



Center for Computational Modeling and Simulation

Example use of Research Tools

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

Adam Zsarnóczay
adamzs@Stanford.edu



NSF award: CMMI 1612843

Objectives

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

Research Tools

- **quoFEM** Uncertainty Quantification and Optimization
 - **EE-UQ** Structural Response Estimation under Earthquakes
 - **WE-UQ** Structural Response Estimation under Wind
 - **CWE** CFD Analysis for a Building
-
- **PBE** Damage and Loss Assessment for a Building
 - **rWHALE** Damage and Loss Assessment for an Urban Region

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

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

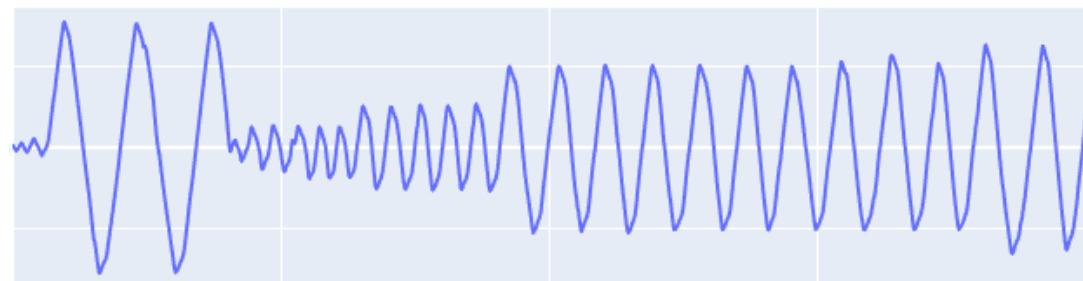
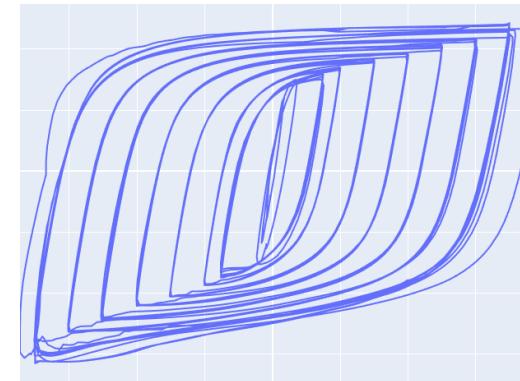
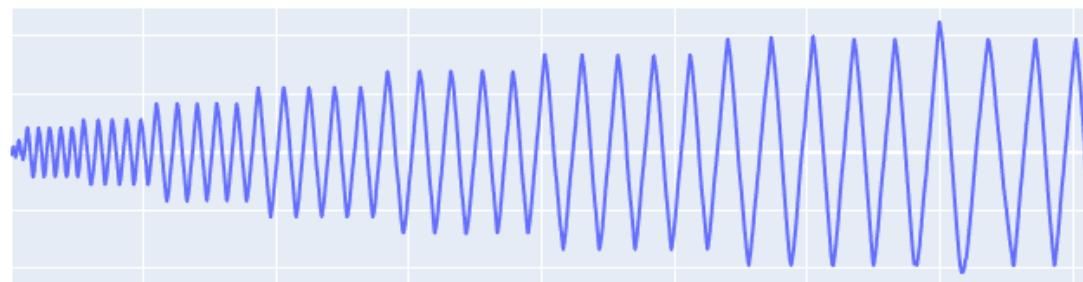
quoFEM

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

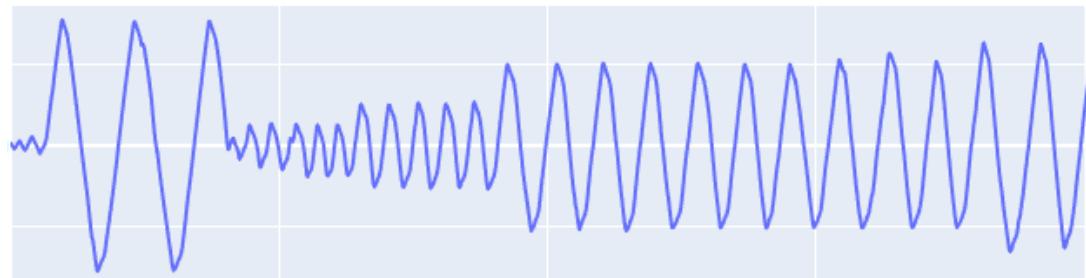
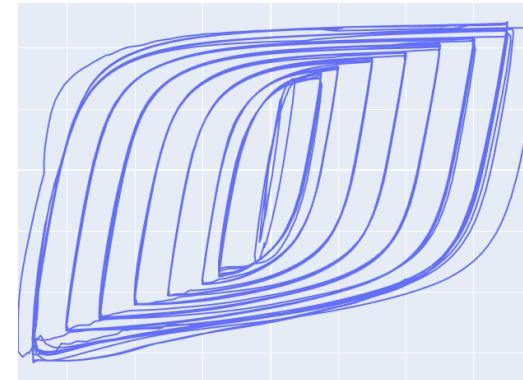
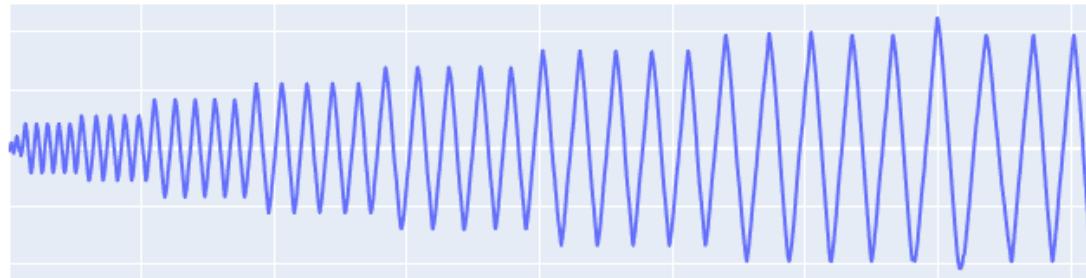
new load protocol



Design an experiment

quoFEM

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



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

Design an experiment

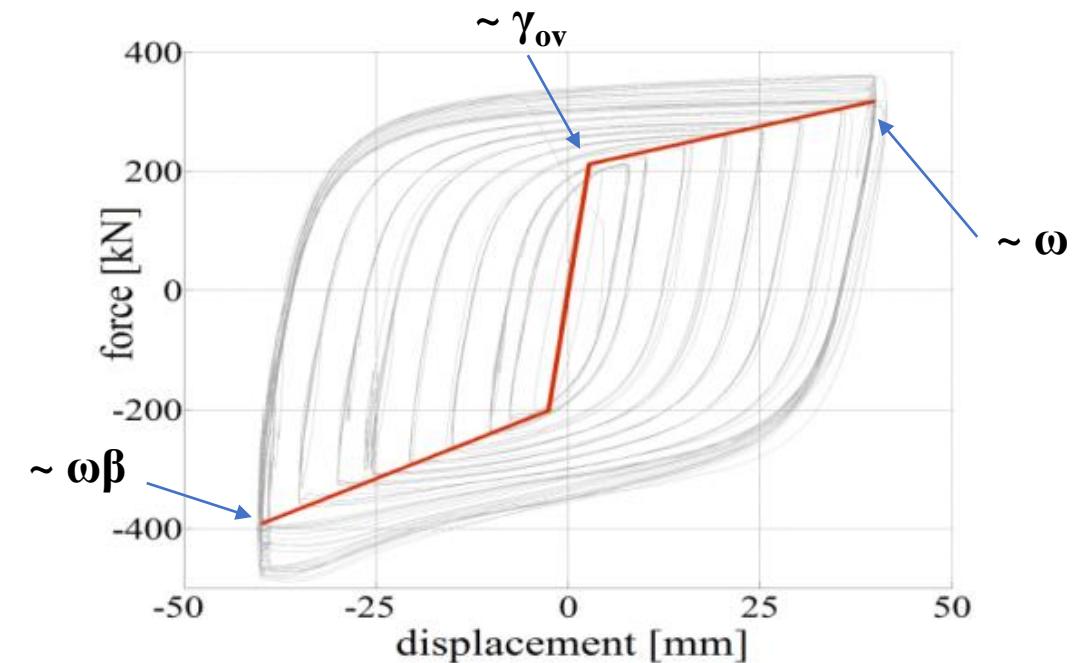
quoFEM

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



γ_{ov}	1.10 – 1.20
ω	1.35 – 1.75
β	1.01 – 1.30
ω_{iso}	0.05 – 0.30

Design an experiment

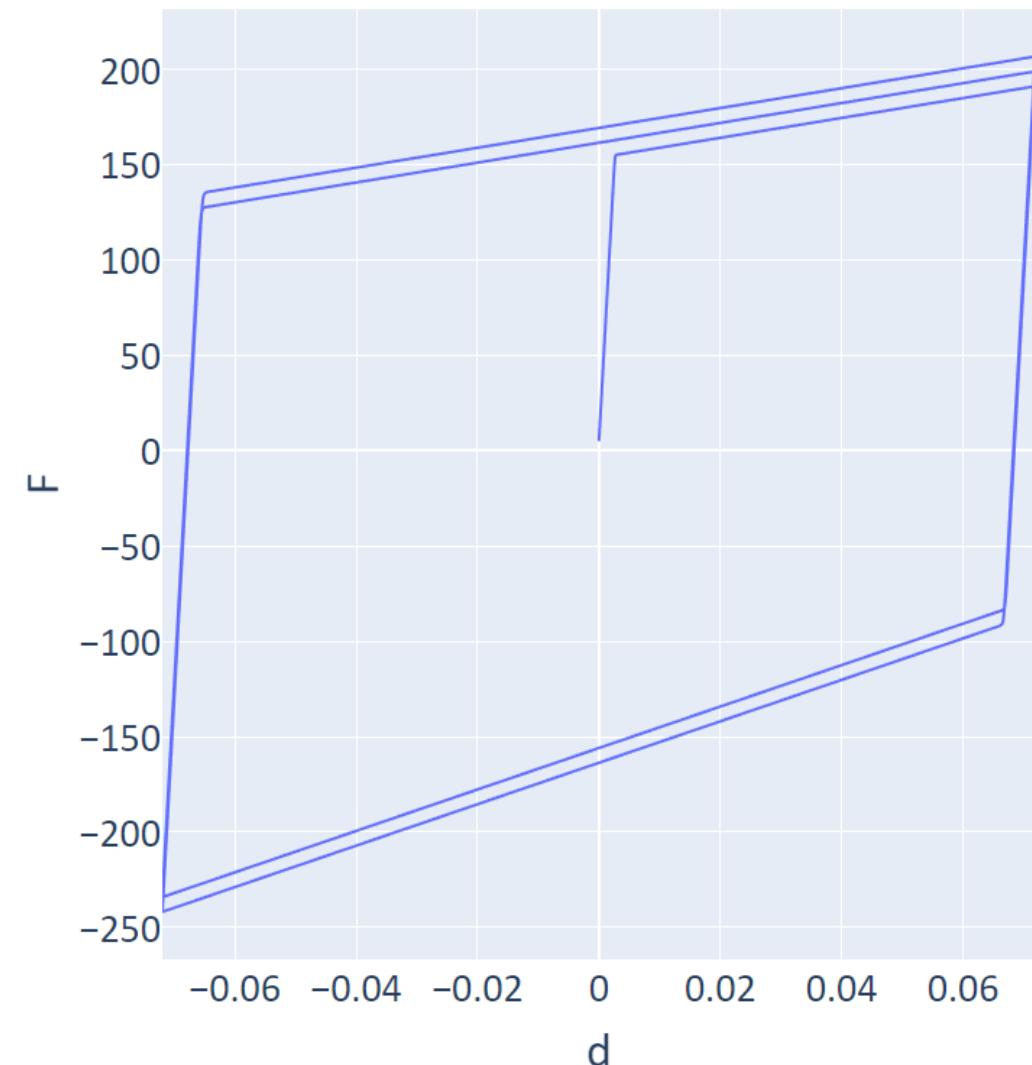
quoFEM

First, through literature review get:

- conservative bounds for attributes
- **simplified BRB model in OpenSees**

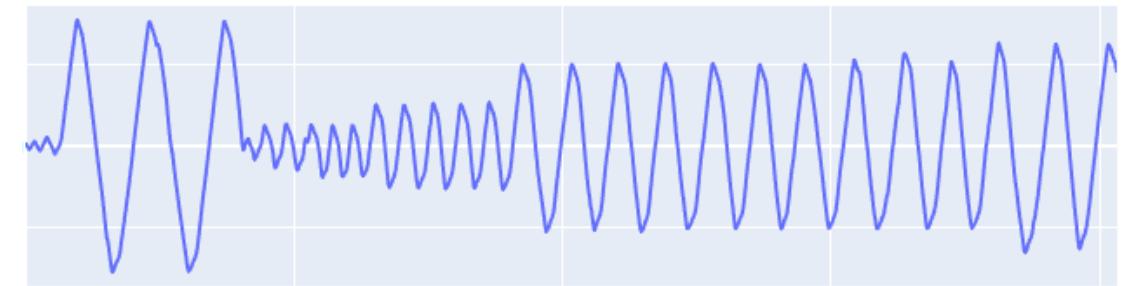
Then, prepare:

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



First, through literature review get:

- conservative bounds for attributes
- simplified BRB model in OpenSees



Then, prepare:

- **new load protocol**
- script to simulate experiment
- script to extract max forces

```
1 set disp_protocol { 0.125 -0.125 0.25 -0.25  
2 3.0 -3.0 3.0 -3.0 3.0 -0.125 0.25 -0.25  
3 0.5 -0.5 0.5 -0.5 0.5 -0.5 0.5 -0.5 0.5  
-0.5 1.0 -1.0 1.0 -1.0 1.0 -1.0 1.0 -1.0  
1.0 -1.0 2.0 -2.0 2.0 -2.0 2.0 -2.0 2.0  
-2.0 2.0 -2.0 2.0 -2.0 2.0 -2.0 2.0 -  
2.0 2.0 -2.0 2.0 -2.0 }
```

disp_protocol.tcl

Design an experiment

quoFEM

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

```
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
13
14 # hyperparameters
15 pset gammaOv 1.1
16 pset omega 1.55
17 pset omegaIso 0.4;
18 pset beta 1.15
19
20 set l [expr $l*$m]
21 set A_y [expr $A_y*$mm2]
22
23 set f_yk [expr 235.0 * $MPa]
24 set E_s [expr 210.0 * $GPa]
25
26 # calculate material props
27 set E_0 [expr $f_SM*$E_s];
28 set f_y [expr $gammaOv*$f_yk];
29 set eps_y [expr $f_y/$E_0]
```

BRB_response.tcl

Design an experiment

quoFEM

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

```
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_
64 -iso $b_i $rho_i $b_l $R_i $l_yp $ 
65 -ult $f_u $R_u $f_u $R_u
66
67 element corotTruss 0 0 100 $A_y $matBRB
68
69 recorder Node -file "force_disp.out" -time -node 1
70
71 pattern Plain 1 Linear {
72   load 100 [expr 1.0*$kN]
73 }
74
75 set IDctrlNode 100
76 set IDctrlDOF 1
77
78 constraints Plain
79 numberer RCM
80 system BandGeneral
81 test NormDispIncr 1.e-10 100
82 algorithm NewtonLineSearch -maxIter 100
```

BRB_response.tcl

Design an experiment

quoFEM

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**

```
1 #!/usr/bin/python
2 # written: adamzs 09/19
3
4 import numpy as np
5 import pandas as pd
6
7 def process_results(response):
8
9     res = pd.read_csv('force_disp.out',
10                       sep=' ', header=None, names=['F', 'd'])
11
12     F_c = np.abs(res['F'].min())
13     F_t = res['F'].max()
14
15     with open('results.out', 'w') as f:
16         f.write('{} {}'.format(F_c, F_t))
```

postprocess.py

1 -262.325 227.717

results.out

Design an experiment

quoFEM

load the pre-defined scripts

quoFEM Application Login

FEM Selection

Finite Element Application OpenSees

Input Script: ehigh/00_forward_example_BRB/BRB_response.tcl Choose **simulation script**

Postprocess Script: /Lehigh/00_forward_example_BRB/postprocess.py Choose **postproc. script**

