Example use of Research Tools

https://simcenter.designsafe-ci.org/research-tools

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NSF award: CMMI 1612843
Objectives

• Demonstrate use-cases of our research tools
• Get feedback on existing features
• Collect requests for new features
### Research Tools

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>quoFEM</strong></td>
<td>Uncertainty Quantification and Optimization</td>
</tr>
<tr>
<td><strong>EE-UQ</strong></td>
<td>Structural Response Estimation under Earthquakes</td>
</tr>
<tr>
<td><strong>WE-UQ</strong></td>
<td>Structural Response Estimation under Wind</td>
</tr>
<tr>
<td><strong>CWE</strong></td>
<td>CFD Analysis for a Building</td>
</tr>
<tr>
<td><strong>PBE</strong></td>
<td>Damage and Loss Assessment for a Building</td>
</tr>
<tr>
<td><strong>rWHALE</strong></td>
<td>Damage and Loss Assessment for an Urban Region</td>
</tr>
</tbody>
</table>
Case study

example application: Buckling Restrained Braced Frames

1. Design an experiment
2. Calibrate a numerical component model
3. Simulate structural response
4. Estimate damage and losses

quoFEM, EE-UQ, PBE
## Case study

**example application: Buckling Restrained Braced Frames**

1. **Design an experiment**  
   quoFEM

2. **Calibrate a numerical component model**  
   quoFEM

3. **Simulate structural response**  
   EE-UQ

4. **Estimate damage and losses**  
   PBE
Design an experiment

setting: uniaxial cyclic load test of a Buckling Restrained Brace
objective: estimate maximum tension/compression during test
problem: some attributes of the specimen are not known
new load protocol
Design an experiment

**quoFEM**: sample the joint distribution of uncertain attributes; simulate the experiment; estimate max loads
Design an experiment

First, through literature review get:
- conservative bounds for attributes
- simplified BRB model in OpenSees

Then, prepare:
- new load protocol
- script to simulate experiment
- script to extract max forces
First, through literature review get:
- **conservative bounds for attributes**
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Then, prepare:
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\[
\begin{align*}
\gamma_{ov} & : 1.10 – 1.20 \\
\omega & : 1.35 – 1.75 \\
\beta & : 1.01 – 1.30 \\
\omega_{iso} & : 0.05 – 0.30
\end{align*}
\]
Design an experiment

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Design an experiment

First, through literature review get:

• conservative bounds for attributes
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Then, prepare:

• new load protocol
• script to simulate experiment
• script to extract max forces

```
60  set matBRB 51
61  uniaxialMaterial Steel4 $matBRB $f_y $E_0 \\
62    -asym \\
63    -kin $b_k $R_0 $r_1 $r_2 $b_kc $R_2 \\
64    -iso $b_i $rho_i $b_l $R_i $l_yp $ \\
65    -ult $f_u $R_u $f_u $R_u \\
66  element corotTruss 0 0 100 $A_y $matBRB
67  recorder Node -file "force_disp.out" -time -node 1
68  pattern Plain 1 Linear {
69    load 100 [expr 1.0*$kN]
70  }
71  set IDctrlNode 100
72  set IDctrlDOF 1
73  constraints Plain
74  numberer RCM
75  system BandGeneral
76  test NormDispIncr 1.e-10 100
77  algorithm NewtonLineSearch -maxIter 100
```

BRB_response.tcl
Design an experiment

First, through literature review get:

• conservative bounds for attributes
• simplified BRB model in OpenSees

Then, prepare:

• new load protocol
• script to simulate experiment
• script to extract max forces

```
import numpy as np
import pandas as pd

def process_results(response):
    res = pd.read_csv('force_disp.out', sep=' ', header=None, names=['F', 'd'])
    F_c = np.abs(res['F'].min())
    F_t = res['F'].max()

    with open('results.out', 'w') as f:
        f.write('{} {}'.format(F_c, F_t))
```

postprocess.py

```
-262.325 227.717
```

results.out
Design an experiment

load the pre-defined scripts

simulation script
postproc. script
Design an experiment

select the task

available methods for forward propagation
- Latin Hypercube Sampling
- Monte Carlo Sampling
- Importance Sampling
- Gaussian Process Regression
Design an experiment

