



National
Science
Foundation



UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Example Use of Research Tools

Adam Zsarnóczay, Postdoctoral Researcher

Stanford University, SimCenter

adamzs@stanford.edu

*Joint Researcher Workshop
UC San Diego, Lehigh & SimCenter*

*December 16-17, 2019
University of California, San Diego*



LEHIGH **NHERI**
Real-Time Multi-Directional Testing Facility

University of California at San Diego
 NHERI
Natural Hazards Engineering Research Infrastructure

SIMCENTER
COMPUTATIONAL MODELING
AND SIMULATION CENTER

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

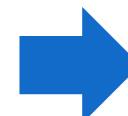
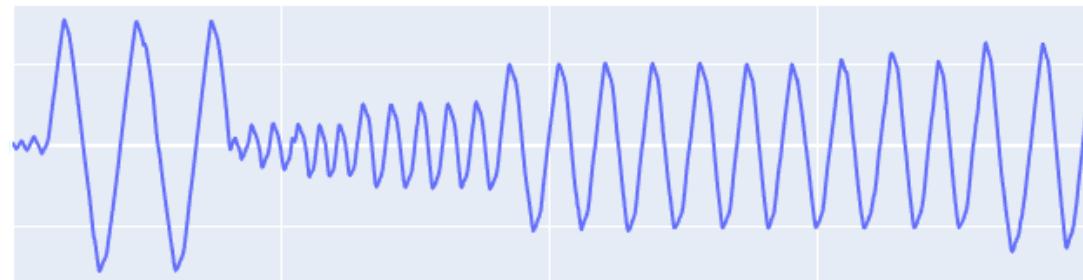
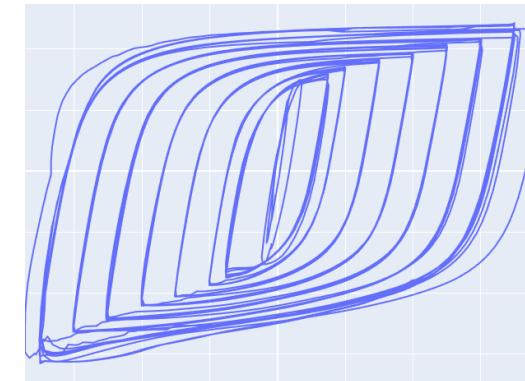
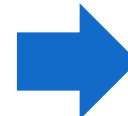
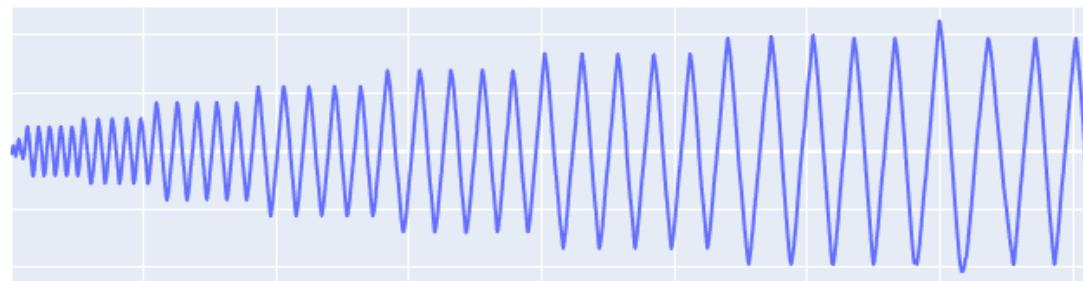
quoFEM

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

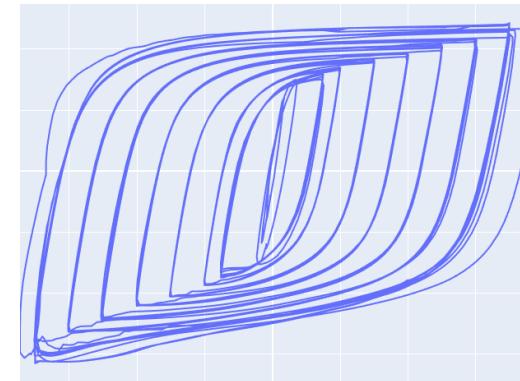
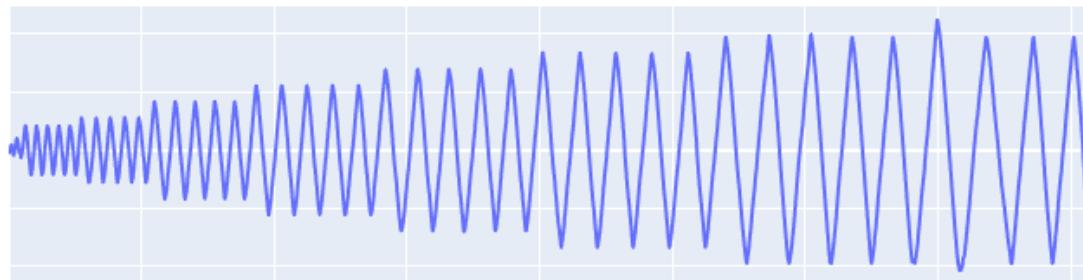
new load protocol



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

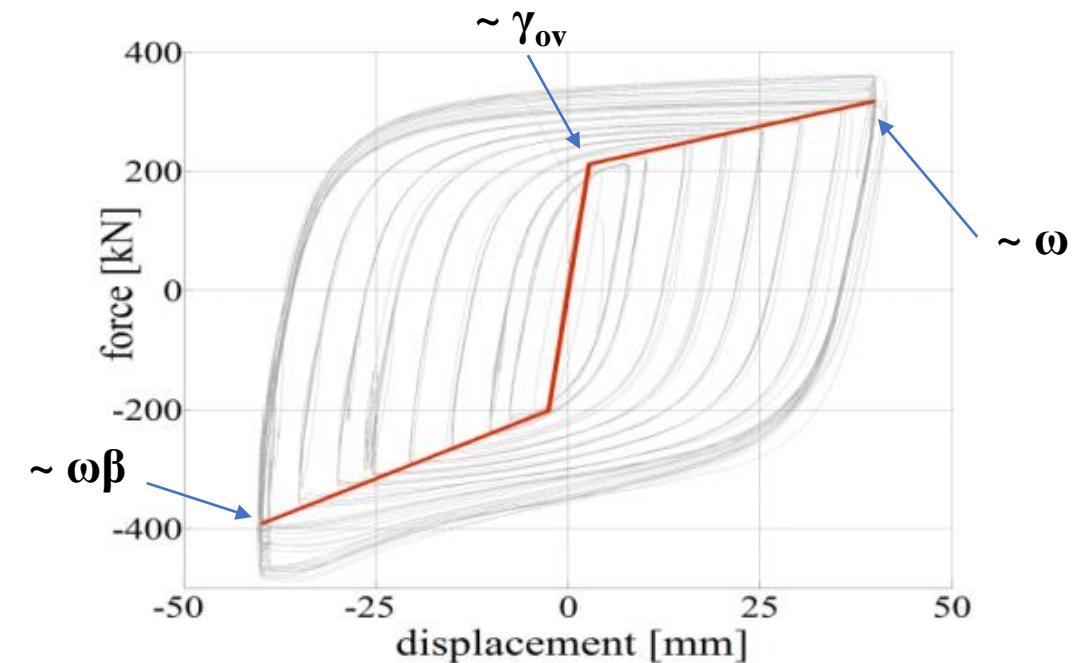
quoFEM

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



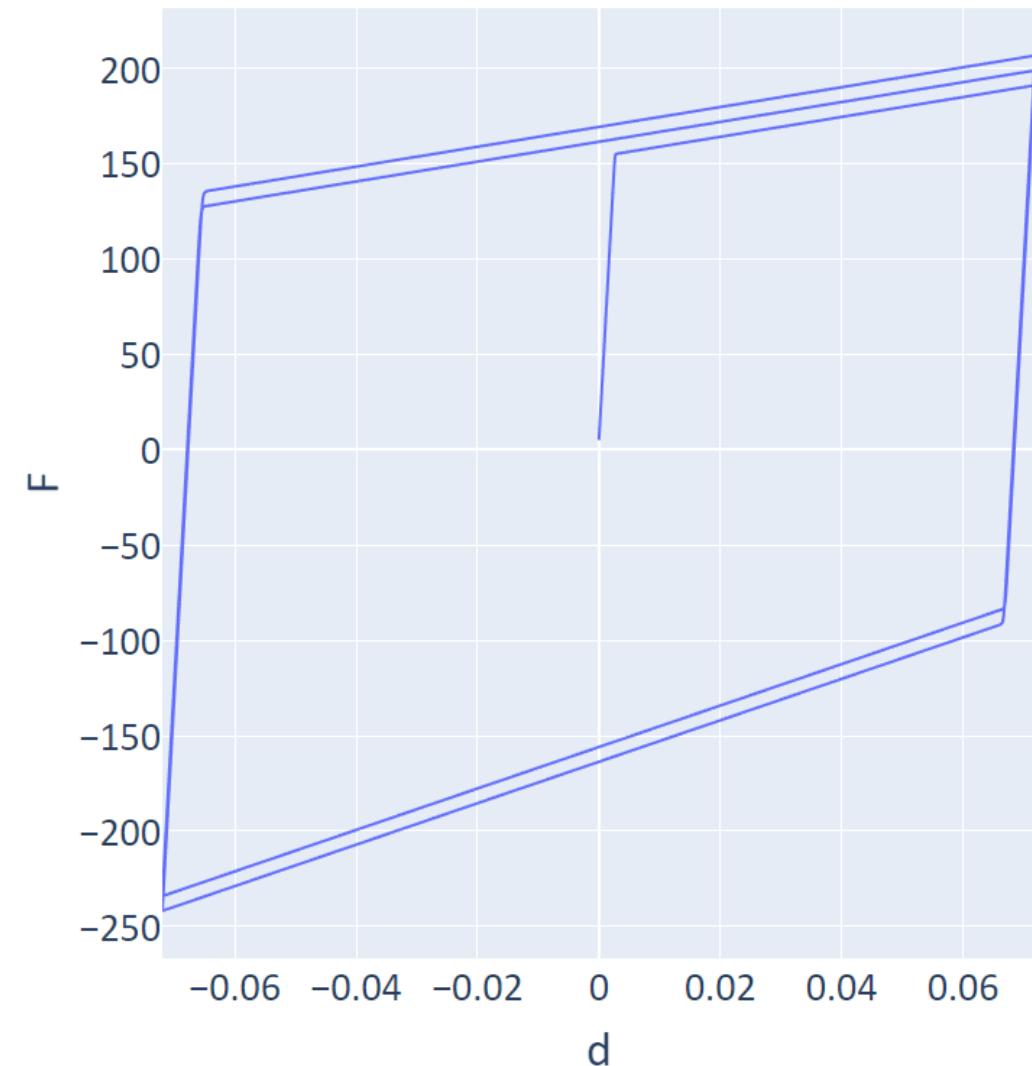
γ_{ov}	1.10 – 1.20
ω	1.35 – 1.75
β	1.01 – 1.30
ω_{iso}	0.05 – 0.30

First, through literature review get:

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

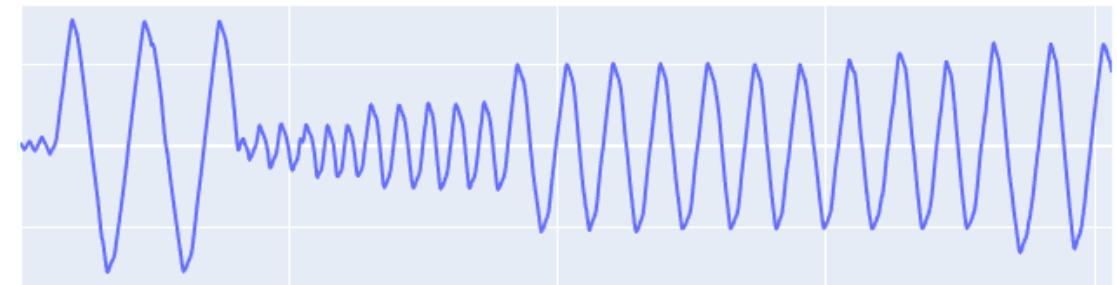
Then, prepare:

- 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

select the type of problem
-> **forward propagation**

available methods:

- **Latin Hypercube Sampling**
- Monte Carlo Sampling
- Importance Sampling
- Gaussian Process Regression
- Polynomial Chaos Expansion

The screenshot shows the quoFEM Application interface. On the left is a sidebar with buttons for UQ (selected), FEM, RV, QoI, and RES. The main area has dropdown menus for 'UQ Engine' set to 'Dakota', 'Dakota Method Category' set to 'Forward Propagation', and 'Method' set to 'LHS'. Below these are input fields for '# Samples' (1000) and 'Seed' (923). At the bottom are four buttons: 'RUN', 'RUN at DesignSafe', 'GET from DesignSafe', and 'Exit'. A NSF logo and a note about National Science Foundation support are at the bottom.