Method Selection

Input Variables

Results

RUN **RUN at DesignSafe** **GET from DesignSafe** **Exit**

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 SimCenter NHERI
Center for Computational Modeling and Simulation

Design an experiment

quoFEM

select the task

available methods for
forward propagation

- Latin Hypercube Sampling
- Monte Carlo Sampling
- Importance Sampling
- Gaussian Process Regression

quoFEM Application Login

UQ Method Forward Propagation

Method: LHS
Samples: 1000
Seed: 923

Response Parameters

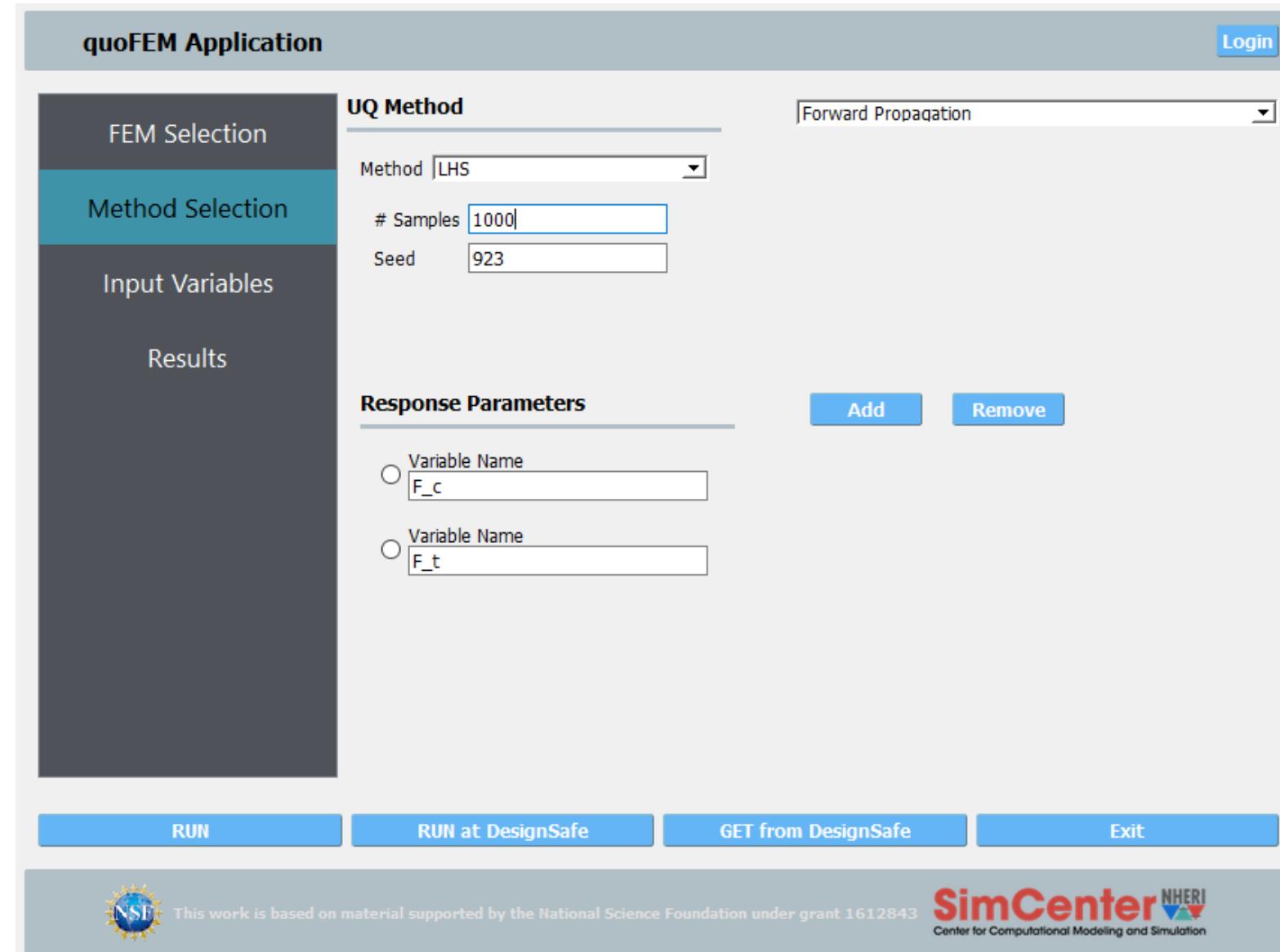
Add Remove

Variable Name: F_c
Variable Name: F_t

RUN RUN at DesignSafe GET from DesignSafe Exit

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Center for Computational Modeling and Simulation



Design an experiment

quoFEM

BRB_response.tcl

```
14 # hyperparameters  
15 pset gammaOv 1.1  
16 pset omega 1.55  
17 pset omegaIso 0.4;  
18 pset beta 1.15
```

supported distributions:

- Normal, Lognormal
- Uniform
- Beta
- Weibull
- Gumbel

quoFEM Application

Login

FEM Selection

Method Selection

Input Variables

Results

Add Remove Correlation Matrix

	Variable Name	Distribution	Min.	Max.
<input type="radio"/>	gammaOv	Uniform	1.35	1.75
<input type="radio"/>	omega	Uniform	1.01	1.3
<input type="radio"/>	omegalso	Uniform	1.1	1.2
<input type="radio"/>	beta	Uniform	0.05	0.3

Correlation Matrix

	gammaOv	omega	omegalso	beta
gammaOv	1.0	0	0	0
omega	0.0	1.0	0.75	0.0
omegalso	0.0	0.75	1.0	0.0
beta	0.0	0.0	0.0	1.0

RUN RUN at DesignSafe GET from DesignSafe Exit

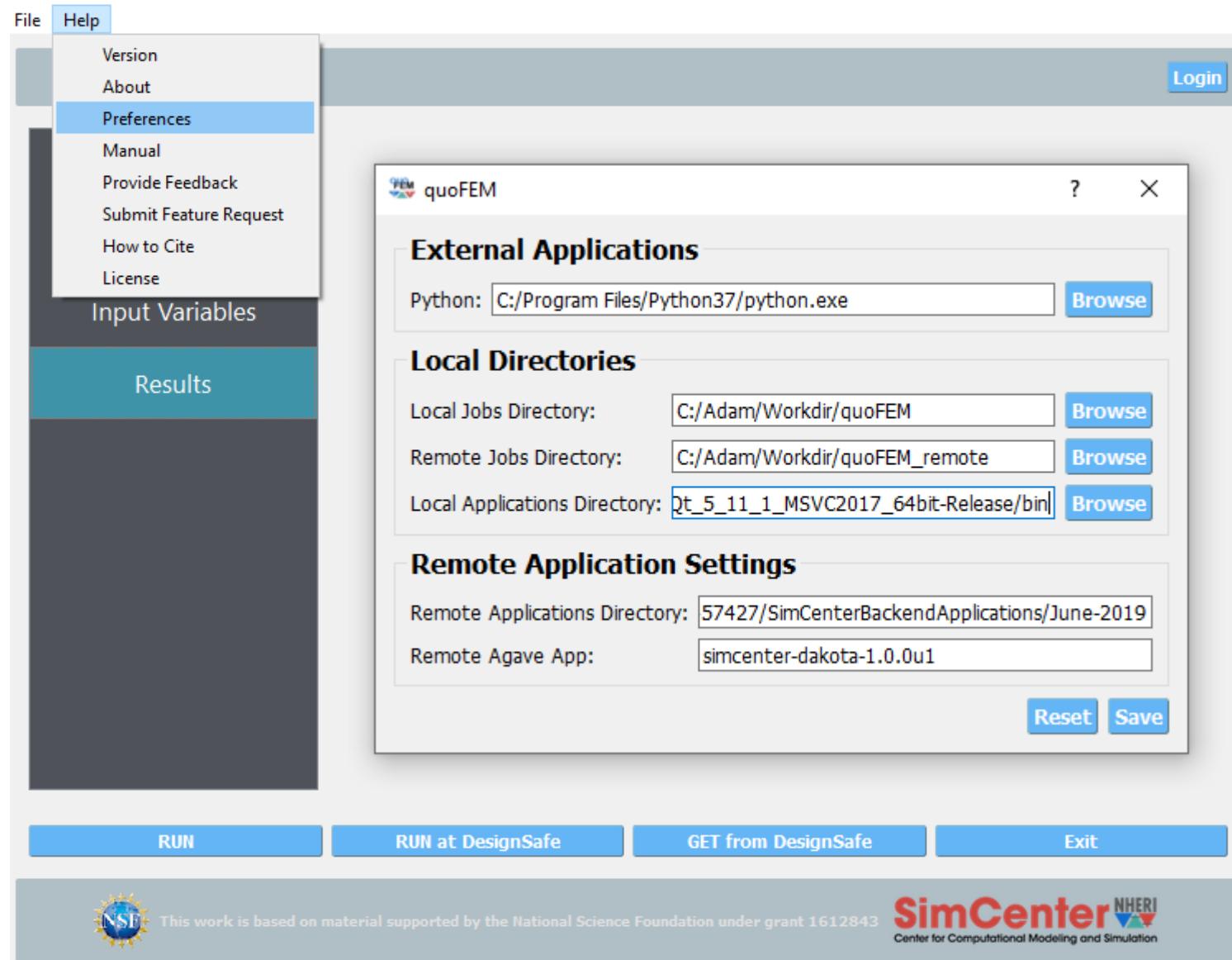
National Science Foundation This work is based on material supported by the National Science Foundation under grant 1612843 SimCenter NHERI Center for Computational Modeling and Simulation

