Computational Workflow Framework for Regional Disaster Simulations

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Performance-Based Methodology

- Collapse & Casualties
- Direct Financial Loss
- Downtime

Decision Variable

Damage Measure

Engineering Demand Parameter

Intensity Measure

\[ v(DV) = \iiint G(DV|DM) \, dG(DM|EDP) \, dG(EDP|IM) \, d\lambda(IM) \]

MAF of:
- collapse
- loss > $
- downtime > t
Performance-Based Earthquake Engineering

Qualitative Targets (ASCE 41)

Explicit Measures (FEMA P-58)

1st-gen (1997)

Nonlinear static pushover analysis

Provides a methodology, basic building information, response quantities, fragilities and consequence data to evaluate the seismic performance of buildings

*Procedures are probabilistic*

**Performance metrics:**
- life safety risks
- direct economic losses
- downtime and indirect losses

**Recommended Use –**
- Evaluate performance of new and existing buildings
- Provide the basis for performance-based design of new buildings and retrofit of existing buildings
Component Performance Toolbox

**PELICUN** *(PROBABILISTIC ESTIMATION OF LOSSES, INJURIES, & COMMUNITY RESILIENCE UNDER NATURAL DISASTERS)*

OpenSource :: Multi-Fidelity :: Multi-Hazard
Economic Benefits of Cripple Wall Retrofit
Limitations to “The Law of Averages”

HAZUS w/def

HAZUS baseline
One-Story, 2ft Cripple Walls, San Francisco Site

- **Wood Siding: Existing**
- **Wood Siding: Retrofit**
- **Stucco: Existing**
- **Stucco: Retrofit**

**Expected Annual Loss**

- **Wood Siding**
  - Benefit: -0.6%

- **Stucco**
  - Benefit: -0.2%

**Loss at 250yr Hazard Intensity**

- **Wood Siding**
  - -40%

- **Stucco**
  - -20%

**Mean Loss [% Replacement]**

- **IM = Sa(0.25s) [g]**
- **Sa_{RP=250} = 1.0g**

**Loss versus Intensity (SF Site)**
Simulation-Based Regional Risk/Resilience Assessment

CURRENT (e.g., HAZUS)
Empirical Models
Census Block Inventory

GOAL
Direct Simulation
Detailed Inventory
Multiple models

ref. M. Hori, Univ. of Tokyo
Application Framework (AF) is designed to assemble a regional workflow and streamline regional risk assessment. State-of-the-art software is available for each task allowing researchers to tailor the workflow to their needs. **New software is easy to add.**

Workflows can run at DesignSafe using **HPC resources** at Texas Advanced Computing Center.
**describe the region**
specify characteristics of buildings and infrastructure in the region

**describe the hazard**
specify the regional distribution of ground shaking, wind, or water

*for each random region-hazard sample:*
propagate uncertain characteristics of the regional assets and the hazard
*for each asset in the region:*

**describe the asset**
create stochastic models for response, damage, and loss estimation

**describe the event at the site**
specify hazard-consistent loads for response estimation

*for each random asset-event sample:*
propagate uncertainties in asset models and event description

**estimate asset response to the event**
describe the response with engineering demand parameters

**estimate asset damage and its consequences**
prepare a stochastic description of damage and loss for the asset

**describe regional damage and direct losses**
aggregate damages and losses in the region considering dependencies

**estimate indirect regional consequences**
describe regional consequences of infrastructure- and social disruption

**simulate regional recovery**
estimate the temporal and spatial variation in the recovery of communities

**AI tools**
SF Bay Area Regional Testbed Study

- M7.0 Hayward rupture modeled using SW4 [1]
- 1.84 M buildings were included in the simulation
- Building information is based on UrbanSim data
- Damage and Loss is based FEMA_P58_LU [2]
- OpenSees structural analysis models are based on MDOF_LU
- Run on DesignSafe HPC Resources
- Example of Results:
  - Red-tagged buildings 141,400
  - Net buildings damage ratio 5.6%

High Resolution Models

Building parcel versus census block resolution of damage and downtime

SimCenter Simulation

USGS Haywired (2018)
High Resolution Models

Parcel-level resolution enables unprecedented quantification of engineered interventions for policy level decisions.

SimCenter Simulation

San Francisco Parcels

Opportunities to evaluate planning and policy decisions (retrofit, land use, recovery planning, etc.)
UrbanSim Output - Sample Results

Displaced Population in Residential Construction
(person/parcel; Oakland, Lake Merritt Area)
Urban Growth & Evolving Risk

D. Lallemand, 2015
San Francisco – Tall Building Inventory

156 Tall Buildings (Over 240 ft)

- Occupancy
- Height & Date/Age
- Structural System & Materials
- Façade, Foundation
- BORP, Instrumentation

Building footprint data from DataSF.org
Impediment of Building Cordons on Recovery

Impact on:
- Emergency Response
- Neighboring Buildings
- Recovery/Reconstruction
- Downtown Economy
Distributed Transportation Systems

Detailed Component Models Linked with Rigorous System Evaluation
1. Risk Landscape

2. Hazards
   - Ground Shaking
   - Liquefaction
   - Landslides
   - Tsunami
   - Flooding
   - Fire

3. Risk/Consequence

4. Capabilities

5. Strategy
Regional Simulation Testbeds

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

EQ Damage to Water System
### Regional Simulation – Anchorage Example

#### 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>

![Recorded GM Map]

![Simulated GM Map]

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**Buildings**

- Generic BIM
- NNGM (Recorded)
- NNGM (Simulated)

**Hazard**

- MDOF NL

**Modeling**

- FEMA P58

**Losses**

- Parcels Loss Ratios
- Buildings Red Tags
Regional Simulation: Anchorage 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.

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http://arcg.is/1X8DLu
### Atlantic City Hurricane Testbed

**N parcels**: 20,654

**Occupancies**: Single & multi-family residential, commercial and industrial

**Typologies**: Wood, steel, masonry, RC, metal buildings

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Cat 5 (Surrogate Model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoM</td>
<td>15.4 to 98 miles</td>
</tr>
<tr>
<td>Cp differential</td>
<td>75 to 100 mbar</td>
</tr>
</tbody>
</table>
AI Tools for Building Feature Identification

Building Feature Identification using AI-enabled Evaluation of Images

- City of Interest
- Metadata collection
- Geocoding
- Satellite / Street Images
- CNN
  - BIM For Individual Bldgs.
  - Uncertainty Quantification (SURF)
  - Regional-scale Building Inventory
Regional Simulation: Memphis Water System

- **pelicun** to estimate pipe damage and pipe repair times
- **rWHALE** to estimate ground PGV (using OpenSHA) and to integrate with pelicun to calculate pipe damage, pipe repair times
- scenario assessments with multiple realizations preserve spatial correlation in ground motions, damage, repairs
- high resolution damage and loss estimates
- support Bayesian approach for model updating and simulation of network interdependencies

**Memphis, TN**

*M7.5 earthquake*

**mean PGV**

**repair time**

**damage**

**expected repair time**

*all realizations*

repair time (worker-days)

repair time / link (worker-days)

leaks/km

SimCenter NHERI
Center for Computational Modeling and Simulation
Recent News (News Archive)

NEW SimCenter Webinar: Gathering Data for Natural Hazards Engineering Using Web Automation
Presenter: Wael Elhaddad

The NHERI REU Summer Program provides research opportunities at the ten NHERI multi-hazard engineering sites during a 10-week summer research program. Applications for the 2020 NHERI REU Summer Program will close February 1, 2020 at 11:59pm Central.