</td>
<td></td>
</tr>
</tbody>
</table>
Regional Simulation (EQ)

Configuration

Chain a set of applications into a building workflow

Low Fidelity Configuration

- Generic BIM
- Seismic Hazard Analysis
- Simple Model
- Hazus

High Fidelity Configuration

- Detailed BIM
- Seismic Wave Propagation
- High Fidelity Model
- FEMA PS8

Multiple Fidelity Configuration

- Multiple Fidelity BIM
- Seismic Hazard Analysis
- Multiple Fidelity Modeling
- FEMA PS8

Regional End-to-End Testbed (EQ)

M7.0 Hayward Fault
1.8 million buildings in SF Bay Area
Policy/Planning: building losses & downtime in 2010 and 2040

Objective: develop/exercise a computational workflow for a significant simulation that can engage broad NEHRI community

Ground Motions: 3D simulation, GM’s at 2km grid (Rodgers, Pitarka & Petersson)
Building Inventory: UrbanSim and DataSF Portal; geometry, age, occupancy
Building Analyses: OpenSees, simplified NL MDOF, FEMA PS8 (w/Cheng & Lu, Tsinghua)
Visualization: Q-GIS, UrbanSim
Interpretation: UrbanSim - urban growth, damage/loss, displaced occupants/population
Comparison of Building Damage

SimCenter Workflow
- Red-tagged buildings 141,400
- Net buildings damage ratio 5.6%

USGS Haywired
- Red-tagged buildings 101,000
- Net buildings damage ratio 2.9%

High Resolution Results

- Parcel-level Data of Building Damage

San Francisco

Oakland - Alameda

Opportunities to evaluate planning and policy decisions (land use, retrofit, etc.)
Regional Workflow – Future Plans

- Open source component tools
  - createEvent, createBIM, createSAM
  - PBE Loss/Recovery
- Robust and scalable UQ tools
- Utility & Transportation Systems
- Other Natural Hazards
  - Wind & Storm Surge
  - Tsunami
- Resilience Decision Tool (RDT)
  - V1 (2020) – EQ
  - V2 (2021) – Hurricane (Wind/Surge)
  - V3 (2022) – Tsunami

Registered Workflow Applications

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>createBIM</td>
<td>UrbanSimDatabase</td>
<td>Creates a simple BIM from UrbanSim simulation outputs</td>
</tr>
<tr>
<td>createBIM</td>
<td>GenericBimDatabase</td>
<td>Creates a simple BIM from a building flat file (csv)</td>
</tr>
<tr>
<td>createEVENT</td>
<td>LLNL_SW4</td>
<td>Gets Event input from SW4 outputs</td>
</tr>
<tr>
<td>createSAM</td>
<td>MDOF_LU</td>
<td>Creates a MDOF shear building model</td>
</tr>
<tr>
<td>createEDP</td>
<td>StandardEarthquakeEDP</td>
<td>Defines the standard EDPs that are used in the seismic event</td>
</tr>
<tr>
<td>performSIM</td>
<td>OpenSeesSimulation</td>
<td>Performs simulation using OpenSees and calculates the EDPs</td>
</tr>
<tr>
<td>createLOSS</td>
<td>FEMA58_LU</td>
<td>Calculates damage and loss estimates using FEMA 58 procedure</td>
</tr>
<tr>
<td>performUQ</td>
<td>DakotaFEM</td>
<td>Propagates uncertainty in all applications using Dakota</td>
</tr>
</tbody>
</table>

Integrated Infrastructure Systems

BIM       EVENT       SAM       EDP       DL

createBIM  createEVENT  createSAM  createEDP  performSIM  createLOSS
AI Applications: BIM to SAM

Structural Engineers

Future Virtual Engineer

Dataset: 87 walls
Training: 98% accurate
Testing: 93% accurate

AI Applications: BIM to SAM

Future Virtual Engineer

In the Future: AI for Data to BIM

Future Virtual Engineer

Machine Learning

images

camera pose

3D models

Future Virtual Engineer

Height
Construction type
Number of stories
……

building properties

- SF building footprints: 117023 buildings, height, GPS coordinates, ...
- SF building permits: 1+ million records, #stories, construction types, GPS coordinates, ...
- SF land use: 115,468 records, land use types, year built, GPS coordinates, ...
Educational Applications

ECO Activities

- SimCenter Online Webinars

- NHERI Summer Institute  (June 5-7)

- Subscribe to SimCenter news and join Slack channels
  - https://simcenter.designsafe-ci.org/join-community/

- Letters of Support and collaboration questions
  - https://simcenter.designsafe-ci.org/about/collaborate/
ECO Activities

- **SimCenter Tool Training Workshop** (Summer 2019)
- **Summer Programming Bootcamp** (Summer 2019)
- **Summer REU Program**
  - [https://www.designsafe-ci.org/learning-center/reu/](https://www.designsafe-ci.org/learning-center/reu/)
  - Applications due February 1, 2019

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**https://simcenter.designsafe-ci.org**

- **SimCenter Research Tools**
  - [https://simcenter.designsafe-ci.org/research-tools](https://simcenter.designsafe-ci.org/research-tools)
- **Software Source Codes and Contributions**
  - [https://github.com/NHERI-SimCenter](https://github.com/NHERI-SimCenter)