Design an experiment

quoFEM

advanced users can

- specify their python interpreter
- edit working directories

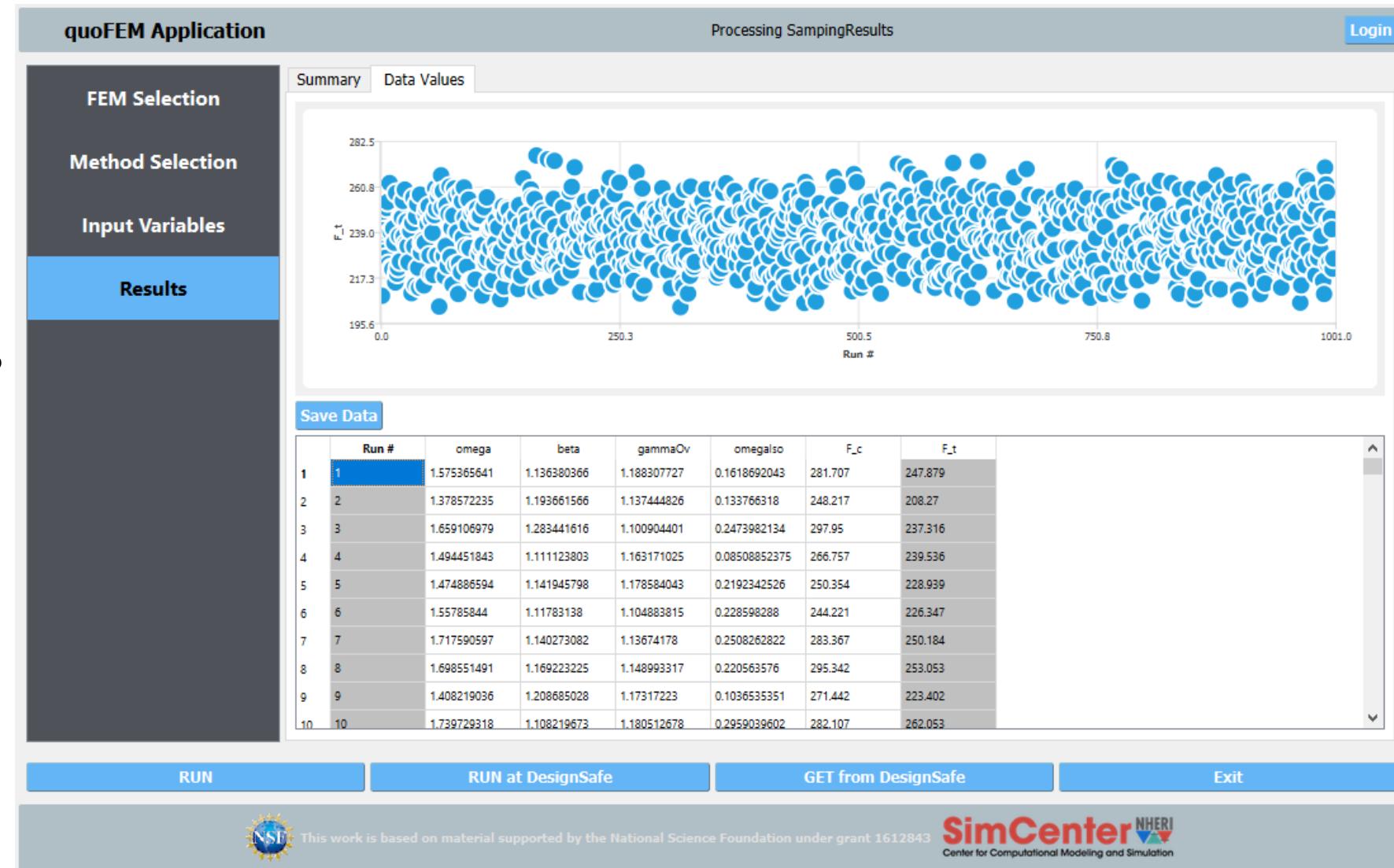


Design an experiment

quoFEM

result visualization

scatterplots show
sampled inputs and
corresponding outputs



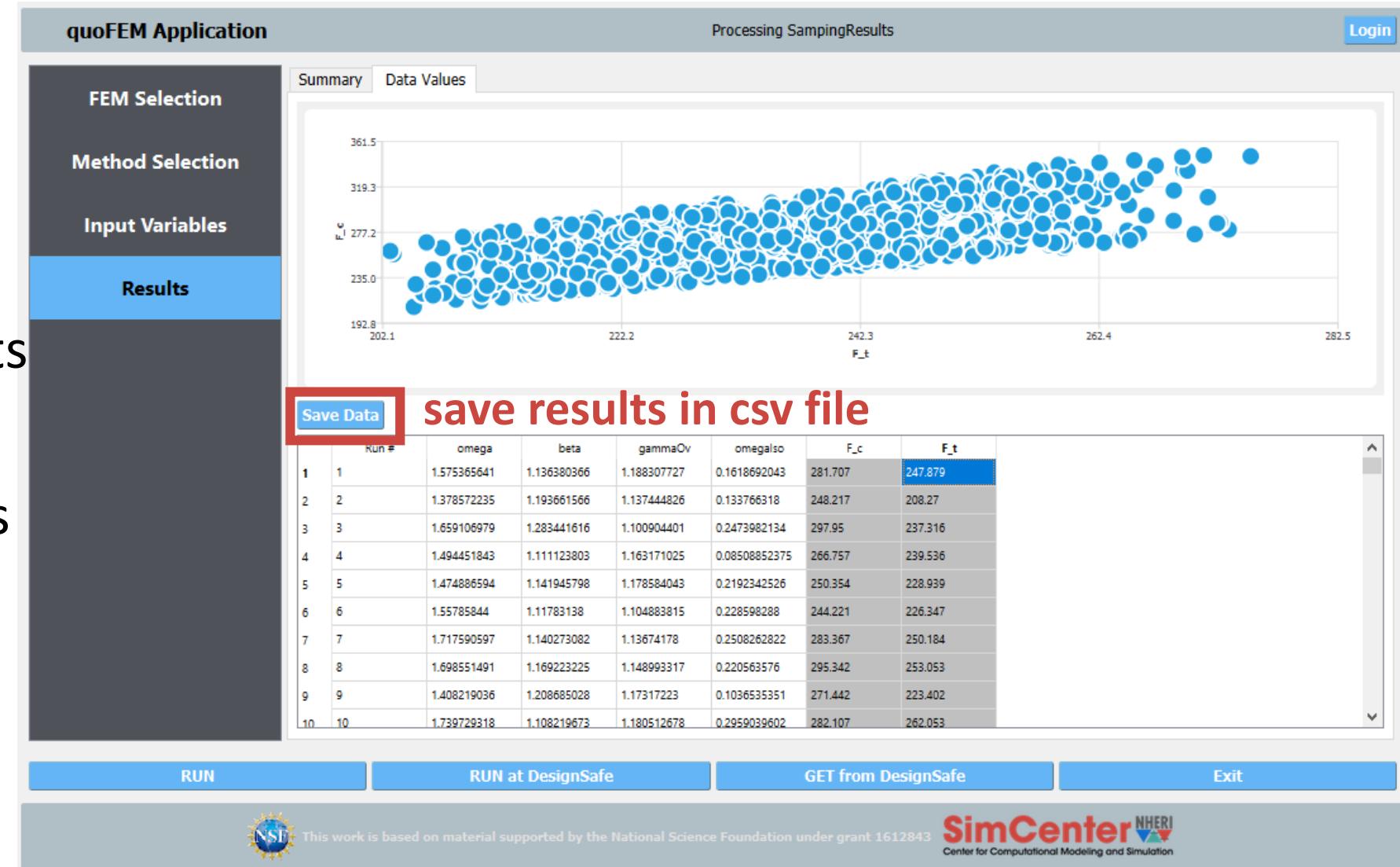
Design an experiment

quoFEM

result visualization

scatterplots show
sampled inputs and
corresponding outputs

and joint distributions



Design an experiment

quoFEM

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)
```

	Run #	omega	beta	gammaOv	omegalso	F_c	F_t
0	1	1.57537	1.13638	1.18831	0.161869	281.707	247.879
1	2	1.37857	1.19366	1.13744	0.133766	248.217	208.270
2	3	1.65911	1.28344	1.10090	0.247398	297.950	237.316
3	4	1.49445	1.11112	1.16317	0.085088	266.757	239.536
4	5	1.47489	1.14195	1.17858	0.219234	250.354	228.939
5	6	1.55786	1.11783	1.10488	0.228598	244.221	226.347
6	7	1.71759	1.14027	1.13674	0.250826	283.367	250.184
7	8	1.69855	1.16922	1.14899	0.220564	295.342	253.053
8	9	1.40822	1.20869	1.17317	0.103654	271.442	223.402
9	10	1.73973	1.10822	1.18051	0.295904	282.107	262.053

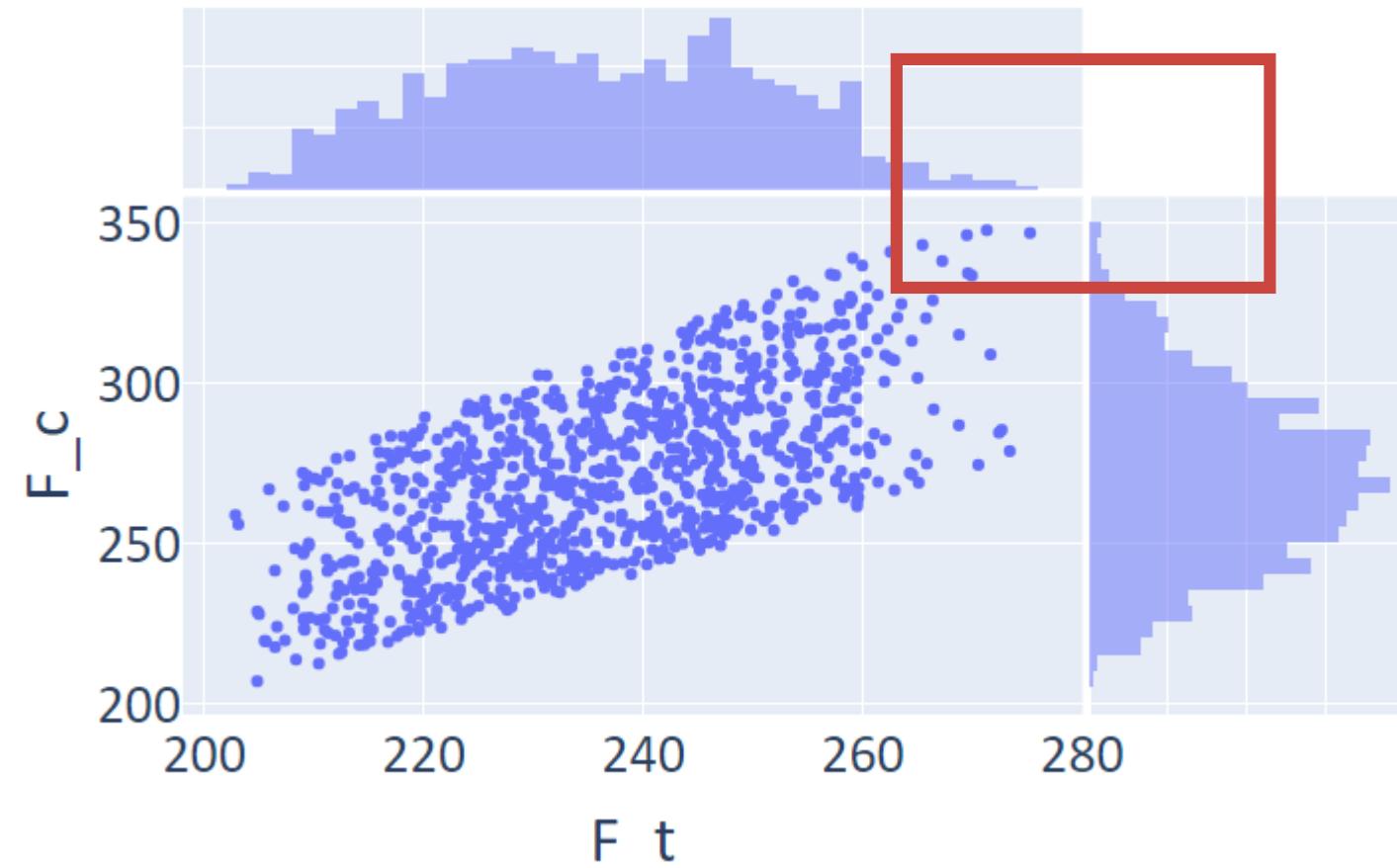
Design an experiment

quoFEM

advanced visualization
and data processing

joint distribution
with marginals

```
1 fig = px.scatter(res, x='F_t', y='F_c',  
2                   marginal_x='histogram', marginal_y='histogram',  
3                   height=500, width=800)  
4 fig['layout'].update(font=dict(family="Calibri", size=28))  
5 fig.show()
```

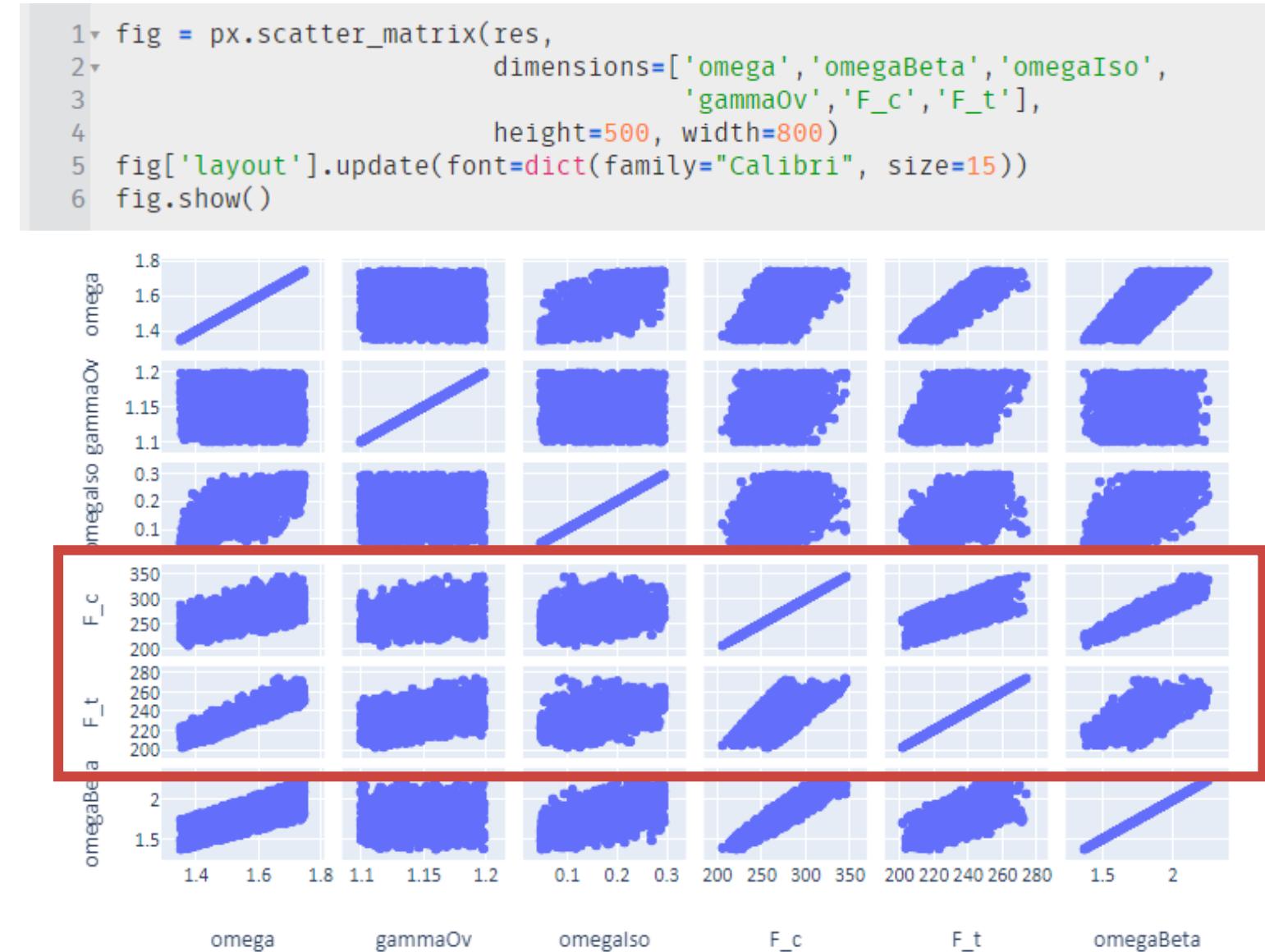


Design an experiment

quoFEM

advanced visualization
and data processing

use scatter matrix to
identify dependencies



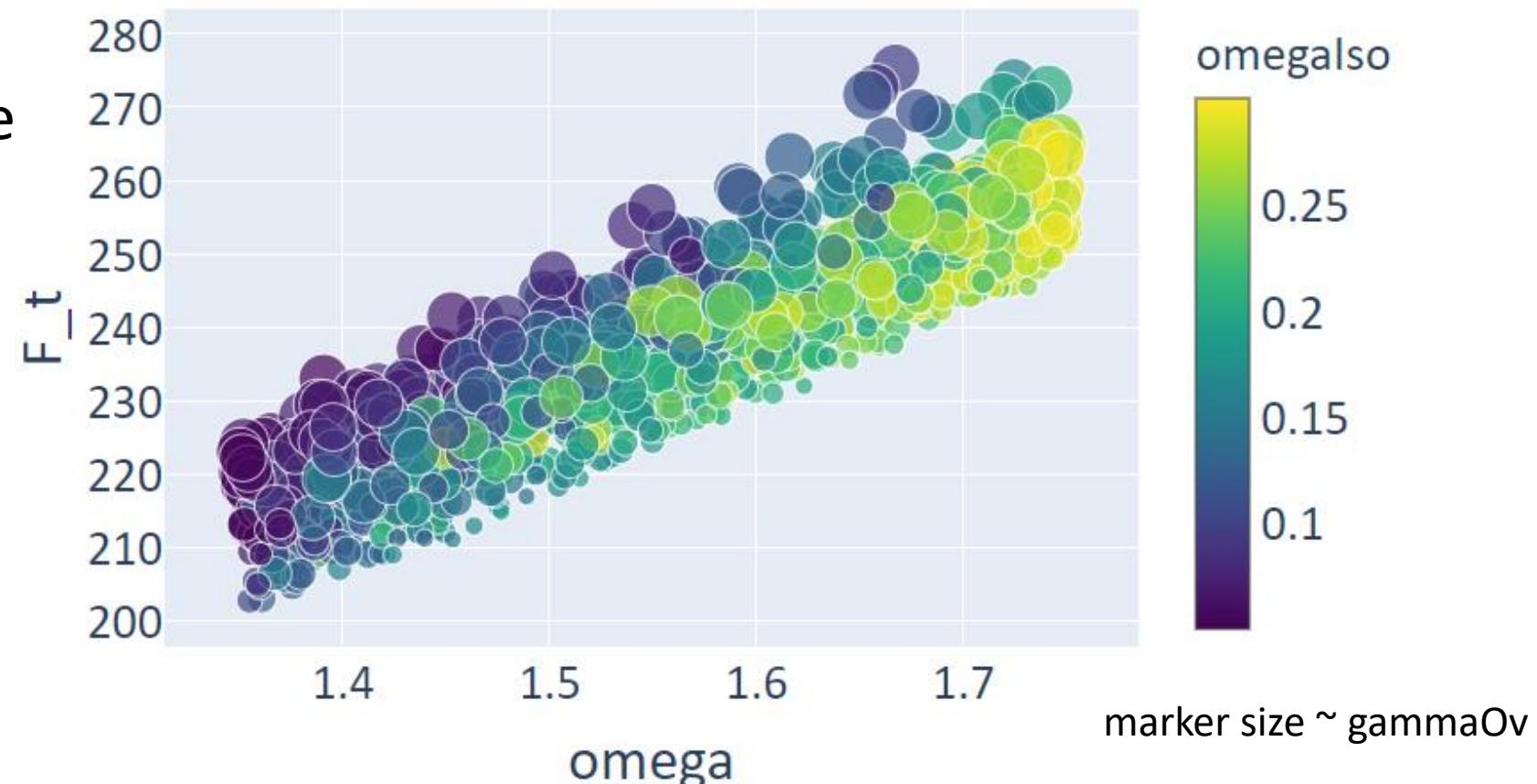
Design an experiment

quoFEM

advanced visualization
and data processing

use color and marker size
to visualize dependency
on 3 parameters

```
1 res['gammaOv_viz'] = np.log(res['gammaOv']*10.0-9.9)
2 fig2 = px.scatter(res, x='omega', y='F_t', color='omegalso',
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()
```



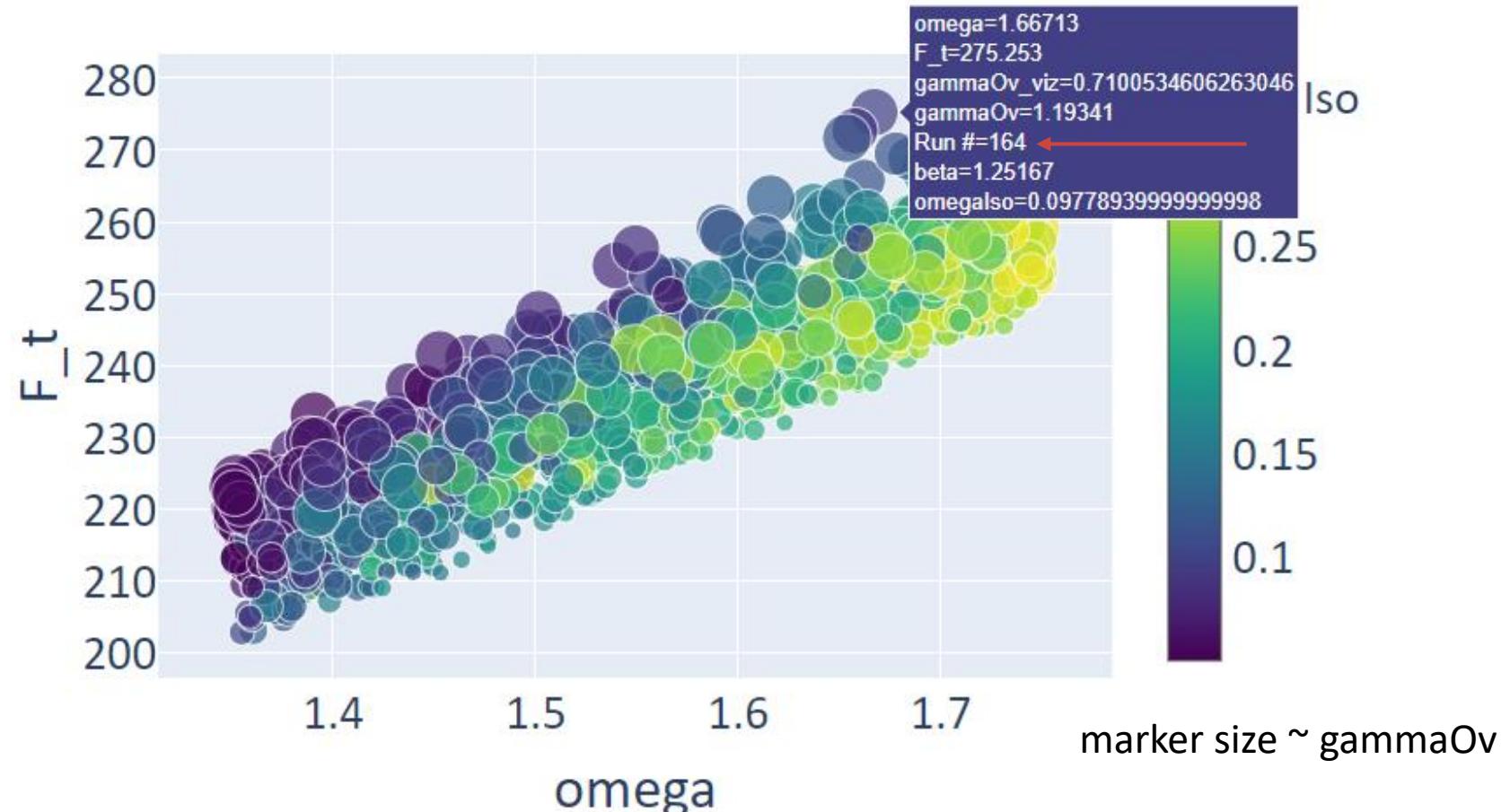
Design an experiment

quoFEM

advanced visualization
and data processing

raw data is available for
every simulation