Design an experiment

quoFEM

load the pre-defined scripts

The screenshot shows the quoFEM Application interface. On the left is a sidebar with buttons for UQ, FEM (which is highlighted in blue), RV, QoI, and RES. The main area has a title "Finite Element Method Application" and a dropdown menu set to "OpenSees". Below this are two input fields: "Input Script" containing "C:/UCSD/00_forward_example_BRB/BRB_response.tcl" with a "Choose" button, and "Postprocess Script" containing "C:/UCSD/00_forward_example_BRB/postprocess.py" with a "Choose" button. At the bottom are four buttons: "RUN", "RUN at DesignSafe", "GET from DesignSafe", and "Exit". A footer bar at the bottom includes the NSF logo, the text "This work is based on material supported by the National Science Foundation under grant 1612843", the SimCenter logo, and the NHERI logo.

quoFEM Application

Finite Element Method Application

OpenSees

Input Script
C:/UCSD/00_forward_example_BRB/BRB_response.tcl

Choose

Postprocess Script
C:/UCSD/00_forward_example_BRB/postprocess.py

Choose

simulation script

postprocess script

UQ

FEM

RV

QoI

RES

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

Design an experiment

quoFEM

BRB_response.tcl

```
12  
13  
14 # hyperparameters  
15 pset gammaOv 1.1  
16 pset omega 1.55  
17 pset omegaIso 0.4;  
18 pset beta 1.15  
19
```

quoFEM Application Login

UQ FEM RV QoI RES

Input Random Variables

Add Remove

Variable Name	Distribution	Min.	Max.
omega	Uniform	1.35	1.75
beta	Uniform	1.01	1.30
gammaOv	Uniform	1.10	1.20
omegaIso	Uniform	0.05	0.30

Buttons: RUN, RUN at DesignSafe, GET from DesignSafe, Exit

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

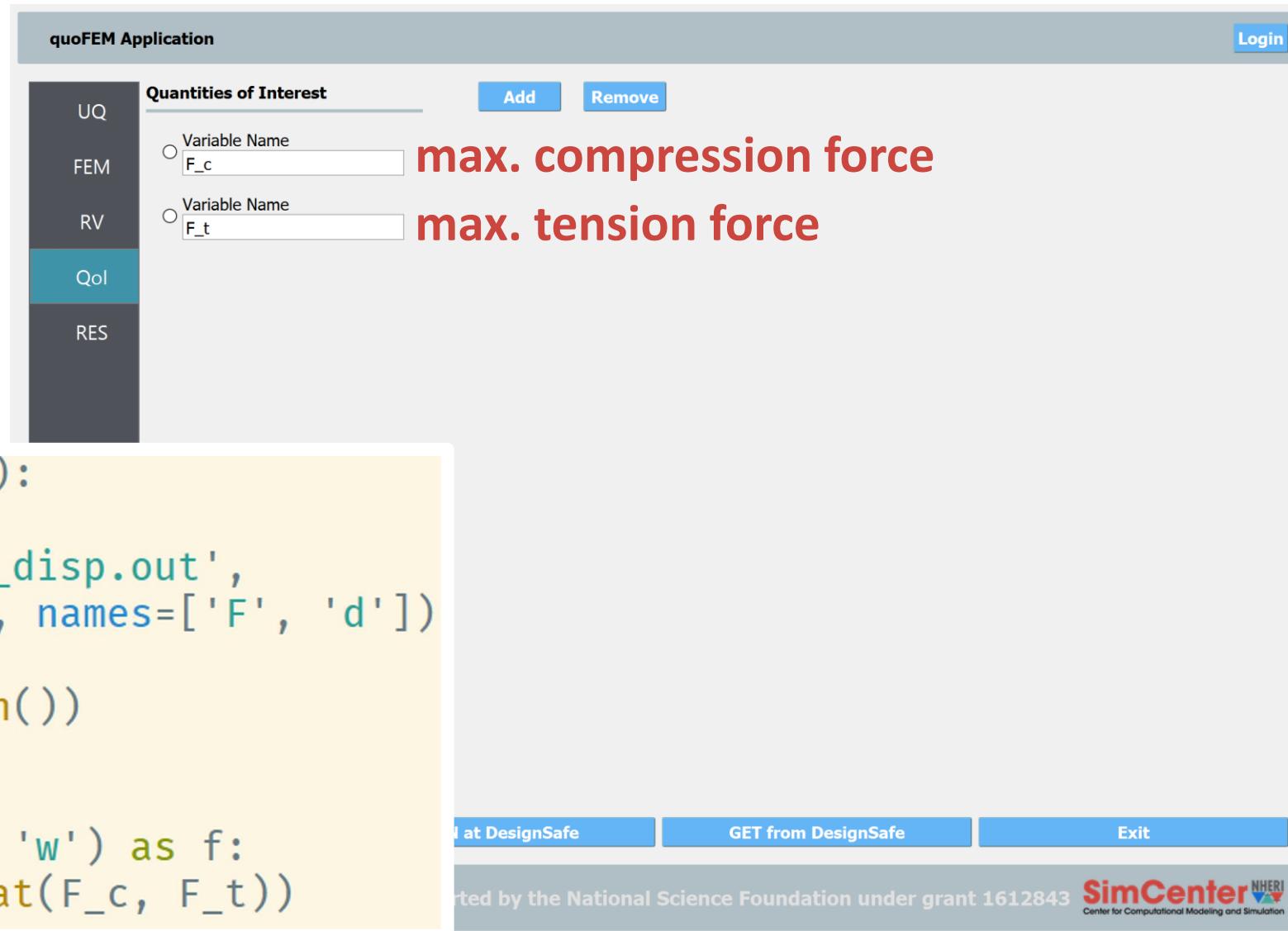
Design an experiment

quoFEM

specify the
Quantities of Interest

postprocess.py:

```
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))
```



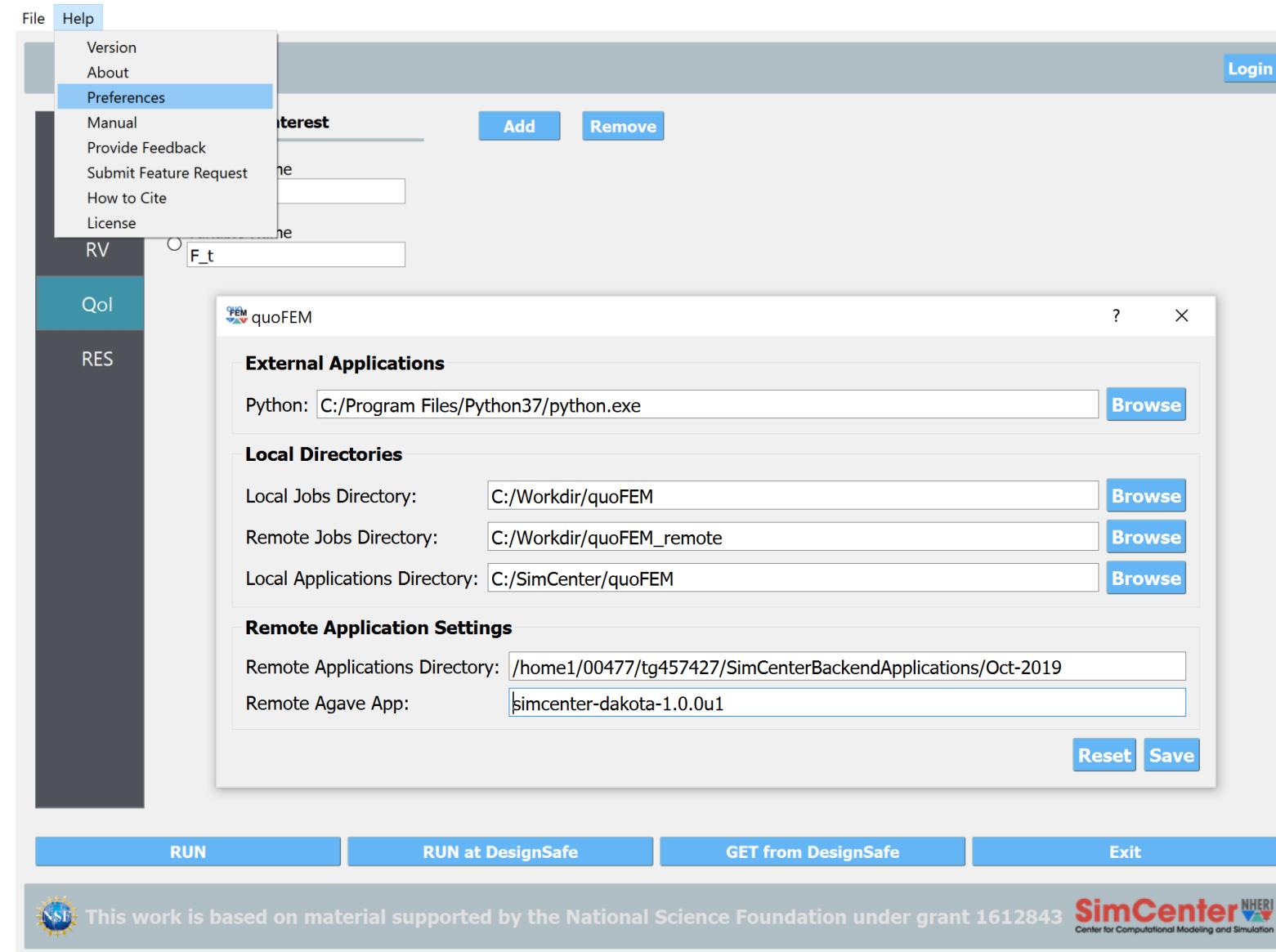
The screenshot shows the quoFEM Application interface. On the left is a vertical sidebar with tabs: UQ, FEM, RV, QoI (which is selected and highlighted in blue), and RES. At the top right is a 'Login' button. Below the sidebar, the main area has a title 'Quantities of Interest' with 'Add' and 'Remove' buttons. Two entries are listed: 'Variable Name F_c' and 'Variable Name F_t'. To the right of these entries, the text 'max. compression force' and 'max. tension force' is displayed in red. At the bottom of the interface are buttons for 'Logout DesignSafe', 'GET from DesignSafe', and 'Exit'. A footer at the very bottom states 'Funded 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