BRB_response.tcl

```
# hyperparameters
pset gammaOv 1.1
pset omega 1.55
pset omegaIso 0.4;
pset beta 1.15
```

supported distributions:
- Normal, Lognormal
- Uniform
- Beta
- Weibull
- Gumbel
Design an experiment

advanced users can
- specify their python interpreter
- edit working directories
Design an experiment

result visualization

scatterplots show sampled inputs and corresponding outputs
Design an experiment

result visualization

scatterplots show sampled inputs and corresponding outputs

and joint distributions
Design an experiment

advanced visualization and data processing

easy to load csv in Python, MatLAB, or Excel

```
1 import pandas as pd
2 import plotly.express as px
3 res = pd.read_csv("C:/Lehigh/00_forward_example_BRB/output.csv", sep=', ', )
4 res.head(10)
```
Design an experiment

advanced visualization and data processing

joint distribution with marginals
Design an experiment

advanced visualization and data processing

use scatter matrix to identify dependencies
Design an experiment

advanced visualization and data processing

use color and marker size to visualize dependency on 3 parameters

```python
1 res['gammaOv_viz'] = np.log(res['gammaOv']*10.8-9.9)
2 fig2 = px.scatter(res, x='omega', y='F_t', color='omegaIso',
3     color_continuous_scale=px.colors.sequential.Viridis,
4     size='gammaOv_viz', size_max=20, height=500, width=800)
5 fig2['layout'].update(font=dict(family="Calibri", size=28))
6 fig2.show()
```
Design an experiment

advanced visualization and data processing

raw data is available for every simulation

marker size ~ gammaOv
Design an experiment

advanced visualization and data processing

raw data is available for every simulation
example application: Buckling Restrained Braced Frames

1. Design an experiment

2. **Calibrate a numerical component model**

3. Simulate structural response

4. Estimate damage and losses
Calibrate component model

objective: calibrate Buckling Restrained Brace model parameters

problem: complex behavior, large number of material parameters

quoFEM: minimize error between simulation and reference result

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Calibrate component model

Prepare:
• reference data from test results
• complex BRB model in OpenSees
• updated simulation script
• script with the objective function
Calibrate component model

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• reference data from test results
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• updated simulation script
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SimCenter NHERI

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Calibrate component model

Prepare:
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Calibrate component model

Prepare:

- reference data from test results
- complex BRB model in OpenSees
- **updated simulation script**
- script with the objective function

```tcl
7 model BasicBuilder -ndm 1 -ndf 1
8 9 set l 2.500
10 set A_y 600
11 set f_DM 1.39
12 set f_SM 1.13
14 # hyperparameters
15 pset gamma0v 1.15
16 pset omega 1.4
17 pset omegaIso 0.25;
18 pset beta 1.15
19 pset rhoxi 0.3
20 pset rx1 0.925
21 pset fxult 1.55
22 pset fxultc 2.5
24 set l [expr $l*$m]
25 set A_y [expr $A_y*$mm2]
27 set f_yk [expr 235.0 * $MPa]
28 set E_s [expr 210.0 * $GPa]
30 # calculate material props
31 set E_0 [expr $f_SM*$E_s];
32 set f_y [expr $gamma0v*$f_yk];
33 set eps_y [expr $f_y/$E_0]
```