```
1 res['gammaOv_viz'] = np.log(res['gammaOv']*10.0-9.9)
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()
```



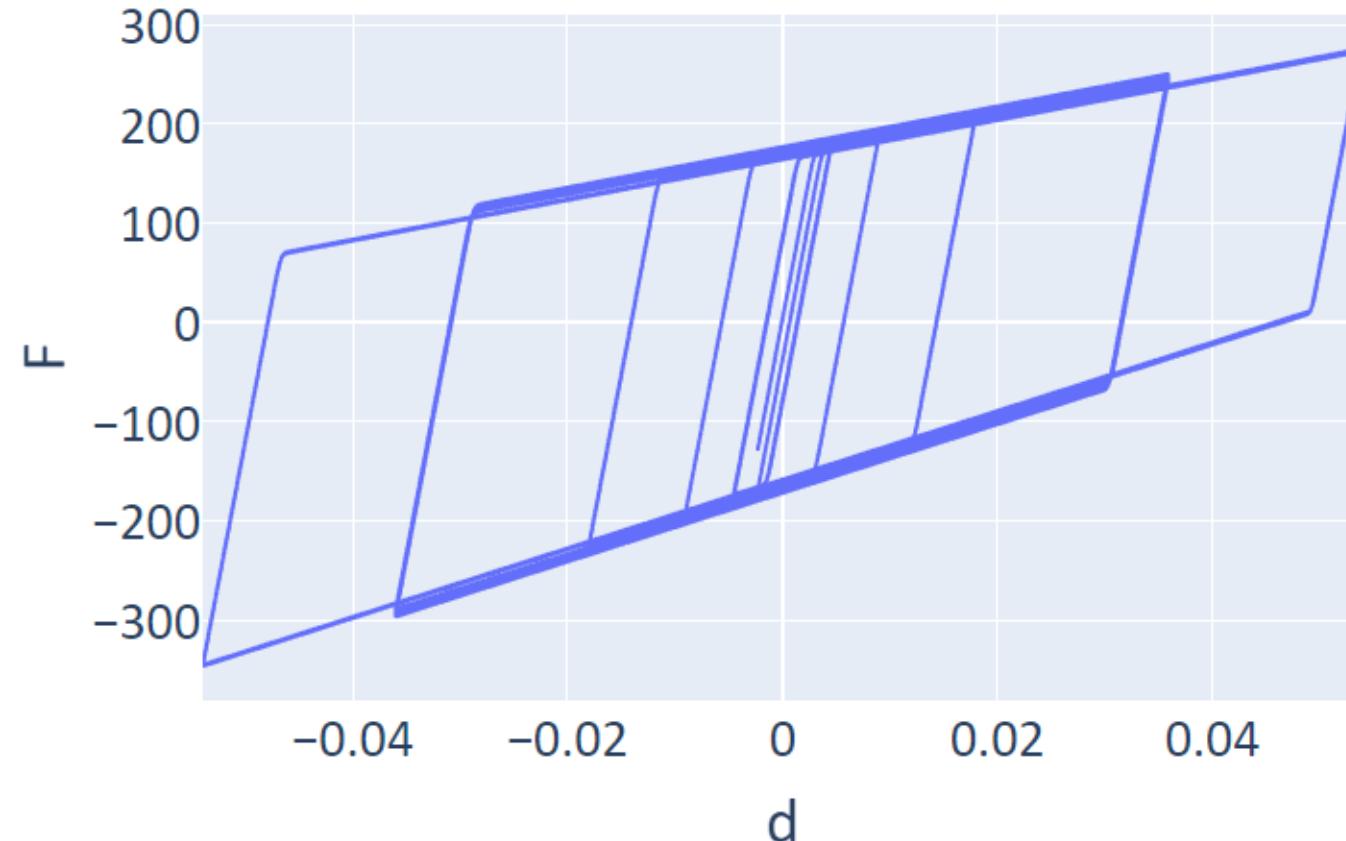
Design an experiment

quoFEM

advanced visualization
and data processing

raw data is available for
every simulation

```
1 output_file =  
2     "C:/Users/zsarn/Downloads/quoFEM/tmp.SimCenter/workdir.164/force_disp.out"  
3 res = pd.read_csv(output_file, sep=' ', header=None, names=['F', 'd'])  
4 fig = px.line(res, x='d', y='F', height=500, width=800)  
5 fig['layout'].update(font=dict(family="Calibri", size=28))  
6 fig.show()
```



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

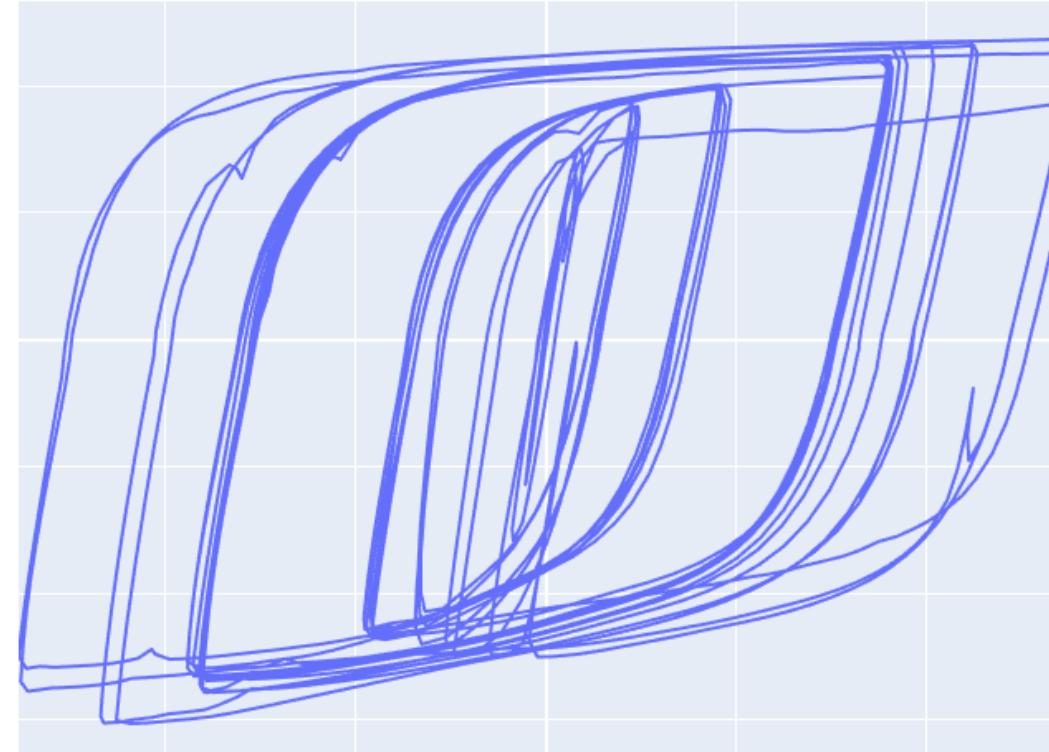
Calibrate component model

quoFEM

objective: calibrate Buckling Restrained Brace model parameters

problem: complex behavior, large number of material parameters

quoFEM: minimize error between simulation and reference result



Prepare:

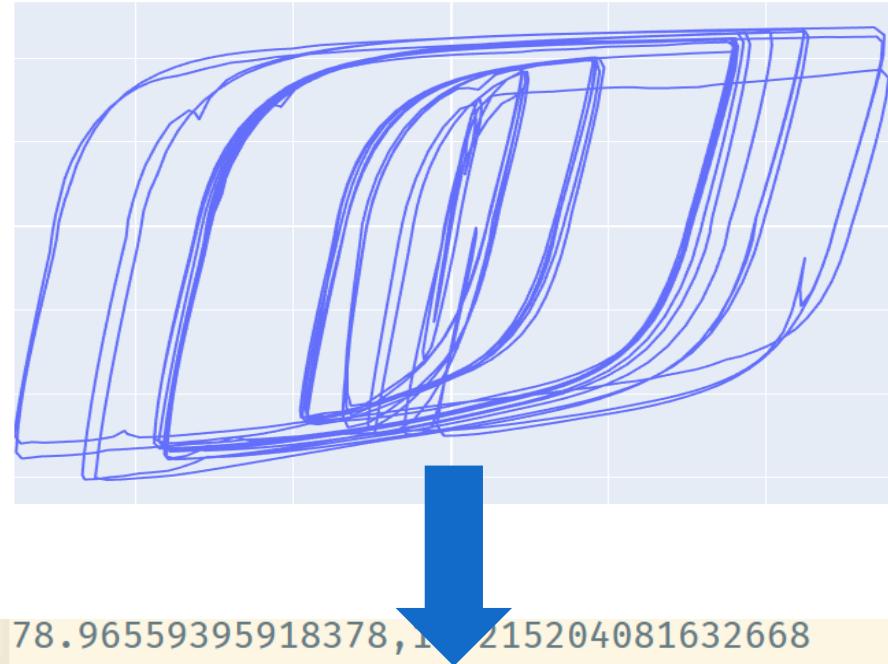
- reference data from test results
- complex BRB model in OpenSees
- updated simulation script
- script with the objective function

Calibrate component model

quoFEM

Prepare:

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



1 78.96559395918378, 1.215204081632668
2 52.411307755102094, 0.9329030612244907
3 26.90855167346942, 0.5383724489795925
4 4.500137142857147, 0.1784795918367349
5 -18.123096000000018, -0.21307142857142883
6 -38.138502857142896, -0.5226428571428579
7 -59.64269926530619, -0.8938724489795928
8 -74.79477551020416, -1.2276428571428586
9 -73.4783206530613, -1.2275918367346954
10 -43.2296948571429, -0.7959540816326539
11 -23.08952375510207, -0.4911122448979598

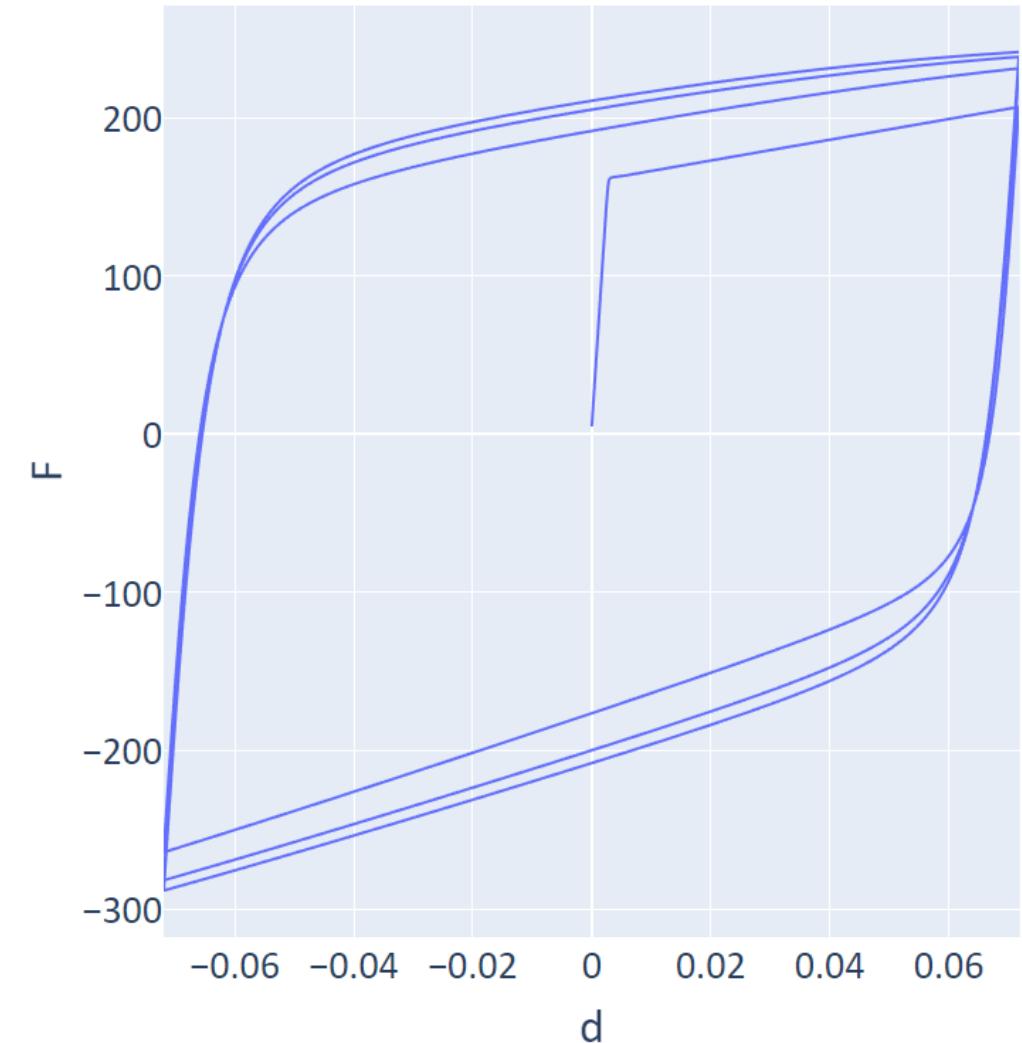
reference.txt

Calibrate component model

quoFEM

Prepare:

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



Calibrate component model

quoFEM

Prepare:

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

```
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
13
14 # hyperparameters|
15 pset gammaOv 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
23
24 set l [expr $l*$m]
25 set A_y [expr $A_y*$mm2]
26
27 set f_yk [expr 235.0 * $MPa]
28 set E_s [expr 210.0 * $GPa]
29
30 # calculate material props
31 set E_0 [expr $f_SM*$E_s];
32 set f_y [expr $gammaOv*$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**

```
1 #!/usr/bin/python
2 # written: adamzs
3
4 import numpy as np
5 import pandas as pd
6
7 def process_results(response):
8
9     data = pd.read_csv('reference.txt',
10                         header=None, names=['F_ref', 'd'])
11     # convert displacements to [m]
12     data['d'] = data['d']/1000.
13
14     sim = pd.read_csv('force_disp.out',
15                         sep=' ', header=None, names=['F', 'd'])
16     data['F_sim'] = sim['F']
17
18     eps_s = (data['F_sim'] - data['F_ref'])**2.
19     eps_srss = np.sqrt(np.sum(eps_s)/len(data.index))
20
21     with open('results.out', 'w') as f:
22         f.write("{:.6f}\n".format(eps_srss))
```

postprocess.py

Calibrate component model

quoFEM

load the pre-defined
scripts

The screenshot shows the quoFEM Application interface. On the left is a sidebar with tabs: FEM Selection (selected), Method Selection, Input Variables, and Results. The main area has a header "Finite Element Application" with a dropdown set to "OpenSees". Below it are two input fields: "Input Script" containing "C:/Lehigh/01_inverse_example_BRB/BRB_response.tcl" and "Postprocess Script" containing "C:/Lehigh/01_inverse_example_BRB/postprocess.py", each with a "Choose" button. At the bottom are four buttons: "RUN", "RUN at DesignSafe", "GET from DesignSafe", and "Exit".