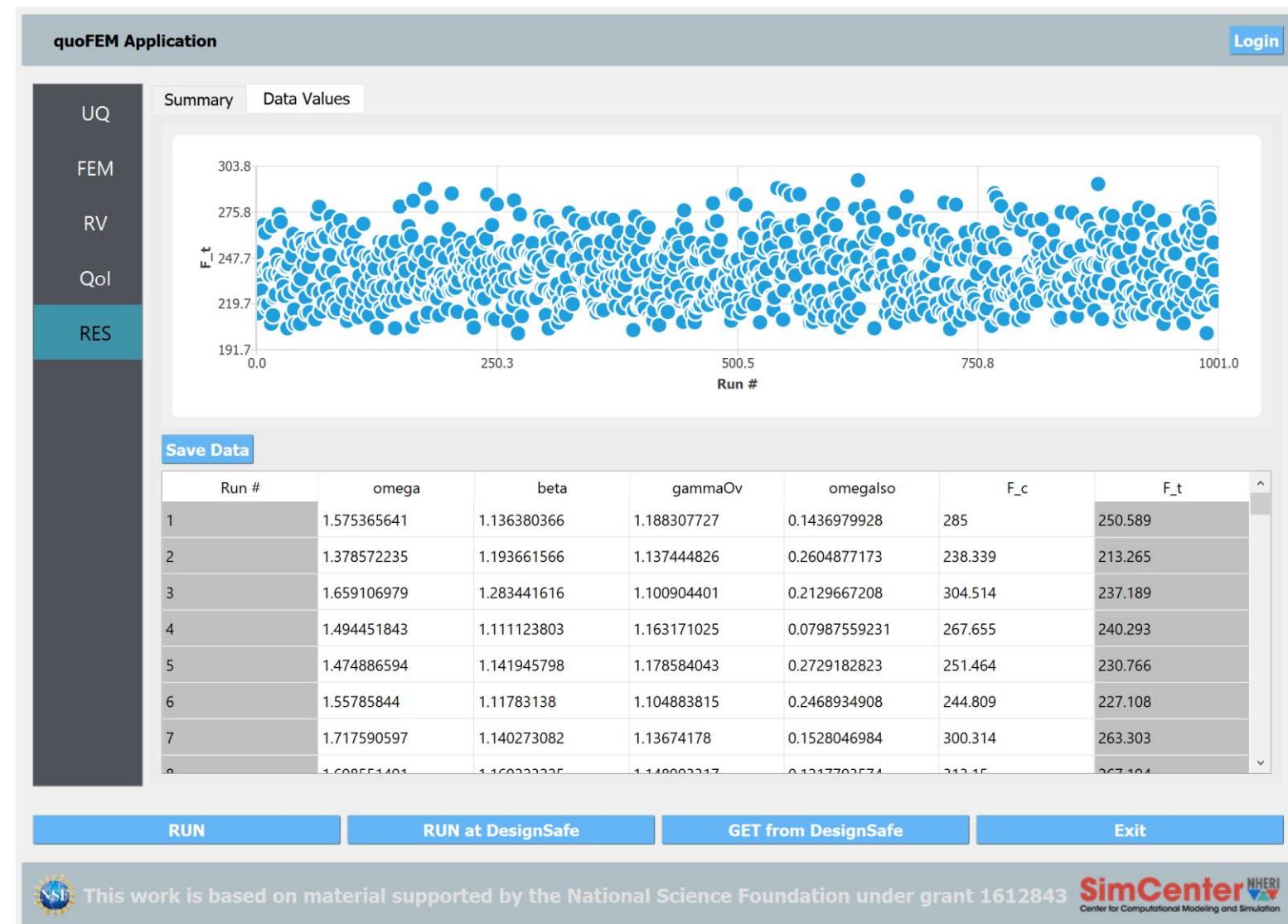


Design an experiment

quoFEM

result visualization

scatterplots show
sampled inputs and
corresponding outputs



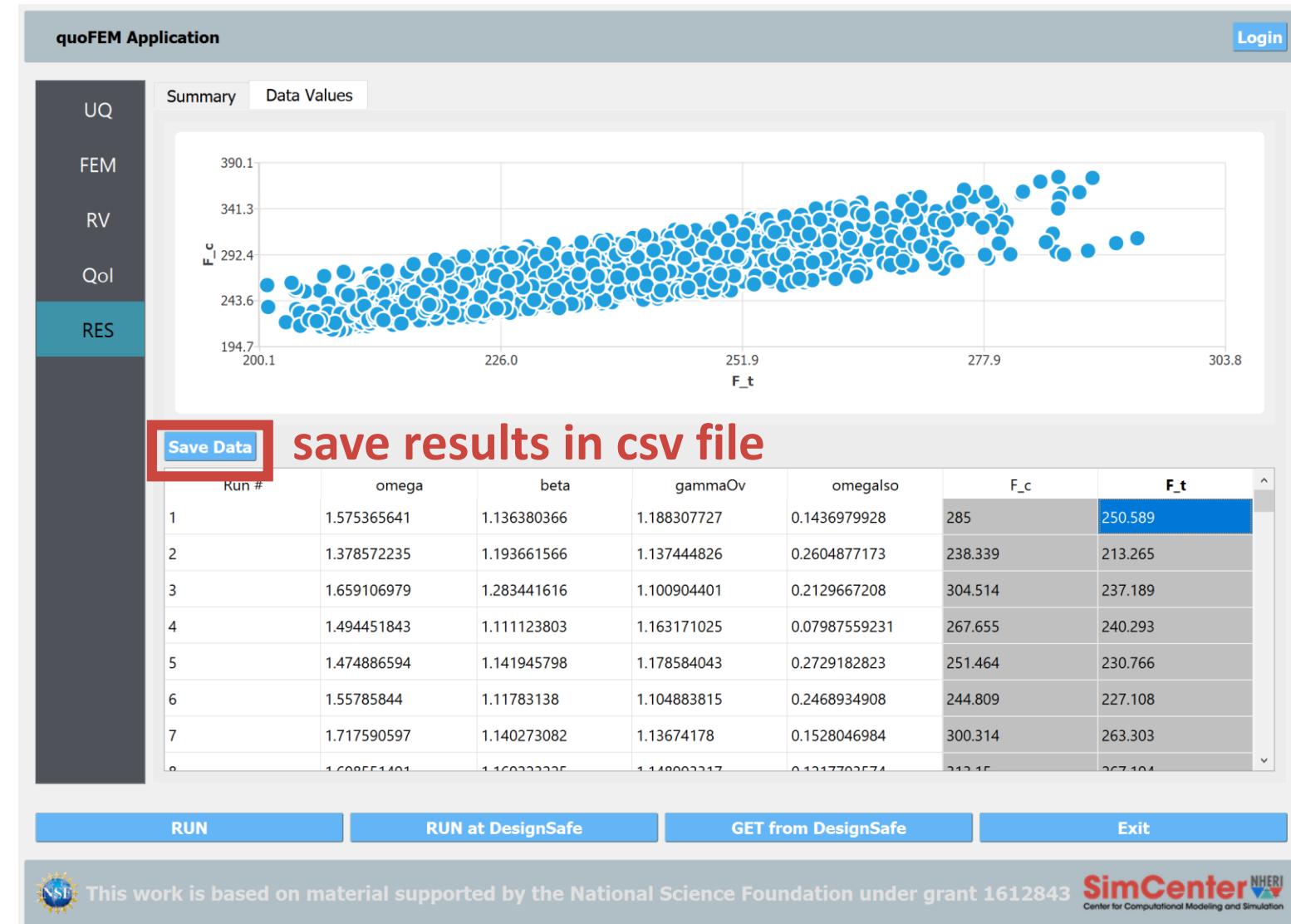
Design an experiment

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:/UCSD/00_forward_example_BRB/output_UCSD.csv",
4                     sep=',\t', dtype=float)
5 res.head(10)
```

	Run #	omega	beta	gammaOv	omegalso	F_c	F_t
0	1.0	1.57537	1.13638	1.18831	0.143698	285.000	250.589
1	2.0	1.37857	1.19366	1.13744	0.260488	238.339	213.265
2	3.0	1.65911	1.28344	1.10090	0.212967	304.514	237.189
3	4.0	1.49445	1.11112	1.16317	0.079876	267.655	240.293
4	5.0	1.47489	1.14195	1.17858	0.272918	251.464	230.766
5	6.0	1.55786	1.11783	1.10488	0.246893	244.809	227.108
6	7.0	1.71759	1.14027	1.13674	0.152805	300.314	263.303
7	8.0	1.69855	1.16922	1.14899	0.121779	313.150	267.194
8	9.0	1.40822	1.20869	1.17317	0.176460	257.507	218.961
9	10.0	1.73973	1.10822	1.18051	0.253128	289.577	262.384



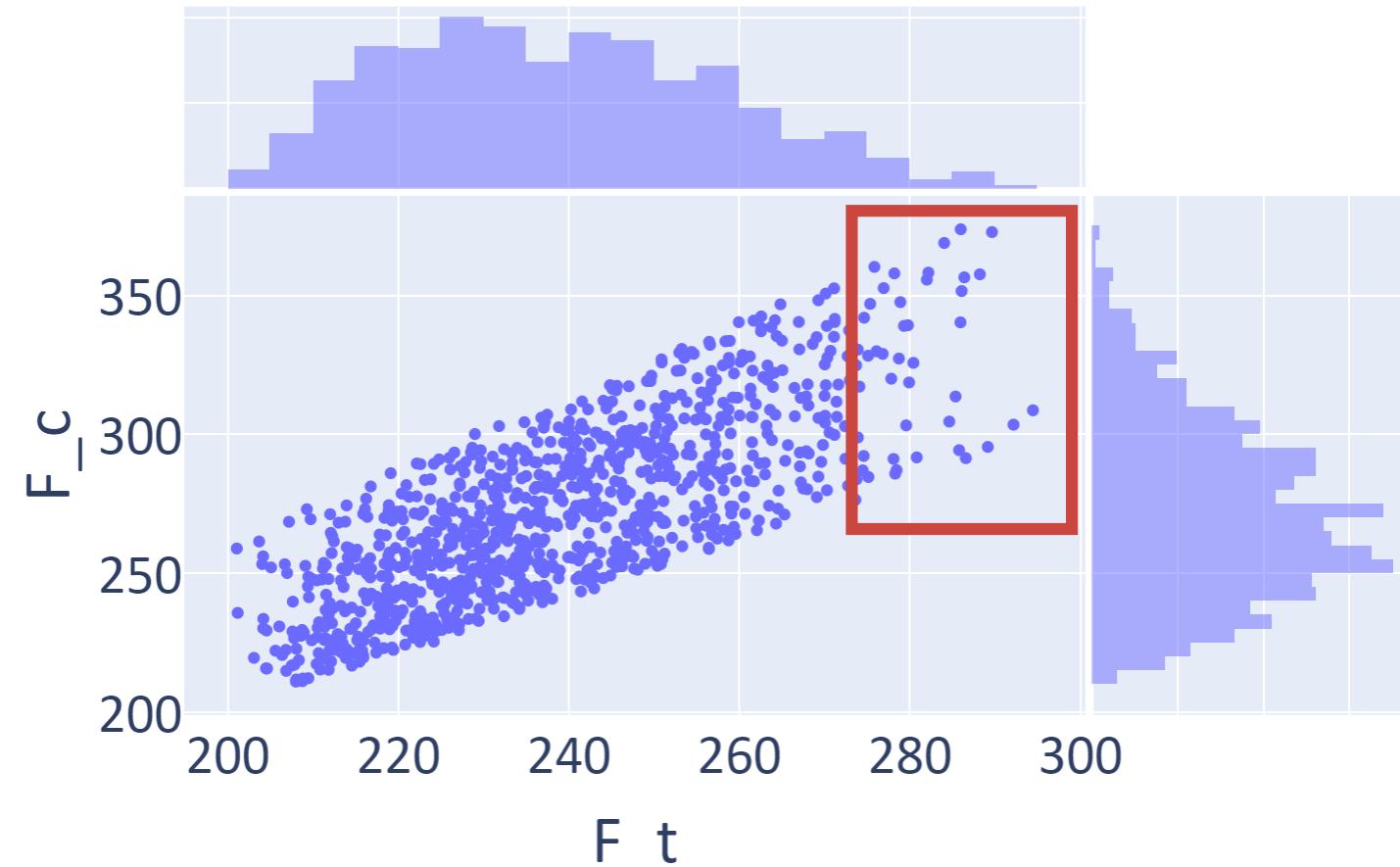
Design an experiment

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()
```