BRB_response.tcl
Prepare:
• reference data from test results
• complex BRB model in OpenSees
• updated simulation script
• script with the objective function

```python
#!/usr/bin/python
# written: adamzs
import numpy as np
import pandas as pd

def process_results(response):
    data = pd.read_csv('reference.txt',
                       header=None, names=['F_ref', 'd'])
    # convert displacements to [m]
    data['d'] = data['d'] / 1000.
    sim = pd.read_csv('force_disp.out',
                       header=None, names=['F', 'd'])
    data['F_sim'] = sim['F']

    eps_s = (data['F_sim'] - data['F_ref']) ** 2.
    eps_srss = np.sqrt(np.sum(eps_s) / len(data.index))

    with open('results.out', 'w') as f:
        f.write("{:6f}".format(eps_srss))
```
Calibrate component model

load the pre-defined scripts

simulation script
postproc. script
Calibrate component model

select the task

Gauss-Newton is a gradient-based optimization method

we are also adding Bayesian methods for solving the inverse problem
Calibrate component model

# hyperparameters
pset gammaOv 1.15
pset omega 1.4
pset omegaIso 0.25;
pset beta 1.15
pset rhoxi 0.3
pset rx1 0.925
pset fxult 1.55
pset fxultc 2.5
Calibrate component model

### quoFEM Application

#### Summerary

<table>
<thead>
<tr>
<th>Name</th>
<th>Best Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>gamma0v</td>
<td>1.2</td>
</tr>
<tr>
<td>omega</td>
<td>1.36955</td>
</tr>
<tr>
<td>omegaIso</td>
<td>0.272546</td>
</tr>
<tr>
<td>beta</td>
<td>1.1156</td>
</tr>
<tr>
<td>rhoxi</td>
<td>0.265941</td>
</tr>
<tr>
<td>rx1</td>
<td>0.931044</td>
</tr>
<tr>
<td>fxult</td>
<td>1.59433</td>
</tr>
<tr>
<td>fxultc</td>
<td>2.50006</td>
</tr>
</tbody>
</table>

#### Method Selection

#### Input Variables

#### Results
Calibrate component model

result visualization

scatterplot shows convergence
Calibrate component model

quoFEM

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example application: Buckling Restrained Braced Frames

1. Design an experiment
2. Calibrate a numerical component model

3. Simulate structural response

4. Estimate damage and losses
objective: estimate interstory drifts and floor accelerations in an earthquake scenario

problem: complex, computationally expensive calculations

EE-UQ: conveniently run simulations through DesignSafe
Simulate structural response

Prepare:
• BRBF model in OpenSees
• ground motion records from PEER NGA2
Simulate structural response

Prepare:
• BRBF model in OpenSees
• ground motion records from PEER NGA2

```tcl
# load the core methods
source core/setAnalysis.tcl
source core/setRecorders.tcl
source core/Basics.tcl

# load the model info
source BRBF/Zsarnoczay_Vigh_2017/6AHHD.tcl

# specify the story height and the nodes
set h [4.0 4.0 4.0 4.0 4.0 4.0]
set driftNodes [0 100 200 300 400 500 600]

# build the model
set pushover 0
source core/ModelBuilder.tcl
```

BRBF.tcl
Prepare:

- BRBF model in OpenSees
- ground motion records from PEER NGA2

<table>
<thead>
<tr>
<th>Record ID</th>
<th>Description</th>
<th>Peak Ground Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSN143_TABAS_TAB-L1.AT2</td>
<td>1.4637</td>
<td></td>
</tr>
<tr>
<td>RSN1193_CHICHI_CHY024-E.AT2</td>
<td>3.1806</td>
<td></td>
</tr>
<tr>
<td>RSN1489_CHICHI_TCU049-E.AT2</td>
<td>3.9083</td>
<td></td>
</tr>
<tr>
<td>RSN1511_CHICHI_TCU076-E.AT2</td>
<td>3.1206</td>
<td></td>
</tr>
<tr>
<td>RSN1521_CHICHI_TCU089-E.AT2</td>
<td>3.5561</td>
<td></td>
</tr>
<tr>
<td>RSN1524_CHICHI_TCU095-E.AT2</td>
<td>3.2244</td>
<td></td>
</tr>
<tr>
<td>RSN1546_CHICHI_TCU122-E.AT2</td>
<td>3.9546</td>
<td></td>
</tr>
<tr>
<td>RSN1549_CHICHI_TCU129-E.AT2</td>
<td>2.0144</td>
<td></td>
</tr>
<tr>
<td>RSN1605_DUZCE_DZC180.AT2</td>
<td>2.3368</td>
<td></td>
</tr>
<tr>
<td>RSN3750_CAPEMEND_LFS270.AT2</td>
<td>3.718</td>
<td></td>
</tr>
<tr>
<td>RSN5827_SIERRA.MEX_MD0000.AT2</td>
<td>2.4069</td>
<td></td>
</tr>
<tr>
<td>RSN5829_SIERRA.MEX_RII000.AT2</td>
<td>2.7287</td>
<td></td>
</tr>
<tr>
<td>RSN5975_SIERRA.MEX_CX0360.AT2</td>
<td>3.6221</td>
<td></td>
</tr>
<tr>
<td>RSN5991_SIERRA.MEX_E10320.AT2</td>
<td>3.1185</td>
<td></td>
</tr>
<tr>
<td>RSN6890_DARFIELD_CMHSN10E.AT2</td>
<td>3.7356</td>
<td></td>
</tr>
<tr>
<td>RSN6893_DARFIELD_DFHSS17E.AT2</td>
<td>3.6641</td>
<td></td>
</tr>
<tr>
<td>RSN6906_DARFIELD_GDLCN55W.AT2</td>
<td>1.5617</td>
<td></td>
</tr>
<tr>
<td>RSN6911_DARFIELD_HORCN18E.AT2</td>
<td>1.9323</td>
<td></td>
</tr>
<tr>
<td>RSN6923_DARFIELD_KPOCN15E.AT2</td>
<td>3.4101</td>
<td></td>
</tr>
<tr>
<td>RSN8161_SIERRA.MEX_E12360.AT2</td>
<td>2.8477</td>
<td></td>
</tr>
</tbody>
</table>
Simulate structural response

general information
load the pre-defined simulation script
Simulate structural response

load the selected ground motions

Records.txt
Simulate structural response

set up the analysis

custom analysis script
Simulate structural response

define random variables
Simulate structural response

choose EDPs

run remotely!
Simulate structural response

collect results from DesignSafe
Simulate structural response

show EDPs for each analysis
Simulate structural response

show joint EDP distribution
Case study

example application: Buckling Restrained Braced Frames

1. Design an experiment  quoFEM
2. Calibrate a numerical component model  quoFEM
3. Simulate structural response  EE-UQ
4. Estimate damage and losses  PBE
setting: damage and loss assessment of a BRBF
objective: estimate damage and losses in an earthquake scenario
problem: connect response estimation with loss assessment
develop and use a custom damage and loss model for BRBF
PBE: conveniently run the whole workflow using pelican
Prepare:

• custom components for BRBF loss model
• building information
Estimate damage and loss

Prepare:

• custom components for BRBF loss model
• building information

```json
{
  "Name": "Steel Buckling Restrained Brace (BRB), Single Diagonal brace, Weight of brace > 41 plf and < 99 plf.",
  "QuantityUnit": [
    1,
    "EA"
  ],
  "Directional": true,
  "Correlated": false,
  "EDP": {
    "Type": "Story Drift Ratio",
    "Unit": [
      1,
      "ea"
    ],
    "Offset": 0
  },
  "GeneralInformation": {
    "ID": "B1033.111b",
    "Description": "None",
    "Author": "John Wallace",
    "Official": true,
    "DateCreated": "2012-10-12T16:47:42.0245683-07:00",
    "Approved": true,
    "Incomplete": false,
    "Notes": "None"
  }
}
```
B1033.111b.json
Estimate damage and loss

Prepare:

• custom components for BRBF loss model

• building information

```
"DSGroups": [
  
  "MedianEDP": 0.02,
  "Beta": 0.4,
  "CurveType": "Lognormal",
  "DSGroupType": "Single",
  "DamageStates": [
    
    "Weight": 1.0,
    "LongLeadTime": false,
    "Consequences": {
      "ReconstructionCost": {
        "Amount": [58395.7011, 39709.0768],
        "Quantity": [3.0, 7.0],
        "CurveType": "Normal",
        "Beta": 0.2986,
        "Bounds": [0, "None"]
      }
    }
  ]
]
```

B1033.111b.json
Estimate damage and loss

Prepare:
• custom components for BRBF loss model
• building information

replacement cost: $10,000,000
replacement time: 1000 days
population: 300
occupancy type: Commercial Office
types, quantities, locations of structural components and non-structural components
collapse modes and consequences
Estimate damage and loss

PBE - Performance Based Engineering Application

Loss Assessment Method
- General
- Components
- Collapse Modes

General Settings

Response Model
- Response Description:
  - EDP distributions: lognormal
  - Item: all results
  - Residuals: 5000

Additional Uncertainty:
- Ground Motion: 0.05
- Model: 0.3
- Detection Limit:
  - Inventory Drift: 0.15
  - Floor Acceleration

Damage Model
- Irreparable Residual Drift:
  - Yield Drift Ratios: 0.005
  - Median: 0.02
  - Log Standard Dev: 0.3

Collapse Probability:
- Approach: estimated
- Prescribed value:
- Basis: sampled EDP

Collapse Limits:
- Inventory Drift: 0.08
- Floor Acceleration

Loss Model
- Replacement Cost: 10000000
- Replacement Time: 1000

Decision variables of interest:
- Reconstruction Cost
- Reconstruction Time
- Red Tag Probability

Inhabitants:
- Occupancy Type: Commercial Office
- Peak Population: 50, 50, 50, 50, 50
- Custom distribution: Choose

Model Dependencies
- Perfect Correlation in...
  - Component Quantities: Independent
  - Component Fragilities: per ATC recommendation
  - Reconstruction Costs: Independent
  - Reconstruction Times: Independent
  - Injuries: Independent
  - Injuries and Fatalities: Independent

SimCenter

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Estimate damage and loss

PBE - Performance Based Engineering Application

Component Selection
- DL Data Folder: C:/Lehigh/Fragility Data
- Available Components: 60/12.023
- Selected Components: B1031.001

Component Details
- Name: Bolted shear tab gravity connections
- Description: Coating is on a per connection basis. Coating does not include firewall removal or reapplication cost.
- EDP type: Story Drift Ratio
- Median Quantity per Story: 1 EA
- Quantity Distribution: Normal
- Component Groups: 0.01
- Weights in direction 1:
- Weights in direction 2:

ID | Median Quantity | Quantity Distribution | Groups in dir 1 | Groups in dir 2
--- | --------------- | ---------------------- | --------------- | ---------------
B1031.001 | 42, 42, 42, 42 | normal 0.001 | 0.07, 0.07, 0.07, 0.07, 0.07, 0.07 | 0.00, 0.07, 0.07, 0.07, 0.07, 0.07
B1031.011c | 9, 9, 9, 9, 9, 9 | normal 0.011 | 0.11, 0.11, 0.11, 0.11 | 0.12, 0.11, 0.11, 0.11
B1031.021c | 9, 9, 9, 9, 9, 9 | normal 0.011 | 0.11, 0.11, 0.11, 0.11 | 0.12, 0.11, 0.11, 0.11
B1033.111b | 0.8, 0.8, 0.8, 0.8 | normal 0.011 | 0.125, 0.125, 0.125, 0.125 | 0.125, 0.125, 0.125, 0.125
B2202.002 | 110, 110, 110, 110 | normal 0.1 | 0.23 | 0.77
C1011.011a | 6.375, 6.375, 6.375, 6.375, 6.375 | normal 0.1 | 0.23 | 0.77
C2011.001a | 0.378, 0.378, 0.378, 0.378, 0.378, 0.378 | normal 0.1 | 0.23 | 0.77
C2022.003a | 10.554, 10.554, 10.554, 10.554, 10.554 | normal 0.1 | 0.23 | 0.77
C2044.002 | 12, 12, 12, 12, 12 | normal 0.001 | 1.0 | 1.0
D1014.011 | 1, 0, 0, 0, 0 | normal 0.001 | 1.0 | 1.0
Estimate damage and loss