simulation script

postproc. script

Processing Results

Login

FEM Selection

Method Selection

Input Variables

Results

Finite Element Application

OpenSees

Input Script

C:/Lehigh/01_inverse_example_BRB/BRB_response.tcl

Choose

Postprocess Script

C:/Lehigh/01_inverse_example_BRB/postprocess.py

Choose

RUN

RUN at DesignSafe

GET from DesignSafe

Exit

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Calibrate component model

quoFEM

select the task

Gauss-Newton is a
gradient-based
optimization method

we are also adding
Bayesian methods
for solving the
inverse problem

quoFEM Application Processing Results Login

FEM Selection Method Selection Input Variables Results

UQ Method Parameter Estimation

Method: OPT++GaussNewton

max # Iterations: 100

Convergence Tol: 0.001

Response Parameters

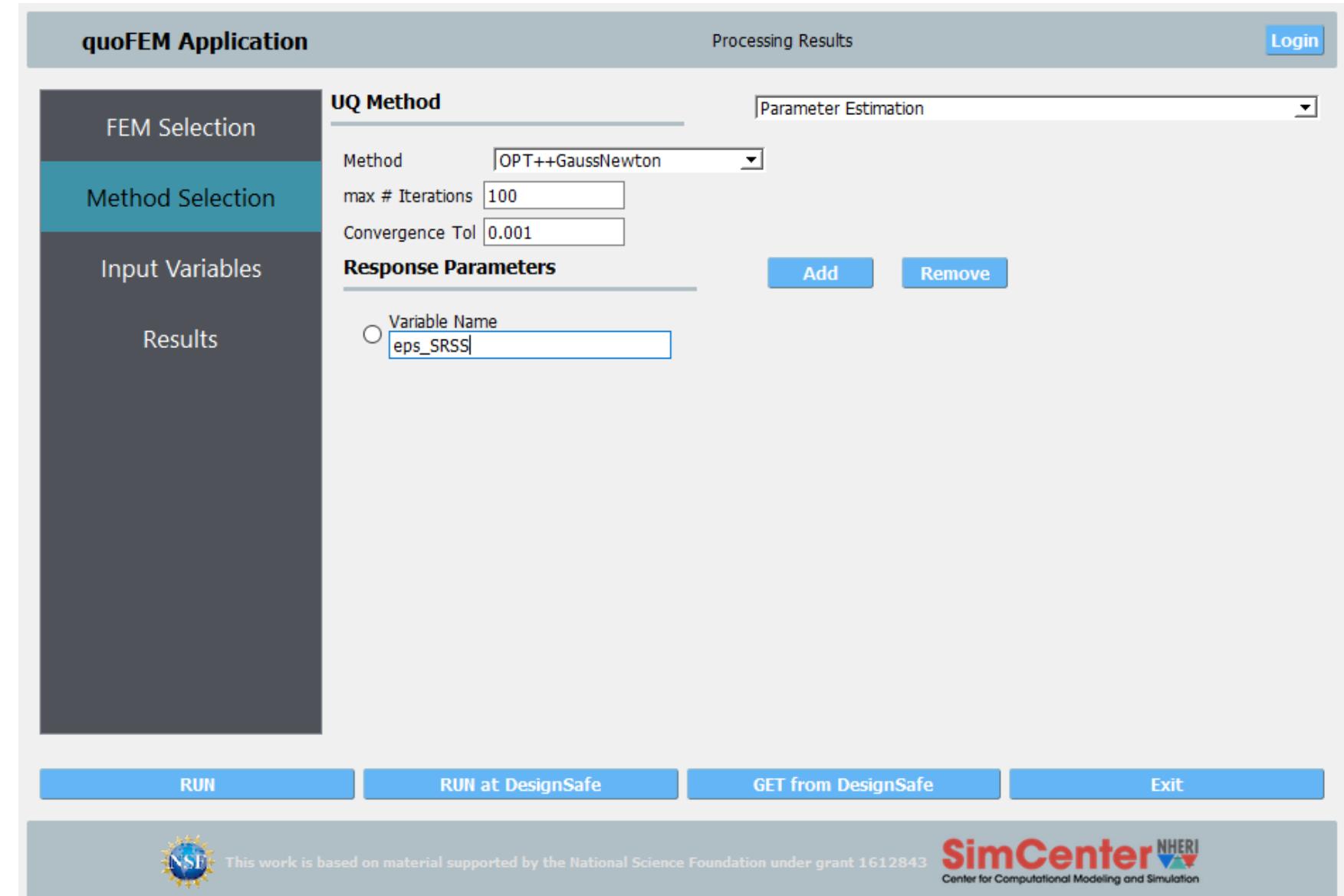
Add Remove

Variable Name: eps_SRSS

RUN RUN at DesignSafe GET from DesignSafe Exit

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Calibrate component model

quoFEM

```
12  
14 # hyperparameters  
15 pset gammaOv 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
```

quoFEM Application Processing Results Login

FEM Selection Method Selection Input Variables Results

Input Random Variables

Add	Remove	Correlation Matrix		
Variable Name gammaOv	Distribution ContinuousDesign	Lower Bound 1.1	Upper Bound 1.2	Initial Point 1.15
Variable Name omega	Distribution ContinuousDesign	Lower Bound 1.35	Upper Bound 1.75	Initial Point 1.4
Variable Name omegaIso	Distribution ContinuousDesign	Lower Bound 0.05	Upper Bound 0.3	Initial Point 0.2
Variable Name beta	Distribution ContinuousDesign	Lower Bound 1.01	Upper Bound 1.3	Initial Point 1.1
Variable Name rhoxi	Distribution ContinuousDesign	Lower Bound 0.1	Upper Bound 0.5	Initial Point 0.25
Variable Name rx1	Distribution ContinuousDesign	Lower Bound 0.9	Upper Bound 0.95	Initial Point 0.925
Variable Name fxult	Distribution ContinuousDesign	Lower Bound 1.5	Upper Bound 1.75	Initial Point 1.6
Variable Name fxultc	Distribution ContinuousDesign	Lower Bound 2	Upper Bound 3	Initial Point 2.5

RUN RUN at DesignSafe GET from DesignSafe Exit

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Center for Computational Modeling and Simulation

Calibrate component model

quoFEM

quoFEM Application Processing Results Login

FEM Selection Method Selection Input Variables Results

Summary	General	Data Values
Name	Best Parameter	gammaOv
	1.2	
Name	Best Parameter	omega
	1.36955	
Name	Best Parameter	omegaIso
	0.272546	
Name	Best Parameter	beta
	1.1156	
Name	Best Parameter	rholi
	0.265941	
Name	Best Parameter	rx1
	0.931044	
Name	Best Parameter	fxult
	1.59433	
Name	Best Parameter	fxultc
	2.50006	

RUN RUN at DesignSafe GET from DesignSafe Exit

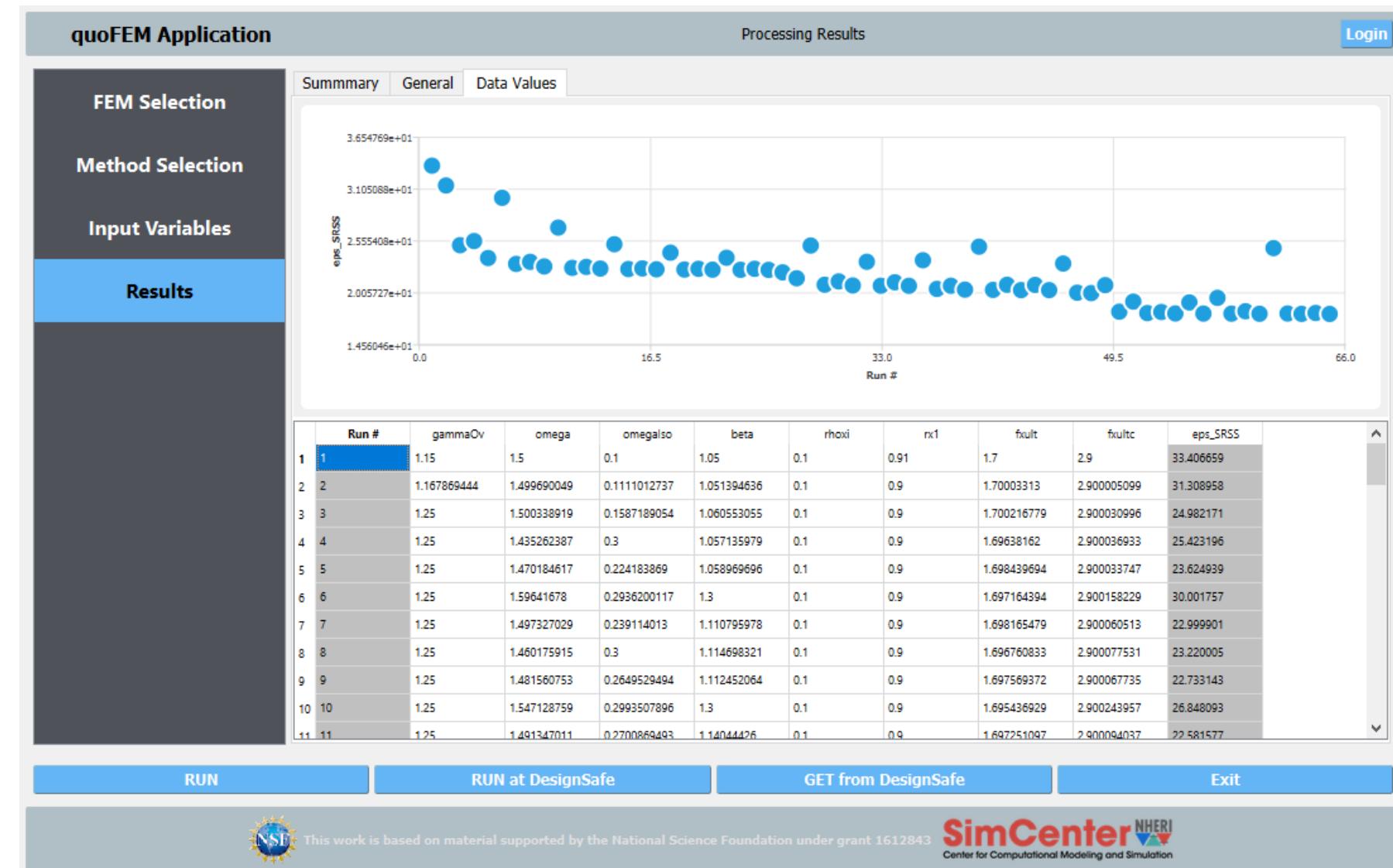
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Center for Computational Modeling and Simulation

Calibrate component model

quoFEM

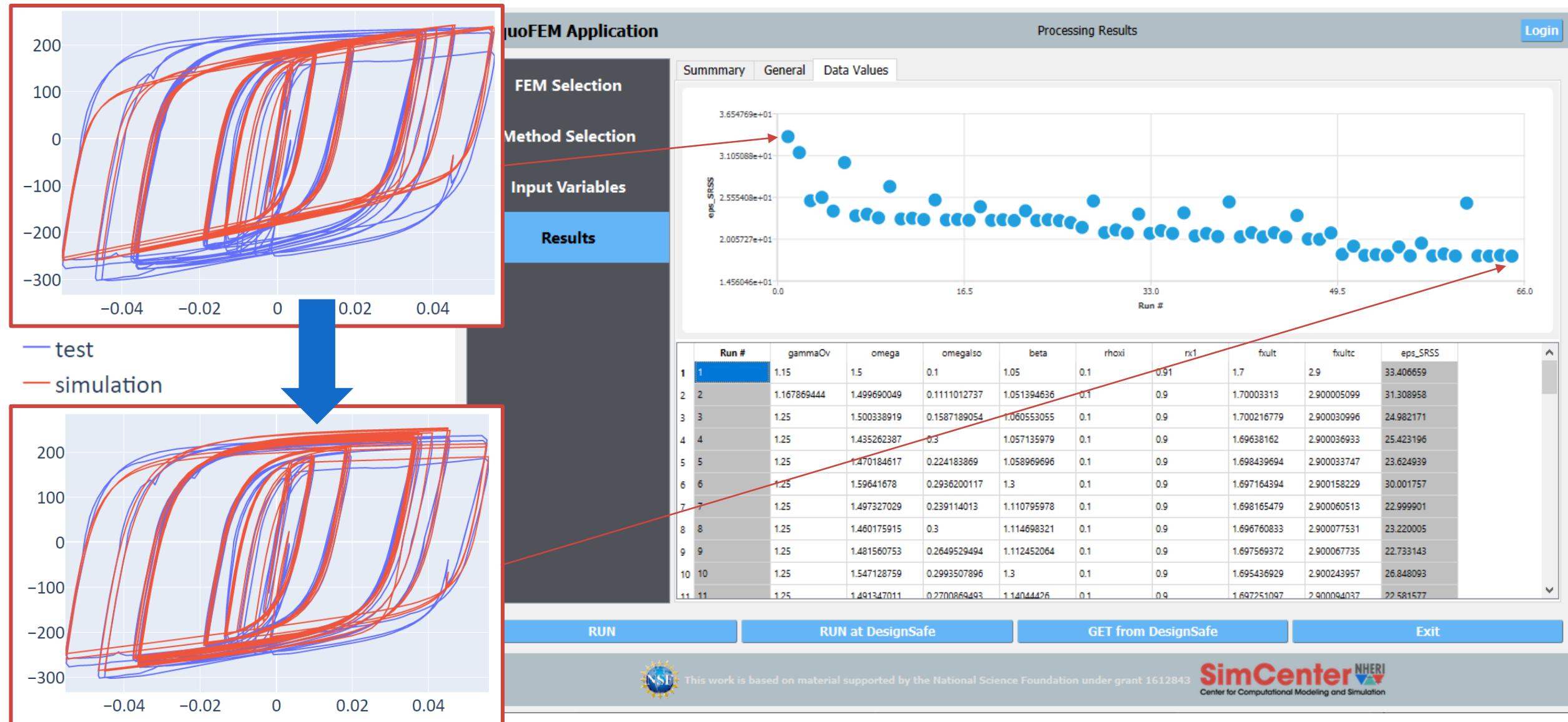
result visualization

scatterplot shows convergence



Calibrate component model

quoFEM



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

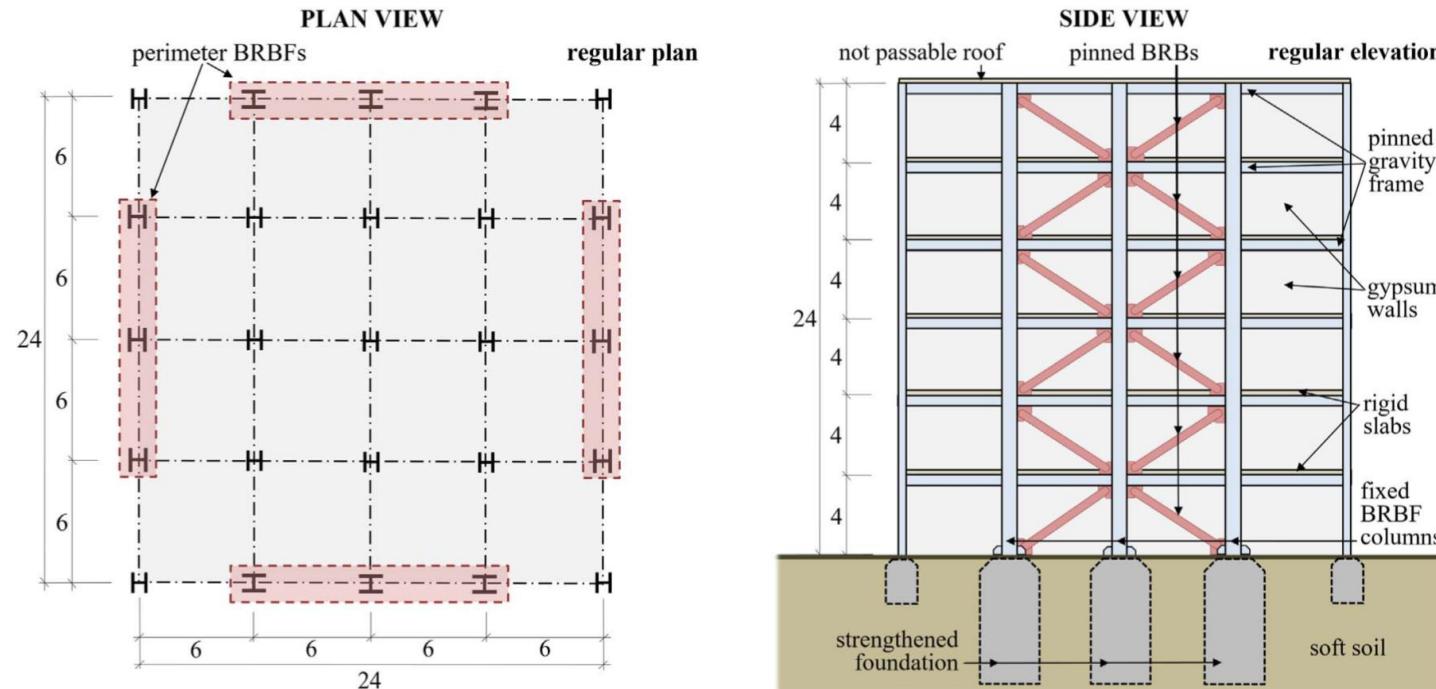
Simulate structural response

EE-UQ

objective: estimate interstory drifts and floor accelerations
in an earthquake scenario

problem: complex, computationally expensive calculations

EE-UQ: conveniently run simulations through DesignSafe



Prepare:

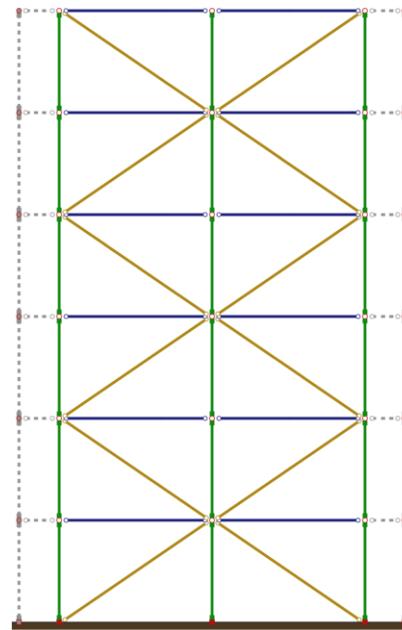
- BRBF model in OpenSees
- ground motion records
from PEER NGA2

Simulate structural response

EE-UQ

Prepare:

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



```
39 # load the core methods
40 source core/setAnalysis.tcl
41 source core/setRecorders.tcl
42 source core/Basic.tcl
43
44 # load the model info
45 source BRBF/Zsarnoczay_Vigh_2017/6AHHD.tcl
46
47 # specify the story height and the nodes
48 # for drift monitoring
49 set h {4.0 4.0 4.0 4.0 4.0 4.0}
50 set driftNodes {0 100 200 300 400 500 600}
51
52 # build the model
53 set pushover 0
54 source core/ModelBuilder.tcl
```

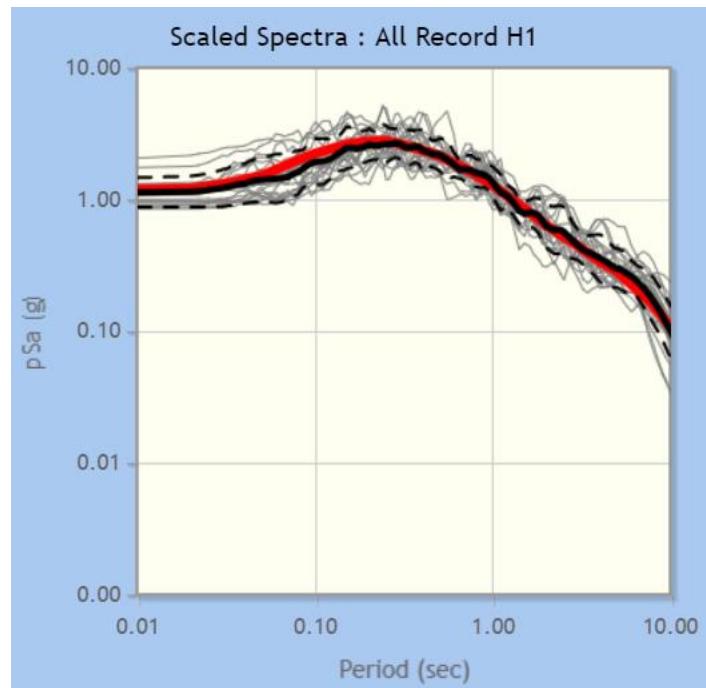
BRBF.tcl

Simulate structural response

EE-UQ

Prepare:

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



1	RSN143_TABAS_TAB-L1.AT2,1.4637
2	RSN1193_CHICHI_CHY024-E.AT2,3.1806
3	RSN1489_CHICHI_TCU049-E.AT2,3.9083
4	RSN1511_CHICHI_TCU076-E.AT2,3.1206
5	RSN1521_CHICHI_TCU089-E.AT2,3.5561
6	RSN1524_CHICHI_TCU095-E.AT2,3.2244
7	RSN1546_CHICHI_TCU122-E.AT2,3.9546
8	RSN1549_CHICHI_TCU129-E.AT2,2.0144
9	RSN1605_DUZCE_DZC180.AT2,2.3368
10	RSN3750_CAPEMEND_LFS270.AT2,3.7118
11	RSN5827_SIERRA.MEX_MD0000.AT2,2.4069
12	RSN5829_SIERRA.MEX_RII000.AT2,2.7287
13	RSN5975_SIERRA.MEX_CX0360.AT2,3.6221
14	RSN5991_SIERRA.MEX_E10320.AT2,3.1185
15	RSN6890_DARFIELD_CMHSN10E.AT2,3.7356
16	RSN6893_DARFIELD_DFHSS17E.AT2,3.6641
17	RSN6906_DARFIELD_GDLCN55W.AT2,1.5617
18	RSN6911_DARFIELD_HORCN18E.AT2,1.9323
19	RSN6923_DARFIELD_KPOCN15E.AT2,3.4101
20	RSN8161_SIERRA.MEX_E12360.AT2,2.8477

Records.txt

Simulate structural response

EE-UQ

general information

EE-UQ: Response of Building to Earthquake

Processing SamplingResults

Logout

GI

SIM

EVT

FEM

UQ

EDP

RES

Building Information

Name: BRBF

Properties

Stories: 6

Height: 0

Width: 0

Depth: 0

Plan Area: 500

Location

Latitude: 37.4200

Longitude: -122.1700

Units

Force: Newtons

Length: Meters

Temperature: Celsius

RUN

RUN at DesignSafe

GET from DesignSafe

Exit

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SimCenter NHERI
Center for Computational Modeling and Simulation

Simulate structural response

EE-UQ

load the pre-defined simulation script

EE-UQ: Response of Building to Earthquake

Processing SamplingResults

Logout

Building Model Input

OpenSees

Input Script: C:/Lehigh/02_response_estimation_BRBF/BRBF.tcl

List of CLine Nodes: 0 100 200 300 400 500 600

Spatial Dimension: 2

DOF at Nodes: 3

Choose

GI

SIM

EVT

FEM

UQ

EDP

RES

simulation script

RUN

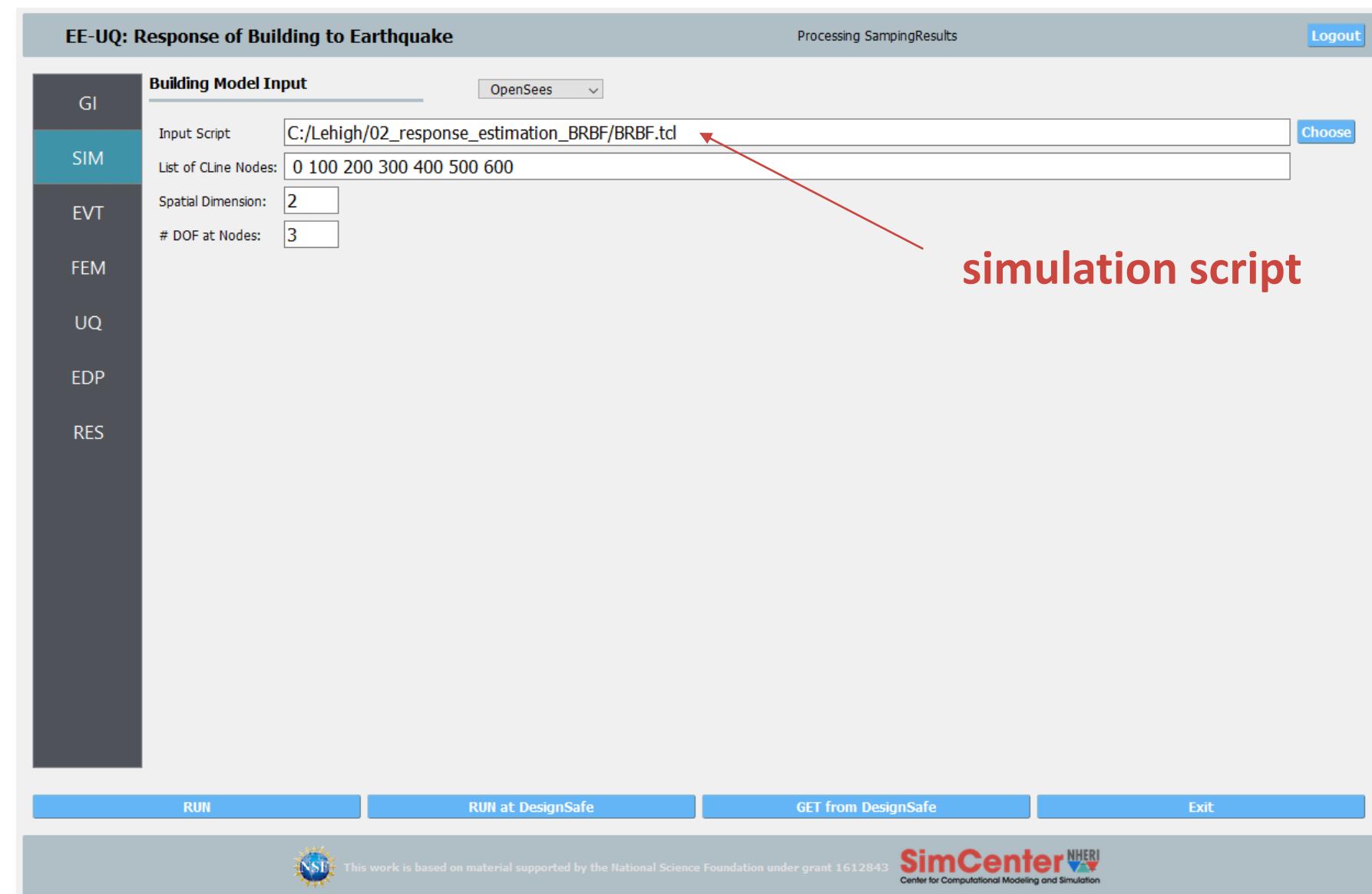
RUN at DesignSafe

GET from DesignSafe

Exit

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SimCenter NHERI
Center for Computational Modeling and Simulation



Simulate structural response

EE-UQ

load the selected ground motions

```
1 RSN143_TABAS_TAB-L1.AT2,1.4637
2 RSN1193_CHICHI_CHY024-E.AT2,3.1806
3 RSN1489_CHICHI_TCU049-E.AT2,3.9083
4 RSN1511_CHICHI_TCU076-E.AT2,3.1206
5 RSN1521_CHICHI_TCU089-E.AT2,3.5561
6 RSN1524_CHICHI_TCU095-E.AT2,3.2244
7 RSN1546_CHICHI_TCU122-E.AT2,3.9546
8 RSN1549_CHICHI_TCU129-E.AT2,2.0144
9 RSN1605_DUZCE_DZC180.AT2,2.3368
10 RSN3750_CAPEMEND_LFS270.AT2,3.718
11 RSN5827_SIERRA.MEX_MD0000.AT2,2.4069
12 RSN5829_SIERRA.MEX_RI1000.AT2,2.7287
13 RSN5975_SIERRA.MEX_CX0360.AT2,3.6221
14 RSN5991_SIERRA.MEX_E10320.AT2,3.1185
15 RSN6890_DARFIELD_CMHSN10E.AT2,3.7356
16 RSN6893_DARFIELD_DFHSS17E.AT2,3.6641
17 RSN6906_DARFIELD_GDLCN55W.AT2,1.5617
18 RSN6911_DARFIELD_HORCN18E.AT2,1.9323
19 RSN6923_DARFIELD_KPOCN15E.AT2,3.4101
20 RSN8161_SIERRA.MEX_E12360.AT2,2.8477
```

Records.txt

EE-UQ: Response of Building to Earthquake

Processing SamplingResults

Logout

GI SIM EVT FEM UQ EDP RES

List of PEER Events

Load Directory

143 File Stanford 2in50/RSN143_TABAS_TAB-L1.AT2 Choose DOF 1 Factor 1.4637

1193 File Stanford 2in50/RSN1193_CHICHI_CHY024-E.AT2 Choose DOF 1 Factor 3.1806

1489 File Stanford 2in50/RSN1489_CHICHI_TCU049-E.AT2 Choose DOF 1 Factor 3.9083

1511 File Stanford 2in50/RSN1511_CHICHI_TCU076-E.AT2 Choose DOF 1 Factor 3.1206

1521 File Stanford 2in50/RSN1521_CHICHI_TCU089-E.AT2 Choose DOF 1 Factor 3.5561

1524 File Stanford 2in50/RSN1524_CHICHI_TCU095-E.AT2 Choose DOF 1 Factor 3.2244

RUN RUN at DesignSafe GET from DesignSafe Exit

NSF This work is based on material supported by the National Science Foundation under grant 1612843 SimCenter NHERI Center for Computational Modeling and Simulation

Simulate structural response

EE-UQ

set up the analysis

EE-UQ: Response of Building to Earthquake

Processing SamplingResults

Logout

GI

SIM

EVT

FEM

UQ

EDP

RES

Algorithm: Newton

Integration: Newmark 0.5 0.25

ConvergenceTest: NormUnbalance

Tolerance: 0.01

Damping Ratio: 0.02

Analysis Script: on_BRBF/dynamic_analysis.tcl [Choose](#)

custom analysis script

RUN

RUN at DesignSafe

GET from DesignSafe

Exit

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SimCenter NHERI
Center for Computational Modeling and Simulation