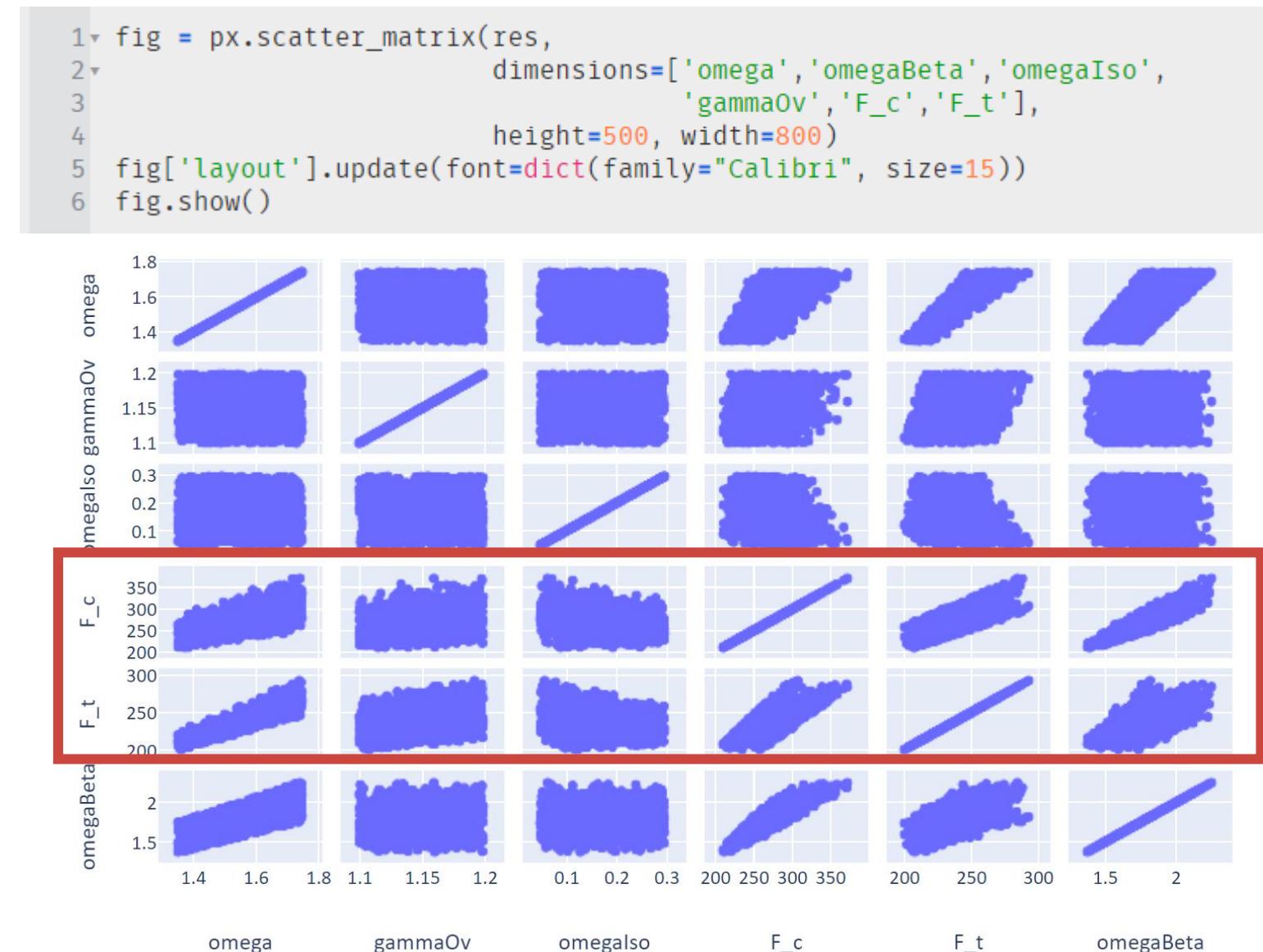


Design an experiment

quoFEM

advanced visualization
and data processing

use scatter matrix to
identify dependencies

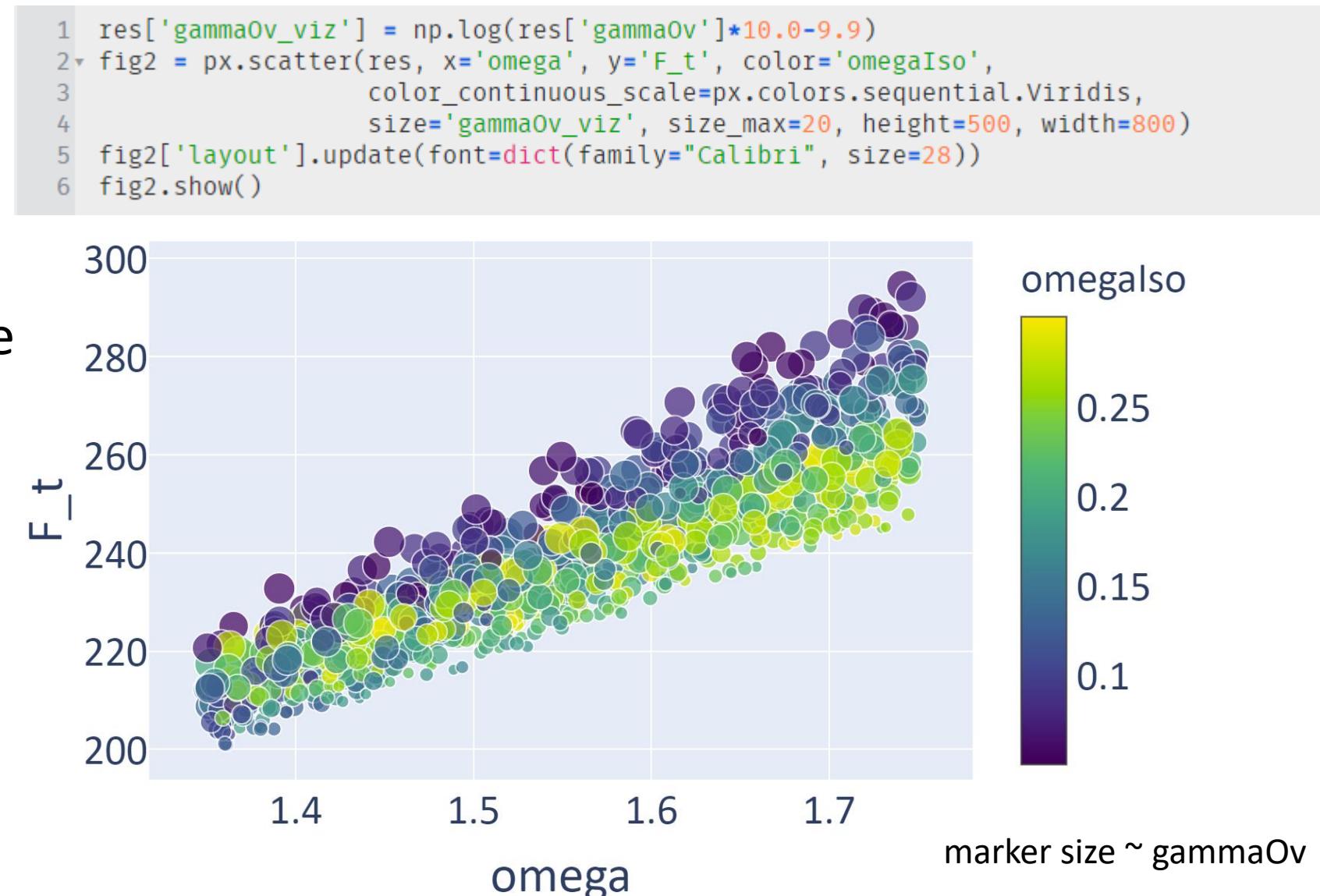


Design an experiment

quoFEM

advanced visualization
and data processing

use color and marker size
to visualize dependency
on 3 parameters



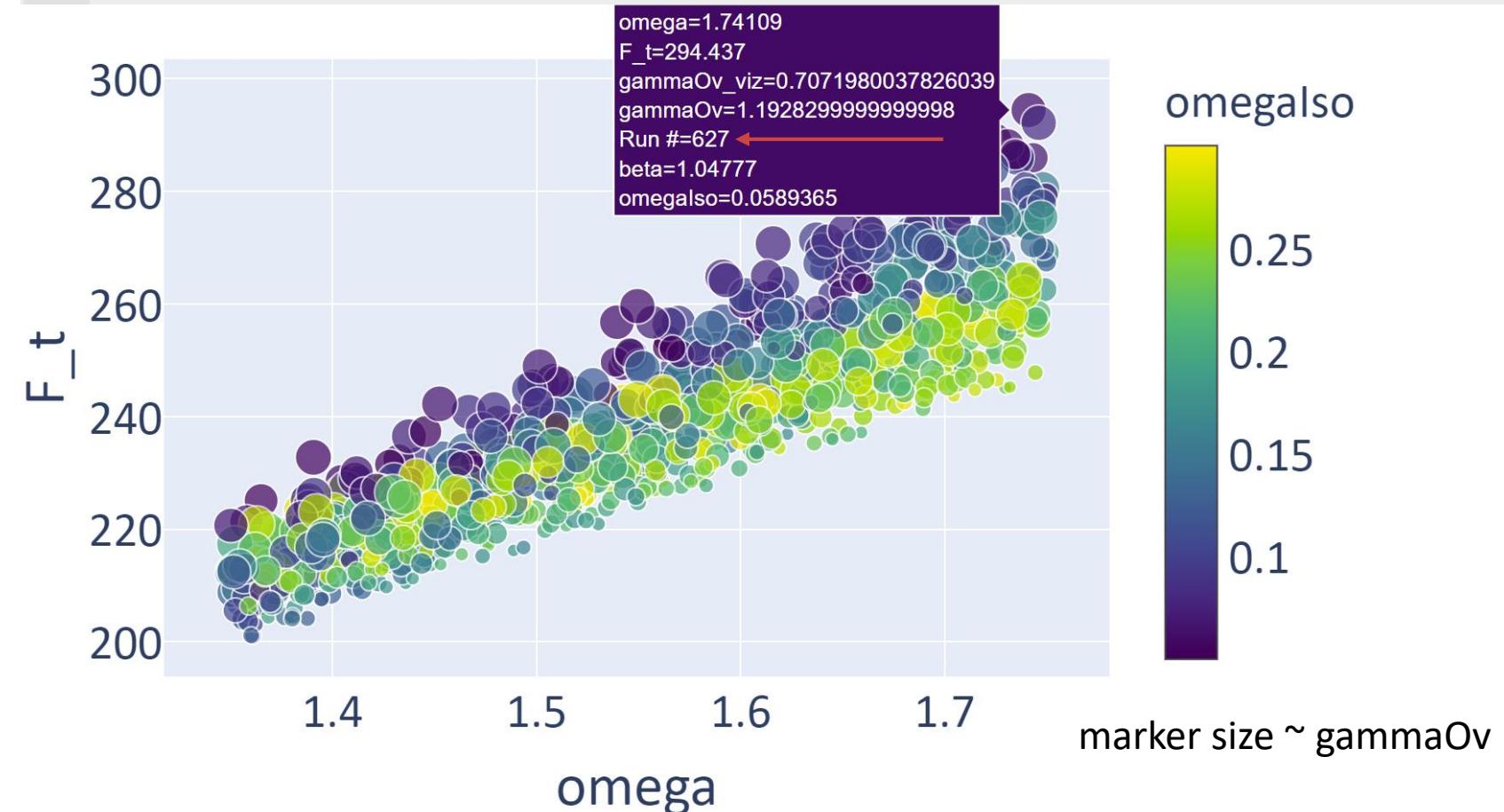
Design an experiment

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='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()
```



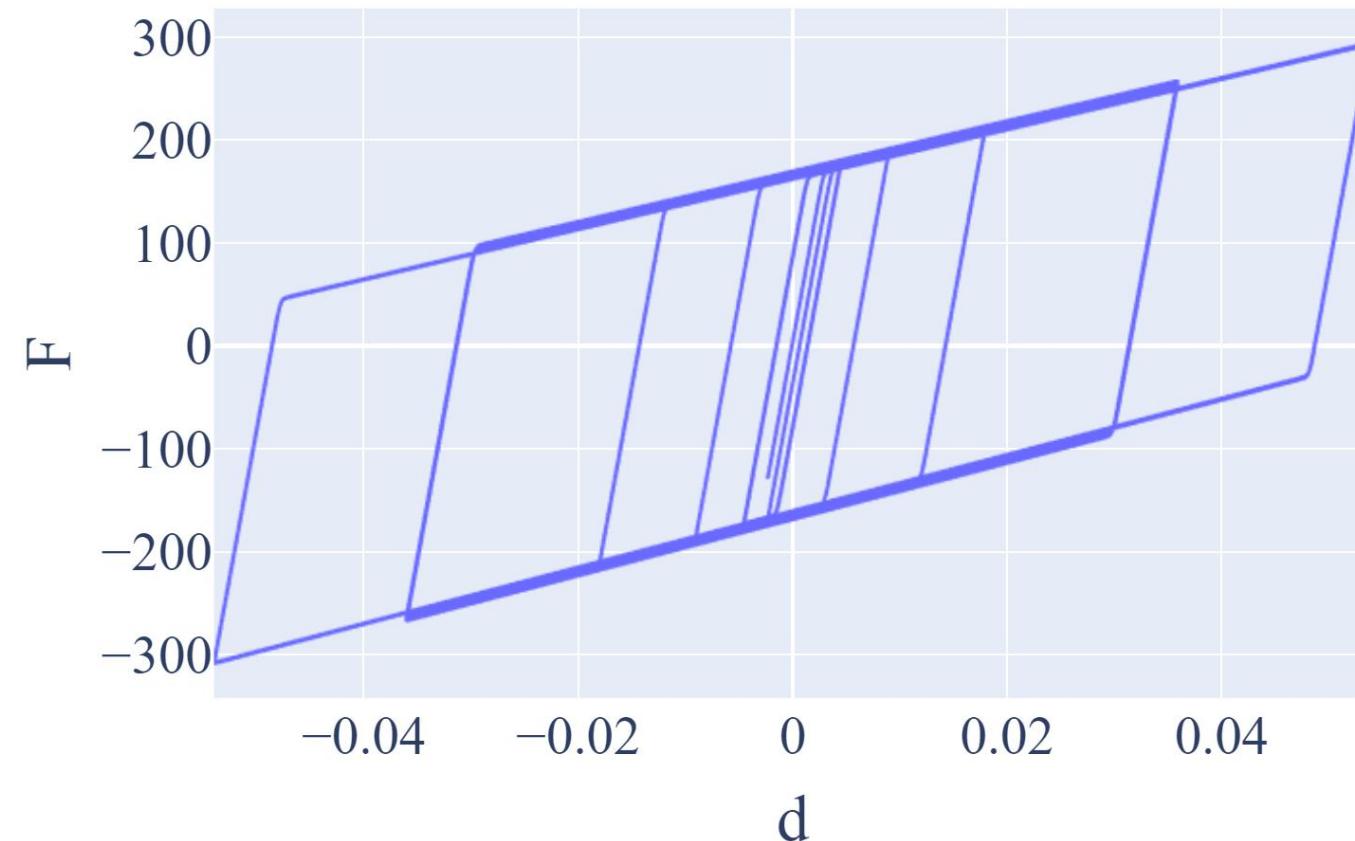
Design an experiment

quoFEM

advanced visualization
and data processing

raw data is available for