PBE - Performance Based Engineering Application

Loss Assessment Method

- FEMA P69

<table>
<thead>
<tr>
<th>Name</th>
<th>Probability</th>
<th>Affected Area</th>
<th>% Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>0.4</td>
<td>1.0</td>
<td>0.6, 0.4</td>
</tr>
<tr>
<td>Partial</td>
<td>0.6</td>
<td>0.1</td>
<td>0.4, 0.1</td>
</tr>
</tbody>
</table>

PBE

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Estimate damage and loss

### PBE - Performance Based Engineering Application

<table>
<thead>
<tr>
<th>Decision Variable</th>
<th>Mean</th>
<th>Standard Dev.</th>
<th>Minimum</th>
<th>10th Percentile</th>
<th>Median</th>
<th>90th Percentile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>event time: month</td>
<td>6.4552</td>
<td>3.44476</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>event time: weekday?</td>
<td>0.7294</td>
<td>0.444314</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>event time: hour</td>
<td>11.9724</td>
<td>6.94118</td>
<td>0</td>
<td>2</td>
<td>12</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>inhabitants:</td>
<td>87.7108</td>
<td>104.189</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>285</td>
<td>300</td>
</tr>
<tr>
<td>collapse?</td>
<td>0.0638</td>
<td>0.0615331</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>collapse: mode</td>
<td>0.730842</td>
<td>0.452414</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>red tagged?</td>
<td>0.972694</td>
<td>0.10472</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>reconstruction: irreparable?</td>
<td>0.239054</td>
<td>0.43365</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>reconstruction: cost impractical?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>reconstruction: cost</td>
<td>3.99527e+6</td>
<td>3.5625e+6</td>
<td>1.00473e+6</td>
<td>1.51521e+6</td>
<td>1.94116e+6</td>
<td>1e+7</td>
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<tr>
<td>reconstruction: time impractical?</td>
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<tr>
<td>reconstruction: time-sequential?</td>
<td>397.23</td>
<td>187.72</td>
<td>1000</td>
<td>1000</td>
<td>4590.66</td>
<td>5965.82</td>
<td>10477.9</td>
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<tr>
<td>reconstruction: time-parallel</td>
<td>609.231</td>
<td>242.364</td>
<td>249.093</td>
<td>383.179</td>
<td>569.825</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

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Estimate damage and loss
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Estimate damage and loss
### Research Tools

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>quoFEM</strong></td>
<td>Uncertainty Quantification and Optimization</td>
</tr>
<tr>
<td><strong>EE-UQ</strong></td>
<td>Structural Response Estimation under Earthquakes</td>
</tr>
<tr>
<td><strong>WE-UQ</strong></td>
<td>Structural Response Estimation under Wind</td>
</tr>
<tr>
<td><strong>CWE</strong></td>
<td>CFD Analysis for a Building</td>
</tr>
<tr>
<td><strong>PBE</strong></td>
<td>Damage and Loss Assessment for a Building</td>
</tr>
<tr>
<td><strong>rWHALE</strong></td>
<td>Damage and Loss Assessment for an Urban Region</td>
</tr>
</tbody>
</table>
Objectives

• Demonstrate use-cases of our research tools
• Get feedback on existing features
• Collect requests for new features
Example use of Research Tools

https://simcenter.designsafe-ci.org/research-tools

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