Simulate structural response

EE-UQ

define random variables

EE-UQ: Response of Building to Earthquake

Processing SamplingResults

Logout

Sampling Method

Method: LHS

Samples: 20

Seed: 203

Random Variables

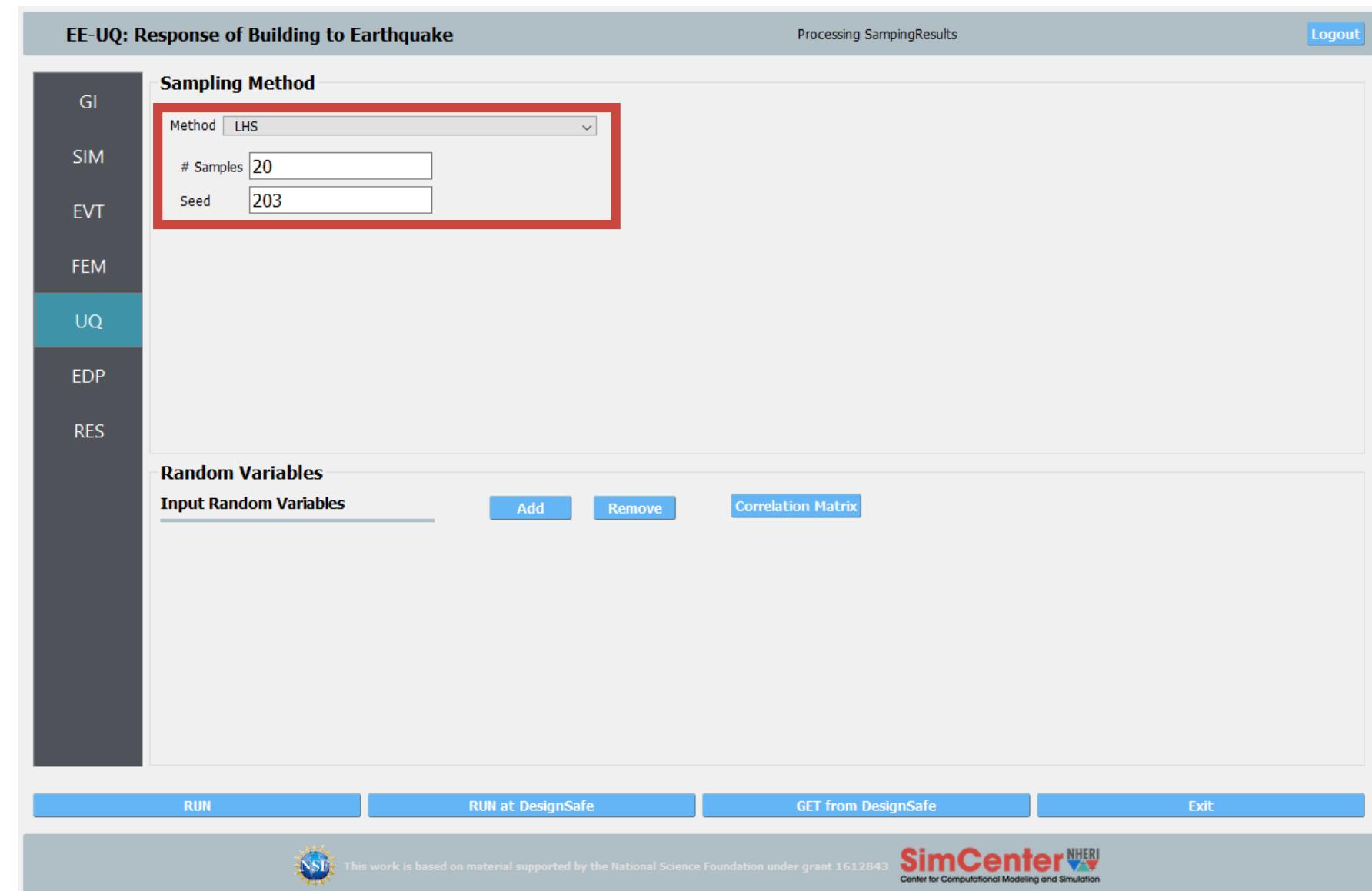
Input Random Variables

Add Remove Correlation Matrix

RUN RUN at DesignSafe GET from DesignSafe Exit

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SimCenter NHERI
Center for Computational Modeling and Simulation



Simulate structural response

EE-UQ

choose EDPs

run remotely!

EE-UQ: Response of Building to Earthquake

Processing SamplingResults

Logout

Engineering Demand Parameters Standard Earthquake

GI
SIM
EVT
FEM
UQ
EDP
RES

EE-UQ

job Name:

Num Nodes:

Total # Processes:

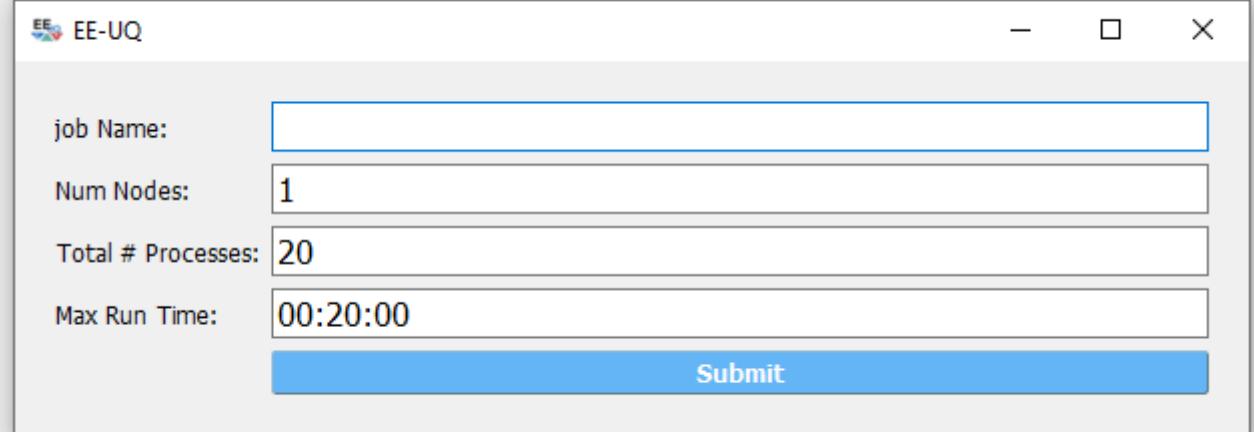
Max Run Time:

Submit

RUN RUN at DesignSafe GET from DesignSafe Exit

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SimCenter NHERI
Center for Computational Modeling and Simulation



Simulate structural response

EE-UQ

collect results from
DesignSafe

EE-UQ: Response of Building to Earthquake Successfully obtained list of submitted jobs Logout

Engineering Demand Parameters Standard Earthquake

GI
SIM
EVT
FEM
UQ
EDP
RES

Name STATUS ID Date Created

1 EE-UQ: Lt	FINISHED	c9bb85d-648f-449f-917f-9fce2	2019-07-25T15:47:35.000-05:00
2 EE-UQ: Lt	FINISHED	77a47816-b231-431e-a310-f2e2	2019-07-25T15:40:01.000-05:00
3 EE-UQ: Lt	FINISHED	994c3e9a-d6a4-4273-ab9e-35c2	2019-07-25T15:40:01.000-05:00
4 EE-UQ: Lt	FINISHED	99255844-cd37-420e-9cad-4ef2	2019-07-25T15:40:01.000-05:00
5 WE-UQ: t3	FINISHED	9d6c4efd-5597-4957-a302-b65	2019-07-25T15:47:35.000-05:00
6 PBE workflow2	FINISHED	cc0bd374-5664-422d-9705-37	2019-07-25T15:40:01.000-05:00
7 EE-UQ workflow	FINISHED	58fdd7b8-7215-40f1-944d-f99	2019-07-25T15:34:28.000-05:00
8 PBE workflowPBE_test	FINISHED	4923647912406618601-242ac	2019-06-18T17:20:27.000-05:00
9 PBE workflowPBE_test	FINISHED	8387246497817956841-242ac	2019-06-18T17:00:19.000-05:00
10 EE-UQUEUQ_test	FINISHED	8014210720913560041-242ac	2019-06-04T20:08:35.000-05:00
11 PBE workflow	FINISHED	6310681001505910295-242ac	2019-06-03T21:22:56.000-05:00
12 PBE workflowPBE_test_01	FINISHED	382000440874504681-242ac11d-0001-007	2019-06-03T19:16:41.000-05:00
13 PBE workflowPBE_test_01	FINISHED	8636236884325569001-242ac	2019-06-03T18:51:16.000-05:00
14 EE-UQ workflowtestWF3	FINISHED	8949878554387485161-242ac	2019-05-07T19:23:24.000-05:00
15 EE-UQ workflowtestWF2	FINISHED	7053970863403897321-242ac	2019-05-07T19:08:21.000-05:00
16 EE-UQ workflowWF_test1	FINISHED	9188448869395075561-242ac	2019-05-07T18:47:42.000-05:00
17 PBE workflow	FINISHED	1520062112107925415-242ac	2019-01-20T04:51:51.000-05:00

Refresh Job
Retrieve Data
Delete Job
Delete Job And Data

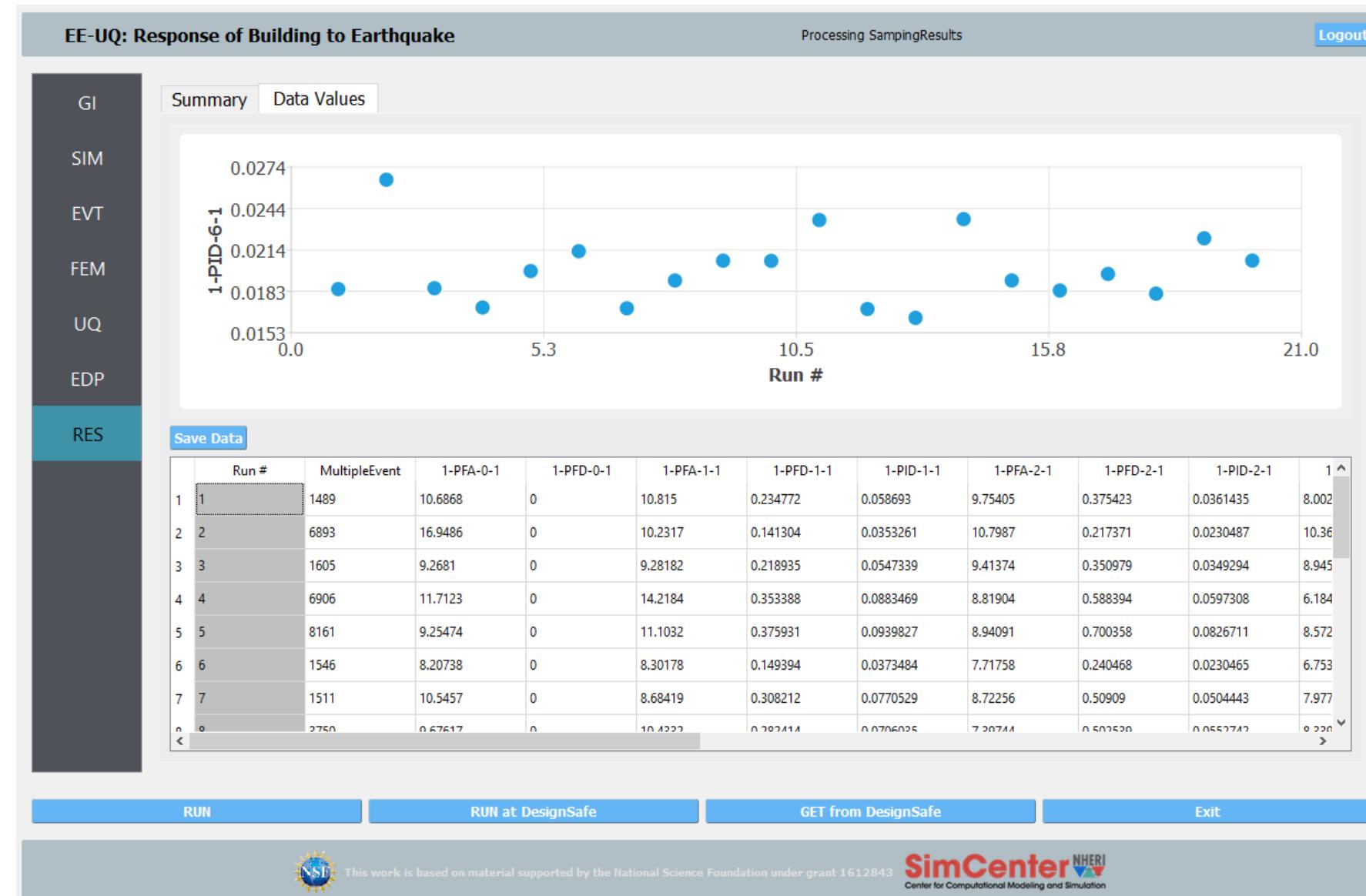
RUN RUN at DesignSafe **GET from DesignSafe** Exit

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Simulate structural response

EE-UQ

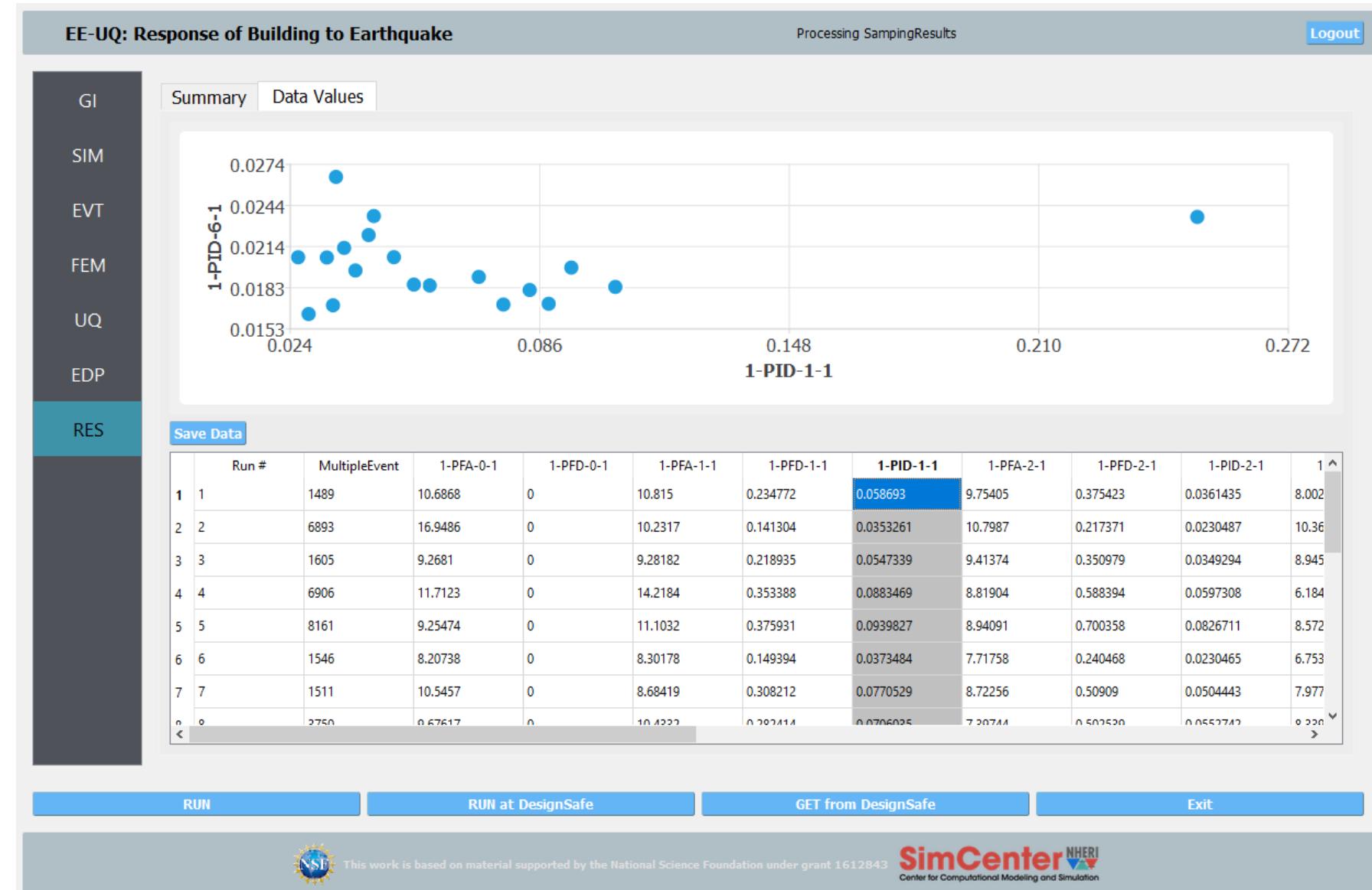
show EDPs for each analysis



Simulate structural response

EE-UQ

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

Estimate damage and loss

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 pelicun

Prepare:

- custom components for BRBF loss model
- building information

Estimate damage and loss

PBE

Prepare:

- **custom components for BRBF loss model**
- building information

```
1  {
2      "Name": "Steel Buckling Restrained Brace (BRB), Single
3          Diagonal brace, Weight of brace > 41 plf and < 99 plf.",
4          "QuantityUnit": [
5              1,
6              "EA"
7          ],
8          "Directional": true,
9          "Correlated": false,
10         "EDP": {
11             "Type": "Story Drift Ratio",
12             "Unit": [
13                 1,
14                 "ea"
15             ],
16             "Offset": 0
17         },
18         "GeneralInformation": {
19             "ID": "B1033.111b",
20             "Description": "None",
21             "Author": "John Wallace",
22             "Official": true,
23             "DateCreated": "2012-10-12T16:47:42.0245683-07:00",
24             "Approved": true,
25             "Incomplete": false,
26             "Notes": "None"
27         }
28     }
```