every simulation

```
1 output_file = "C:/Workdir/quoFEM/tmp.SimCenter/workdir.627/force_disp.out"
2 res = pd.read_csv(output_file, sep=' ', header=None, names=['F', 'd'])
3 fig = px.line(res, x='d', y='F', height=500, width=800)
4 fig['layout'].update(font=dict(family="Calibri", size=28))
5 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

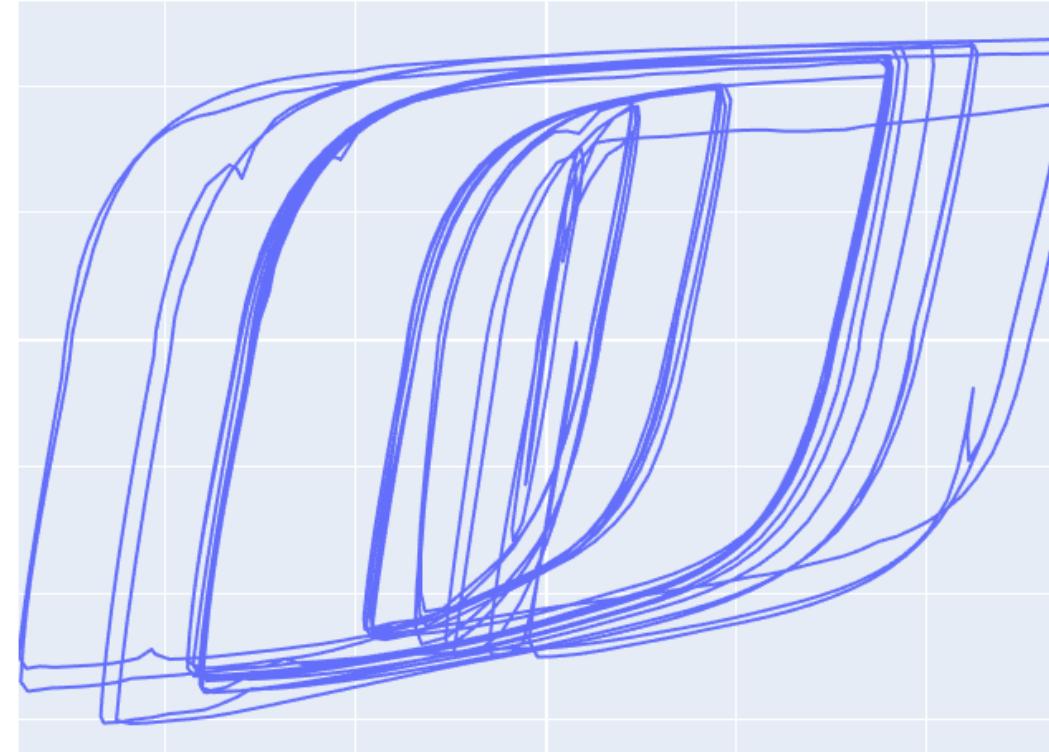
Calibrate component model

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:

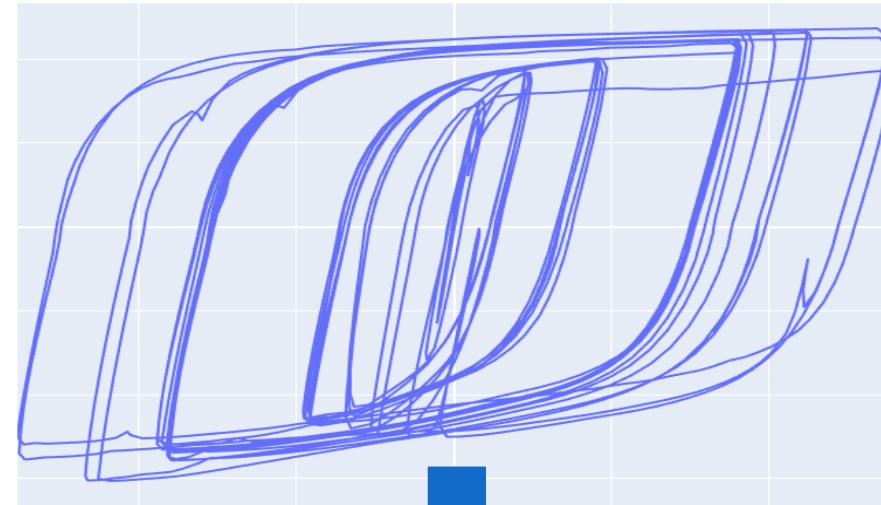
- reference data from test results
- complex BRB model in OpenSees
- updated simulation script
- script with the objective function