B1033.111b.json

Estimate damage and loss

PBE

Prepare:

- **custom components for BRBF loss model**
- building information

```
33 "DSGroups": [
34   {
35     "MedianEDP": 0.02,
36     "Beta": 0.4,
37     "CurveType": "LogNormal",
38     "DSGroupType": "Single",
39     "DamageStates": [
40       {
41         "Weight": 1.0,
42         "LongLeadTime": false,
43         "Consequences": {
44           "ReconstructionCost": {
45             "Amount": [
46               58395.7011,
47               39709.0768
48             ],
49             "Quantity": [
50               3.0,
51               7.0
52             ],
53             "CurveType": "Normal",
54             "Beta": 0.2986,
55             "Bounds": [
56               0,
57               "None"
58             ]
59           }
60         }
61       }
62     ]
63   }
64 ]
```

B1033.111b.json

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 Login

Loss Assessment Method FEMA P58

General Components Collapse Modes

General Settings

Response Model

response description:
 EDP distribution: lognormal
 Basis: all results
 Realizations: 5000

Additional Uncertainty:
 Ground Motion: 0.05
 Model: 0.3

Detection Limits:
 Interstory Drift: 0.15
 Floor Acceleration:

Damage Model

Irreparable Residual Drift:
 Yield Drift Ratio: 0.005
 Median: 0.02
 Log Standard Dev: 0.3

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

Collapse Limits:
 Interstory Drift: 0.08
 Floor Acceleration:

Loss Model

Replacement Cost: 10000000
 Replacement Time: 1000

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

Inhabitants:
 Occupancy Type: Commercial Office
 Peak Population: 50, 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
 btw. Rec. Cost and Time:
 Injuries: Independent
 btw. Injuries and Fatalities:
 Red Tag Probabilities: Independent

RUN **RUN at DesignSafe** **GET from DesignSafe** **Exit**

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Center for Computational Modeling and Simulation

Estimate damage and loss

PBE

PBE - Performance Based Engineering Application Login

Loss Assessment Method FEMA P58

GI General Components Collapse Modes

SIM

EVT

FEM

UQ

DL Selected

RES

Define building components

Component Selection

DL Data Folder: C:/Lehigh/Fragility Data Choose

Available Components: D5012.023I Add Add All

Selected Components: B1031.001 Remove Remove All

ID	Median Quantity	Quantity Distribution	Groups in dir 1	Groups in dir 2
B1031.001	42, 42, 42, 42, 42, 42	normal 0.001	0.07,0.07,0.07,0.07,0.07,0.08	0.08,0.07,0.07,0.07,0.07,0.07,0.0
B1031.011c	9, 0, 0, 0, 0, 0	normal 0.001	0.11,0.11,0.11,0.11	0.12,0.11,0.11,0.11,0.11
B1031.021c	9, 9, 9, 9, 9, 9	normal 0.001	0.11,0.11,0.11,0.11	0.12,0.11,0.11,0.11,0.11
B1033.111b	8, 8, 8, 8, 8, 8	normal 0.001	0.125,0.125,0.125,0.125	0.125,0.125,0.125,0.125
B2022.002	110, 110, 110, 110, 110, 110	normal 0.1	0.23	0.77
C1011.011a	6.375, 6.375, 6.375, 6.375, 6.375, 6.375,	normal 0.1	0.23	0.77
C3011.001a	0.378, 0.378, 0.378, 0.378, 0.378,	normal 0.1	0.23	0.77
C3032.003a	10.554, 10.554, 10.554, 10.554, 10.554,	normal 0.1		1.0
C3034.002	12, 12, 12, 12, 12, 12	normal 0.001		1.0
D1014.011	1, 0, 0, 0, 0, 0	normal 0.001		1.0

Component Details

Name: Bolted shear tab gravity connections

Description: Costing is on a per connection basis. Costing does not include fireproofing removal or reapplication cost.

EDP type: Story Drift Ratio

Median Quantity per Story: 1 EA

Quantity Distribution: family: cov:

Component Groups

Weights in direction 1:

Weights in direction 2:

RUN RUN at DesignSafe GET from DesignSafe Exit

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Estimate damage and loss

PBE

PBE - Performance Based Engineering Application [Login](#)

Loss Assessment Method [FEMA P58](#)

[General](#) [Components](#) [Collapse Modes](#)

List of Collapse Modes

[add](#) [remove](#)

	name	probability	affected area	injuries
<input type="radio"/>	complete	0.4	1.0	0.6, 0.4
<input type="radio"/>	partial	0.6	0.1	0.4, 0.1

GI
SIM
EVT
FEM
UQ
DL
RES

[RUN](#) [RUN at DesignSafe](#) [GET from DesignSafe](#) [Exit](#)

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Center for Computational Modeling and Simulation

Estimate damage and loss

PBE

Login
PBE - Performance Based Engineering Application
Running the UQ engine ...

GI
SIM
EVT
FEM
UQ
DL
RES

Decision Variable	Mean	Standard Dev.	Minimum	10 th Percentile	Median	90 th Percentile	Maximum
<i>event time: month</i>	6.4552	3.44476	1	2	6	11	12
<i>event time: weekday?</i>	0.7294	0.444314	0	0	1	1	1
<i>event time: hour</i>	11.5724	6.94118	0	2	12	21	23
<i>inhabitants:</i>	87.7108	104.189	0	0	0	285	300
<i>collapses: collapsed?</i>	0.0038	0.0615331	0	0	0	0	1
<i>collapses: mode</i>	0.736842	0.452414	0	0	1	1	1
<i>red tagged?:</i>	0.972094	0.16472	0	1	1	1	1
<i>reconstruction: irreparable?</i>	0.250954	0.433605	0	0	0	1	1
<i>reconstruction: cost impractical?</i>	0	0	0	0	0	0	0
<i>reconstruction: cost</i>	3.90927e+6	3.5626e+6	1.06473e+6	1.51521e+6	1.941e+6	1e+7	1e+7
<i>reconstruction: time impractical?</i>	0	0	0	0	0	0	0
<i>reconstruction: time-sequential</i>	3975.23	1872.72	1000	1000	4590.66	5865.82	10477.9
<i>reconstruction: time-parallel</i>	609.231	242.364	249.093	383.179	500.825	1000	1000

RUN
RUN at DesignSafe
GET from DesignSafe
Exit


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SimCenter NHERI

SimCenter
NHERI

Adam Zsarnóczay adamzs@stanford.edu

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Estimate damage and loss

PBE

PBE - Performance Based Engineering Application Running the UQ engine ... Login

GI SIM EVT FEM UQ DL RES

Summary Data Values

reconstruction/time-p... Realization

The scatter plot displays the relationship between 'reconstruction/time-p...' (Y-axis) and 'Realization' (X-axis). The Y-axis ranges from 229.3 to 1019.8. The X-axis shows realization numbers at intervals of 1184.0, specifically: -131.6, 1184.0, 2499.5, 3815.0, and 5130.6. The data points are scattered across the plot, with a dense cluster around a value of 426.9.

	Realization	event_time/month	ent_time/weekda	event_time/hour	inhabitants/	collapses/collapsed	collapses/mode	red_tagged?/	instruction/irrepair	reduction/cost_impr	reconstruction/cos	reduction/time_impr	reduction/time-seq	reduction/time-p	injuries/s
1	0	6	1	23	0.0	0.0		1.0	0.0	0.0	1934372.908	0.0	5548.047623	479.5760955	0.0
2	1	12	1	4	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0
3	2	4	1	4	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0
4	3	10	1	14	300.0	0.0		1.0	0.0	0.0	2219427.366	0.0	6305.501585	573.5112385	11.9656
5	4	6	1	5	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0
6	5	7	1	12	142.5	0.0		1.0	1.0		1000000.0		1000.0	1000.0	6.95567
7	6	9	1	18	71.25	0.0		1.0	0.0	0.0	1662027.74884492	0.0	4220.711378	449.6581697	1.13129
8	7	1	1	14	273.0	0.0		1.0	0.0	0.0	1819505.219	0.0	4732.700367	445.6298166	3.34907
9	8	9	1	13	142.5	0.0		1.0	0.0	0.0	1666846.716	0.0	4248.451072	414.4232047	7.54120738

RUN RUN at DesignSafe GET from DesignSafe Exit

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Center for Computational Modeling and Simulation

Estimate damage and loss

PBE

PBE - Performance Based Engineering Application Running the UQ engine ... Login

GI Summary Data Values

SIM

EVT

FEM

UQ

DL

RES

Frequency %

reconstruction/time-parallel

me/month	event_time/weekdays	event_time/hour	inhabitants/	collapses/collapsed	collapses/mode	red_tagged?/	instruction/irrepair	reduction/cost_impr	reconstruction/cost_impr	reconstruction/time_impr	reconstruction/time-parallel	reconstruction/time-seq	reconstruction/time-p	injuries/sev._1	injuries/sev._2
1	1	23	0.0	0.0		1.0	0.0	0.0	1934372.908	0.0	5548.047623	479.5760955	0.0	0.0	0.0
2	1	4	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0	0.0
3	1	4	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0	0.0
4	1	14	300.0	0.0		1.0	0.0	0.0	2219427.366	0.0	6305.501585	573.5112385	11.96562751	0.019048730	
5	1	5	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0	
6	1	12	142.5	0.0		1.0	1.0		1000000.0		1000.0	1000.0	6.955677442	0.0	
7	1	18	71.25	0.0		1.0	0.0	0.0	1662027.74884492	0.0	4220.711378	449.6581697	1.131298857	0.0	
8	1	14	273.0	0.0		1.0	0.0	0.0	1819505.219	0.0	4732.700367	445.6298166	3.349077693	0.0	
9	1	13	142.5	0.0		1.0	0.0	0.0	1666846.716	0.0	4248.451072	414.4232047	7.54120738241332	0.0	
10	1	5	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0	

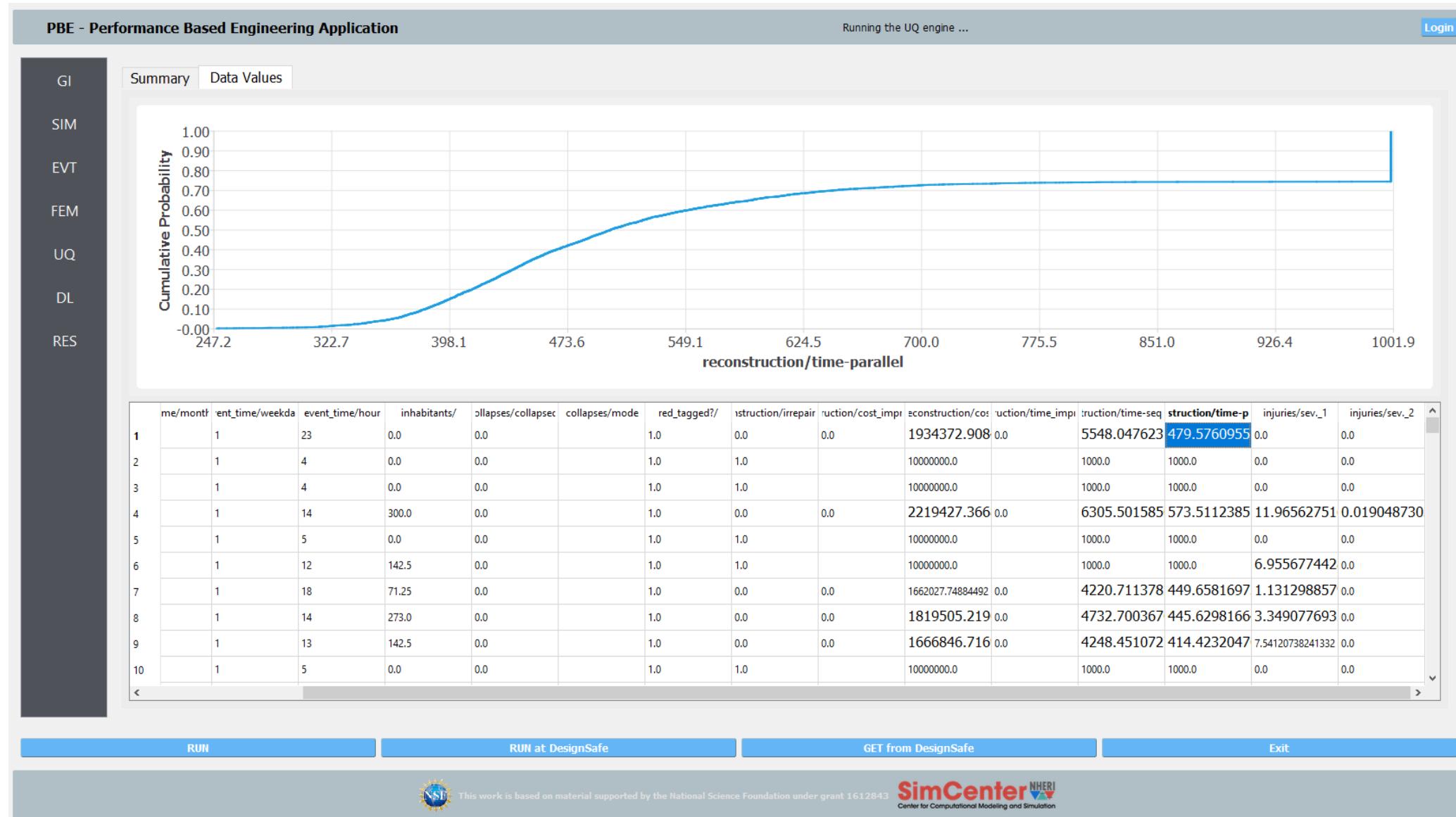
RUN RUN at DesignSafe GET from DesignSafe Exit

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SimCenter NHERI Center for Computational Modeling and Simulation

Estimate damage and loss

PBE



Estimate damage and loss

PBE

PBE - Performance Based Engineering Application

Running the UQ engine ...

Login

GI

SIM

EVT

FEM

UQ

DL

RES

Summary Data Values

reconstruction/time-paral... 1019.8
822.2
624.5
426.9
229.3

829590.8 3180977.8 5532364.8 7883751.7 10235138.7

reconstruction/cost

me/month	event_time/weekdays	event_time/hour	inhabitants/	collapses/collapsed	collapses/mode	red_tagged?/	instruction/irrepair	reduction/cost_impr	reconstruction/cost	reduction/time_impr	reduction/time-seq	reduction/time-paral	injuries/sev_1	injuries/sev_2
1	1	23	0.0	0.0		1.0	0.0	0.0	1934372.908	0.0	5548.047623	479.5760955	0.0	0.0
2	1	4	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0
3	1	4	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0
4	1	14	300.0	0.0		1.0	0.0	0.0	2219427.366	0.0	6305.501585	573.5112385	11.96562751	0.019048730
5	1	5	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0
6	1	12	142.5	0.0		1.0	1.0		1000000.0		1000.0	1000.0	6.955677442	0.0
7	1	18	71.25	0.0		1.0	0.0	0.0	1662027.74884492	0.0	4220.711378	449.6581697	1.131298857	0.0
8	1	14	273.0	0.0		1.0	0.0	0.0	1819505.219	0.0	4732.700367	445.6298166	3.349077693	0.0
9	1	13	142.5	0.0		1.0	0.0	0.0	1666846.716	0.0	4248.451072	414.4232047	7.54120738241332	0.0
10	1	5	0.0	0.0		1.0	1.0		1000000.0		1000.0	1000.0	0.0	0.0

RUN RUN at DesignSafe GET from DesignSafe Exit

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Research Tools

- **quoFEM** Uncertainty Quantification and Optimization
 - **EE-UQ** Structural Response Estimation under Earthquakes
 - **WE-UQ** Structural Response Estimation under Wind
 - **CWE** CFD Analysis for a Building
-
- **PBE** Damage and Loss Assessment for a Building
 - **rWHALE** Damage and Loss Assessment for an Urban Region

Objectives

- Demonstrate use-cases of our research tools
- **Get feedback on existing features**
- **Collect requests for new features**



Center for Computational Modeling and Simulation

Example use of Research Tools

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

Adam Zsarnóczay
adamzs@Stanford.edu



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