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
```

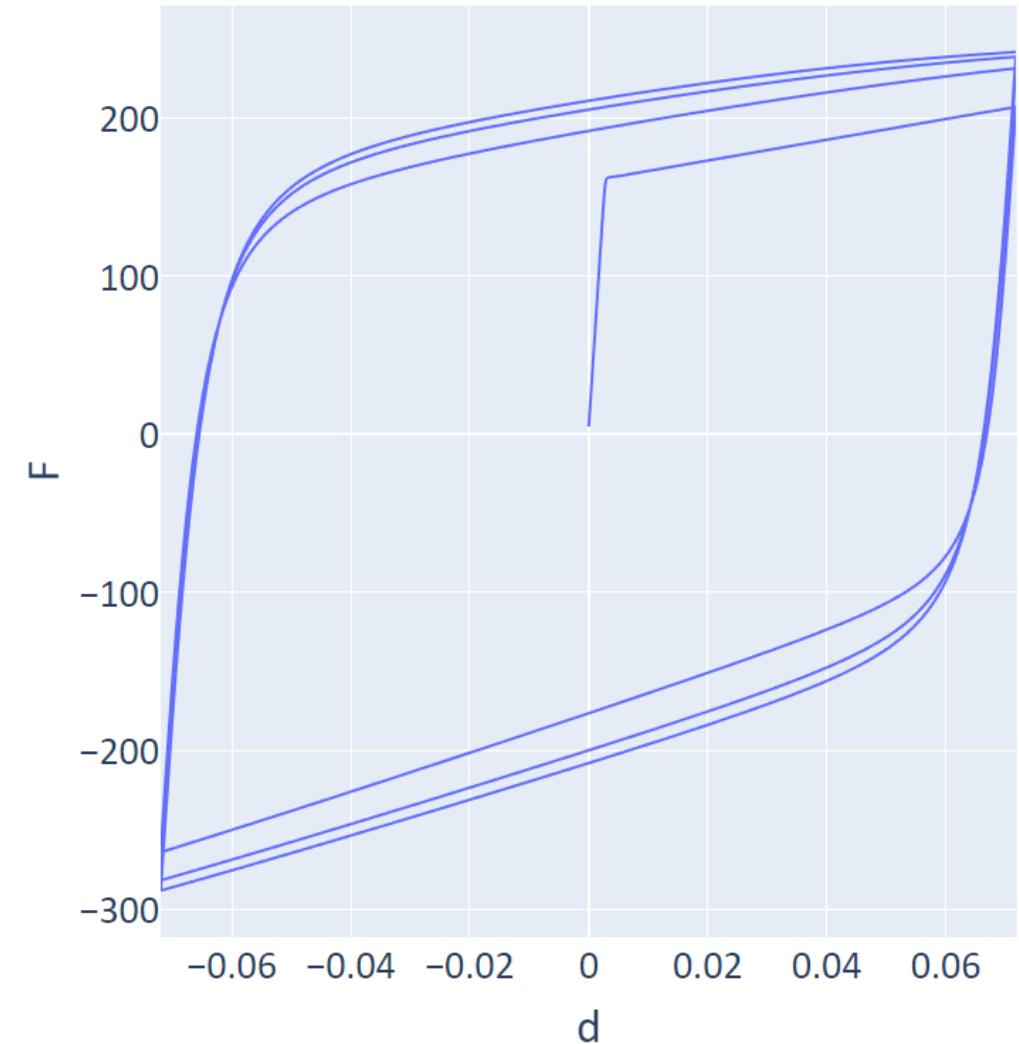
reference.txt

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

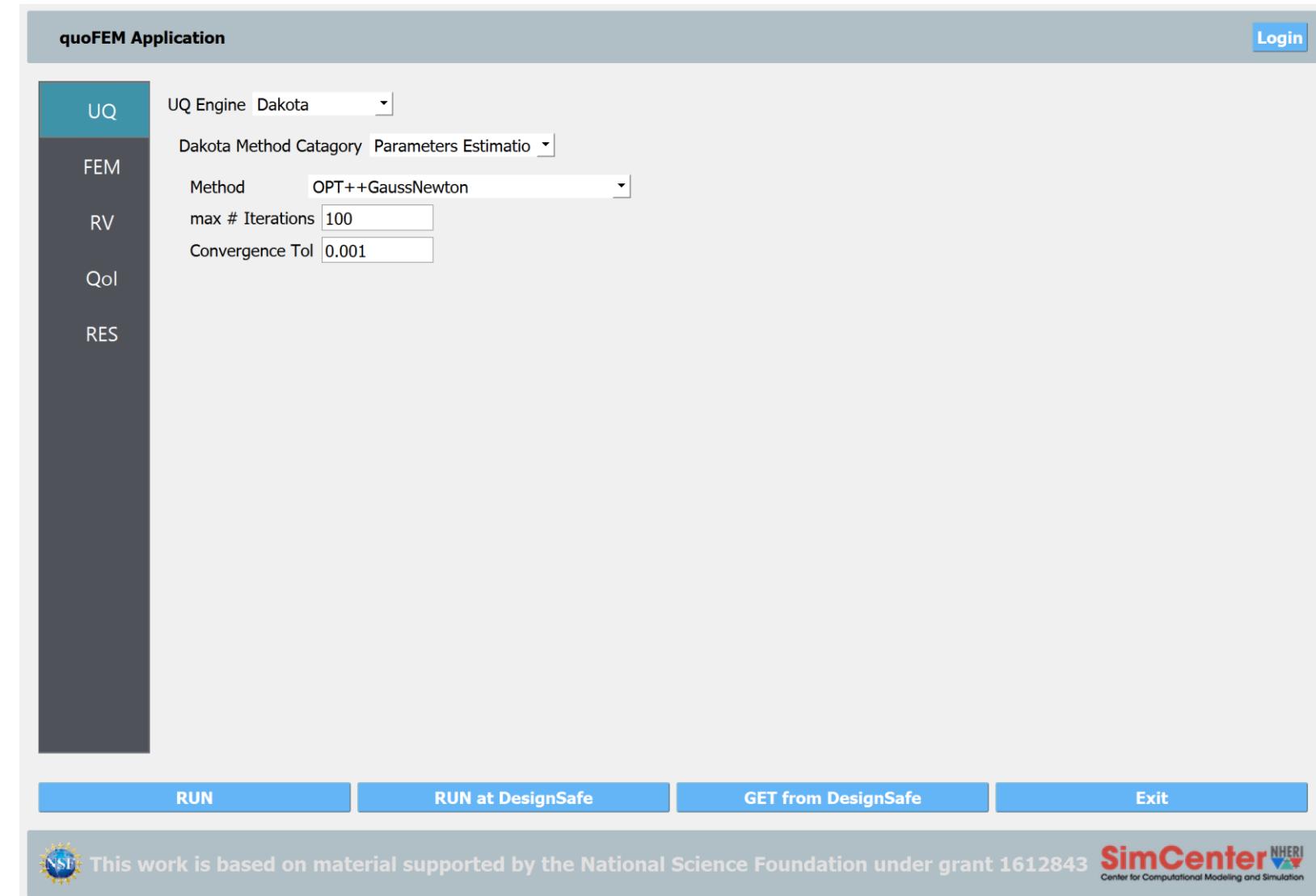
Calibrate component model

quoFEM

select the type of problem
-> parameter estimation

Gauss-Newton is a
gradient-based
optimization method

we also have
Bayesian methods
for solving the
inverse problem



Calibrate component model

quoFEM

load the pre-defined
scripts

quoFEM Application

Login

Finite Element Method Application OpenSees

Input Script C:/UCSD/01_inverse_example_BRB/BRB_response_NL.tcl Choose simulation script

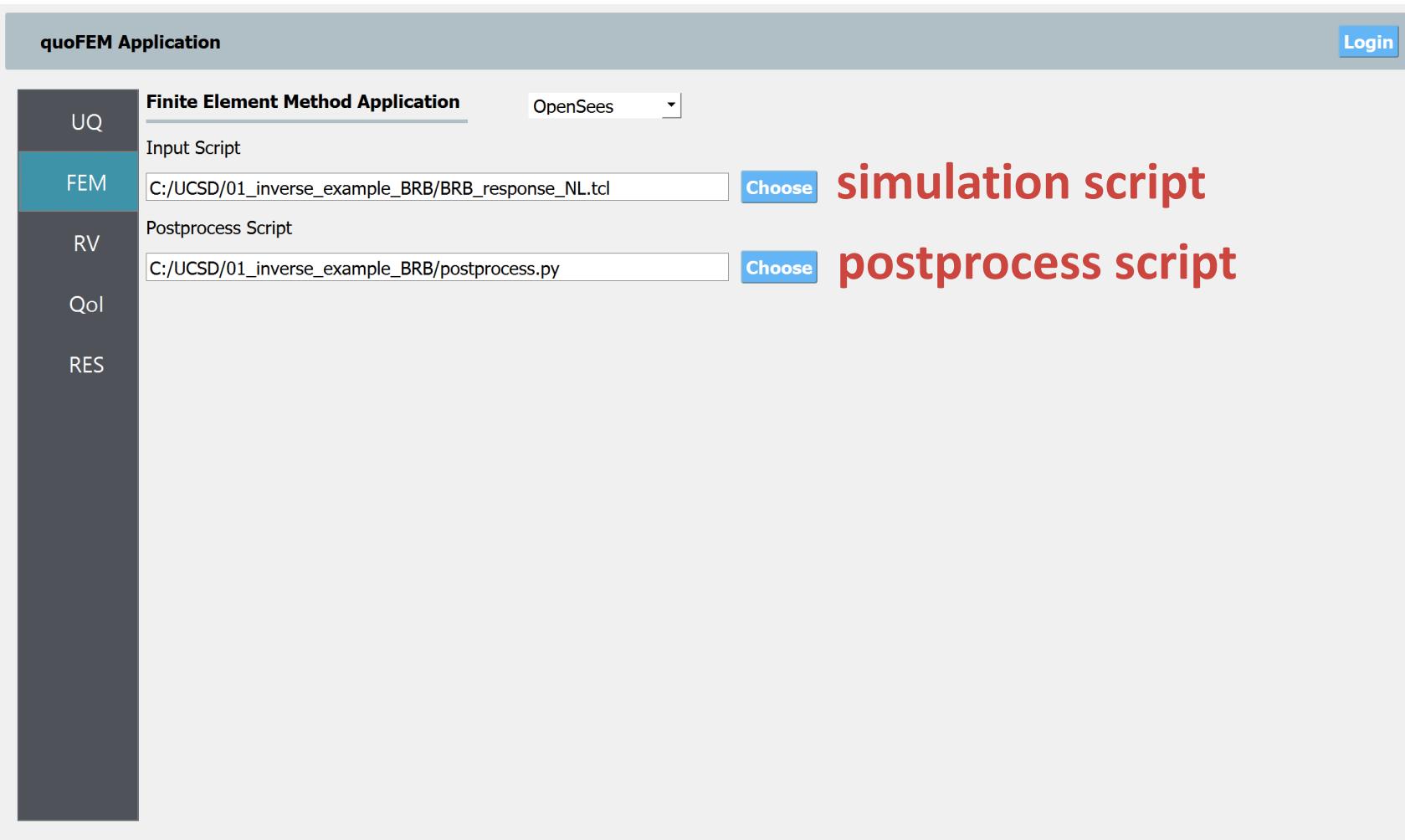
Postprocess Script C:/UCSD/01_inverse_example_BRB/postprocess.py Choose postprocess script

UQ FEM RV QoI RES

RUN RUN at DesignSafe GET from DesignSafe Exit

 This work is based on material supported by the National Science Foundation under grant 1612843

SimCenter NHERI
Center for Computational Modeling and Simulation



Calibrate component model

quoFEM

```
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

UQ FEM RV QoI RES

Input Random Variables

Add	Remove			
<input type="radio"/> gammaOv	ContinuousDesig	Lower Bound 1.1	Upper Bound 1.2	Initial Point 1.15
<input type="radio"/> omega	ContinuousDesig	Lower Bound 1.35	Upper Bound 1.75	Initial Point 1.5
<input type="radio"/> omegaIso	ContinuousDesig	Lower Bound 0.05	Upper Bound 0.3	Initial Point 0.1
<input type="radio"/> beta	ContinuousDesig	Lower Bound 1.01	Upper Bound 1.3	Initial Point 1.05
<input type="radio"/> rhoxi	ContinuousDesig	Lower Bound 0.1	Upper Bound 0.5	Initial Point 0.10
<input type="radio"/> rx1	ContinuousDesig	Lower Bound 0.9	Upper Bound 0.95	Initial Point 0.91
<input type="radio"/> fxult	ContinuousDesig	Lower Bound 1.5	Upper Bound 1.75	Initial Point 1.7
<input type="radio"/> fxultc	ContinuousDesig	Lower Bound 2	Upper Bound 3	Initial Point 2.9

RUN RUN at DesignSafe GET from DesignSafe Exit

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

Calibrate component model

quoFEM

specify the
Quantities of Interest

postprocess.py:

```
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))
```

quoFEM Application

Quantities of Interest

Add Remove

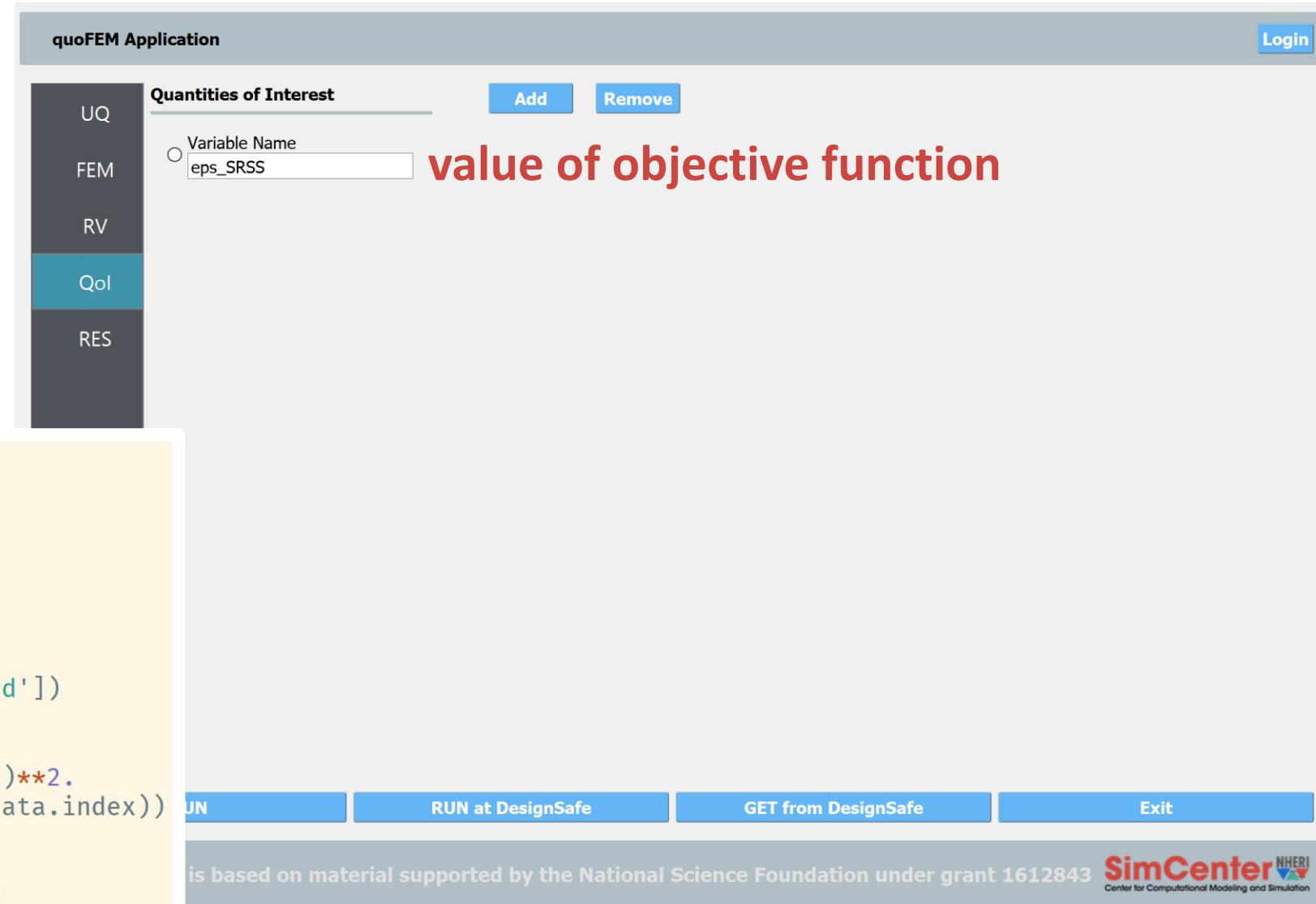
Variable Name:

value of objective function

UQ FEM RV QoI RES

RUN RUN at DesignSafe GET from DesignSafe Exit

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



Calibrate component model

quoFEM

quoFEM Application Processing Results Login

	Summary	General	Data Values
UQ	Name gammaOv	Best Parameter 1.2	
FEM	Name omega	Best Parameter 1.4485	
RV	Name omegaIso	Best Parameter 0.3	
QoI	Name beta	Best Parameter 1.17555	
RES	Name rhoxi	Best Parameter 0.185586	
	Name rx1	Best Parameter 0.92079	
	Name fxult	Best Parameter 1.69555	
	Name fxultc	Best Parameter 2.90029	

RUN RUN at DesignSafe GET from DesignSafe Exit

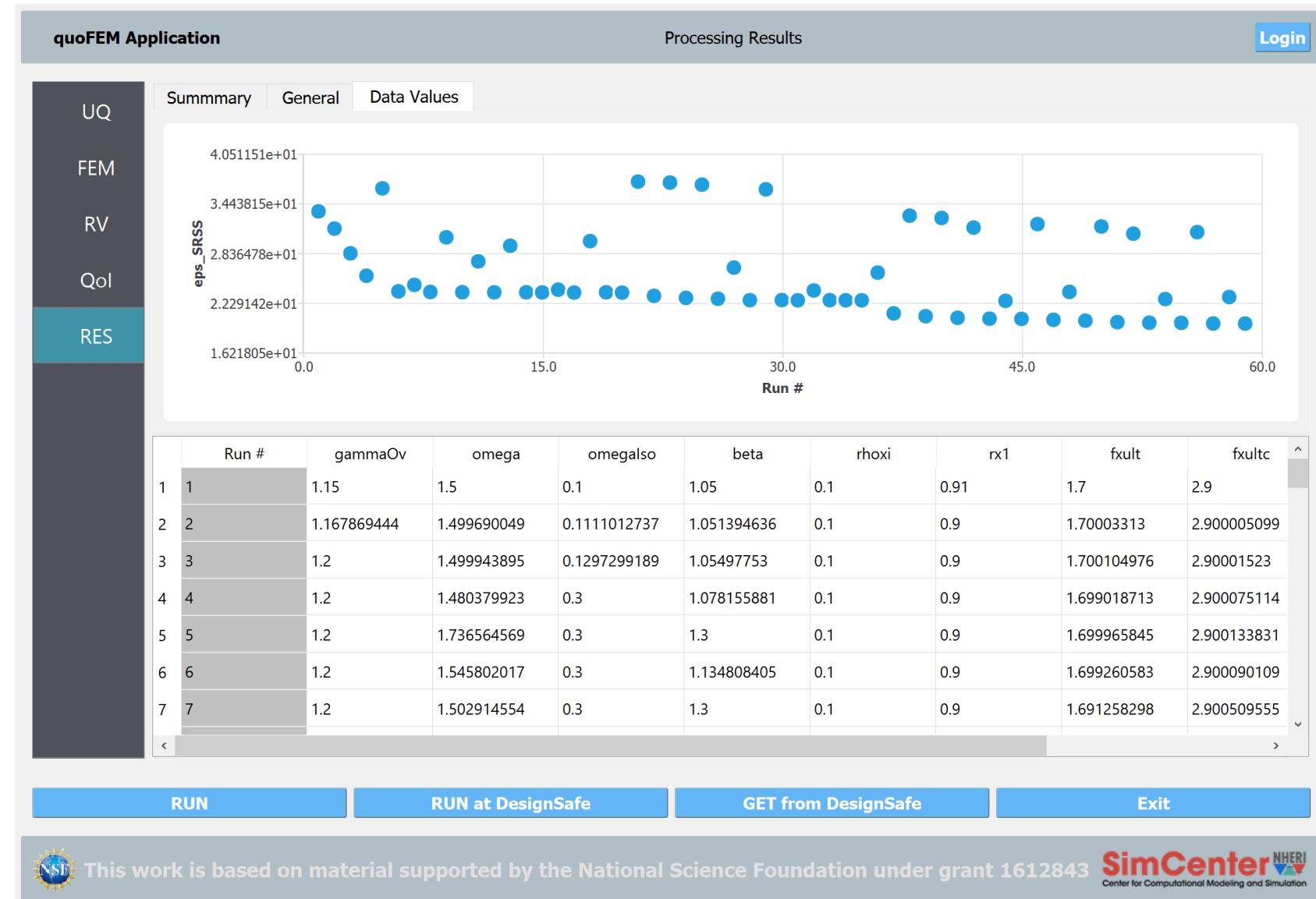
 This work is based on material supported by the National Science Foundation under grant 1612843 SimCenter NHERI
Center for Computational Modeling and Simulation

Calibrate component model

quoFEM

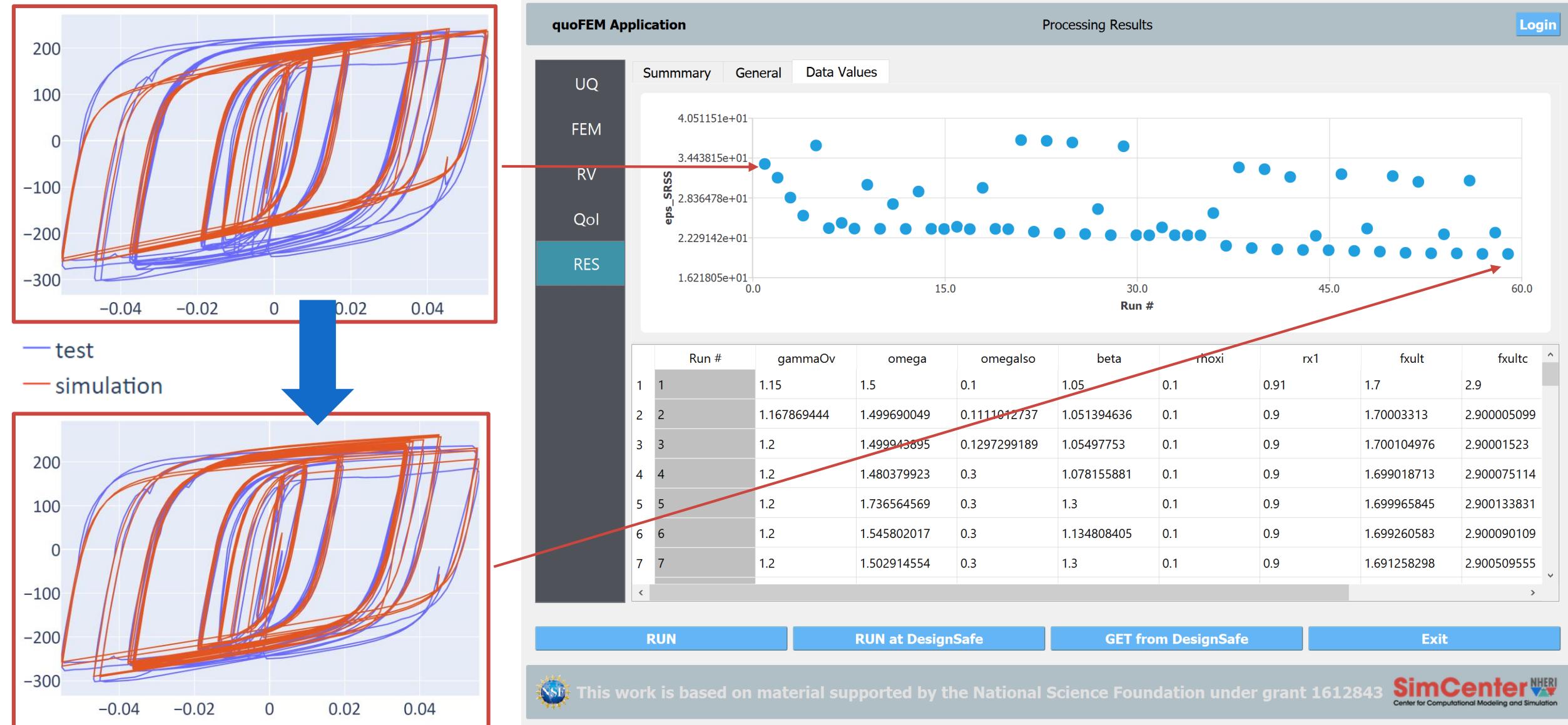
result visualization

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

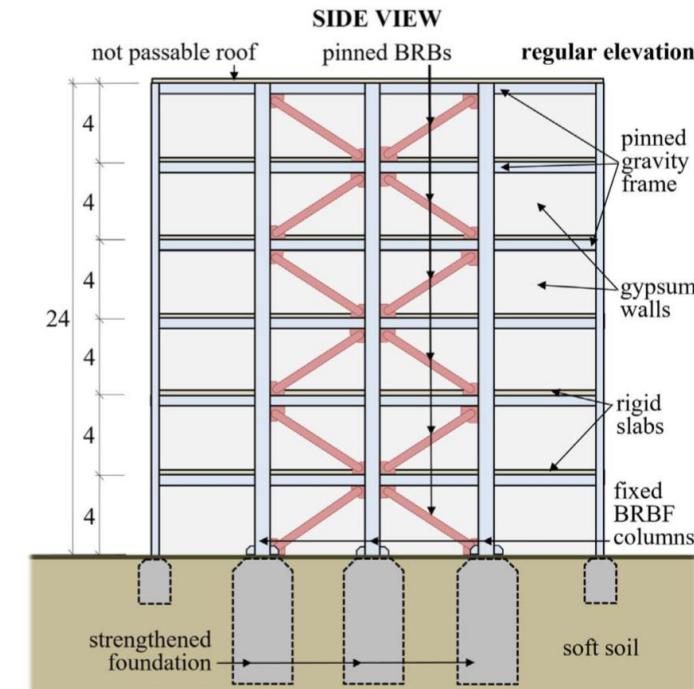
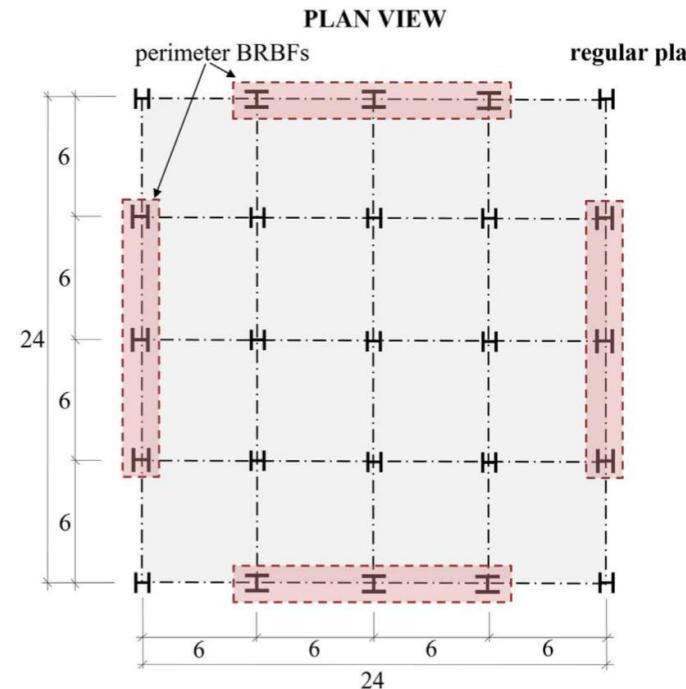
Simulate structural response

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:

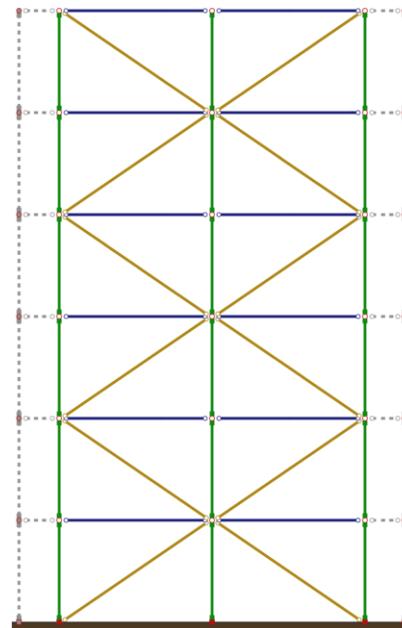
- BRBF model in OpenSees
- ground motion records
from PEER NGA2

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



SimCenter NHERI

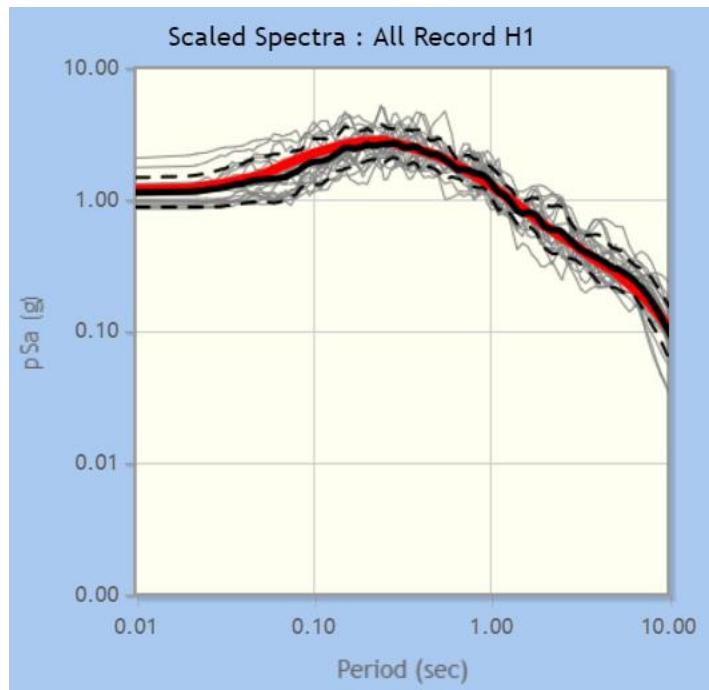
Adam Zsarnóczay adamzs@stanford.edu

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



SimCenter NHERI

Adam Zsarnóczay adamzs@stanford.edu

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

 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

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

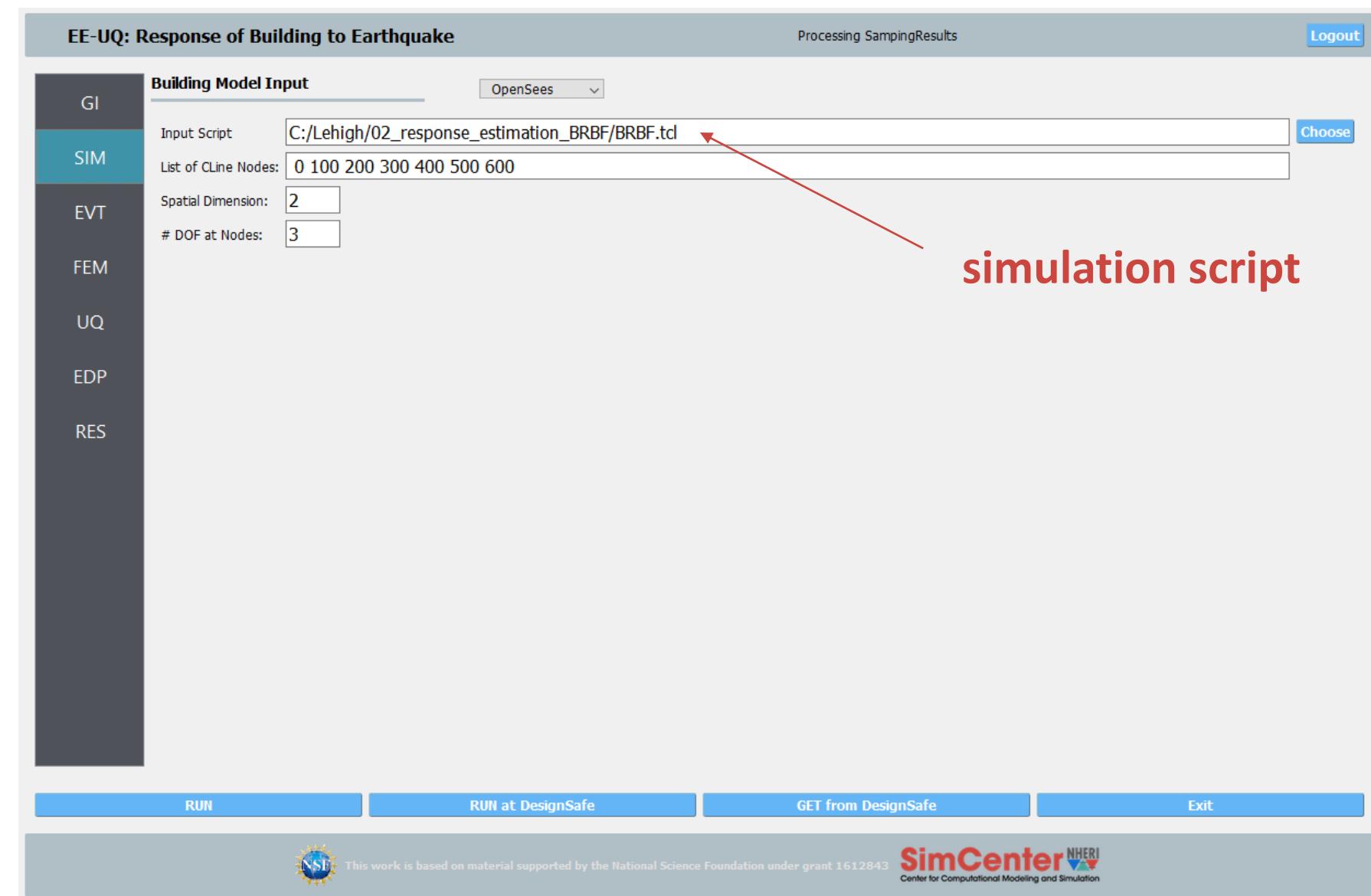
RUN at DesignSafe

GET from DesignSafe

Exit

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

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

Loading Type: Multiple PEER

Add Remove 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

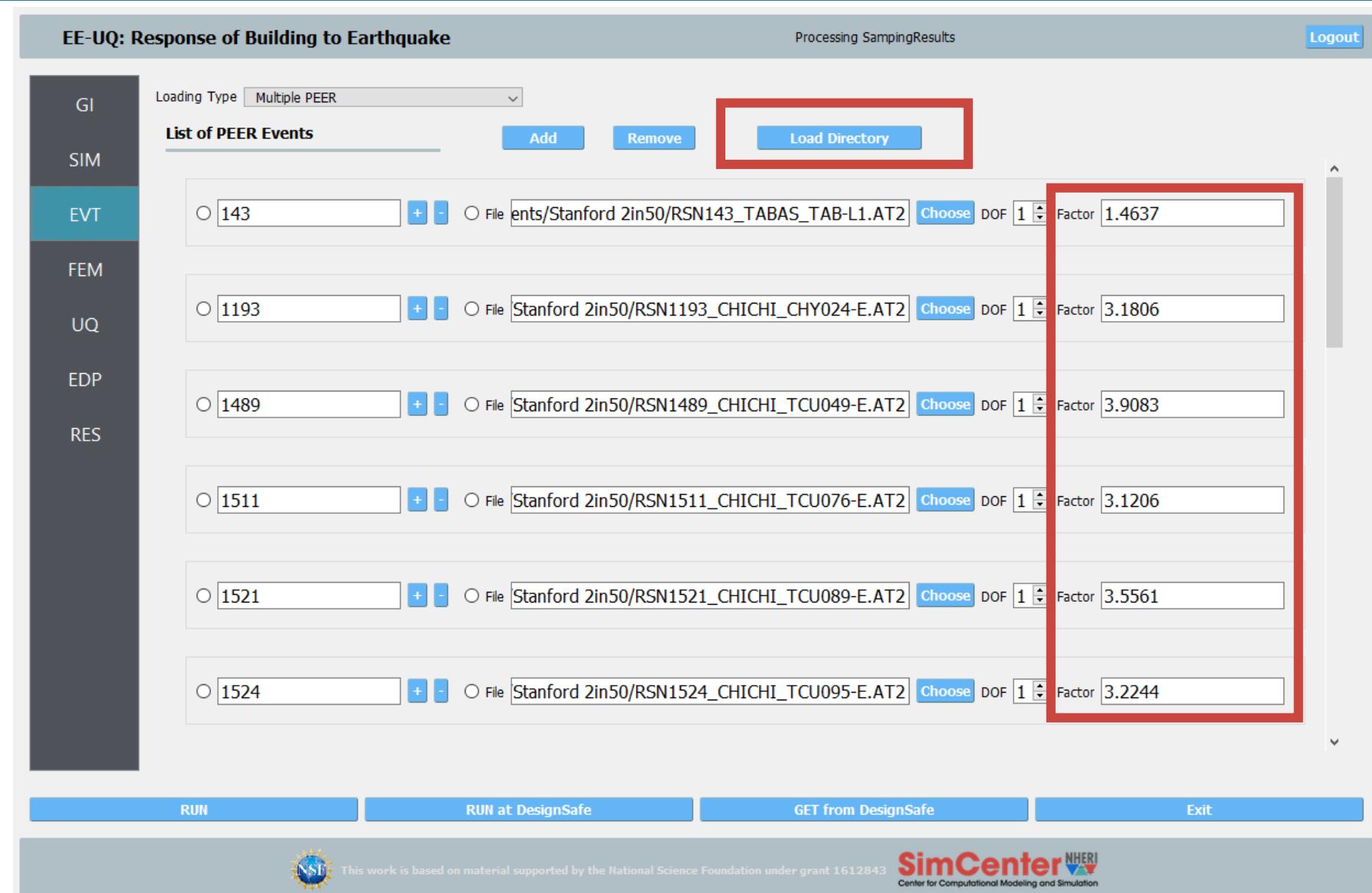
1511 File Stanford 2in50/RSN1511_CHICHI_TCU076-E.AT2 Choose DOF 1 Factor 3.1206

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

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

define random variables

EE-UQ: Response of Building to Earthquake

Processing SamplingResults

Logout

GI

SIM

EVT

FEM

UQ

EDP

RES

Sampling Method

Method LHS

Samples 20

Seed 203

Random Variables

Add Remove Correlation Matrix

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

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

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

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

EE-UQ

	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-UQEUQ_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	EE-UQ workflowWF_test2	FINISHED	1520062112107925415-242ac	2019-05-07T18:47:42.000-05:00

Refresh Job
Retrieve Data
Delete Job
Delete Job And Data

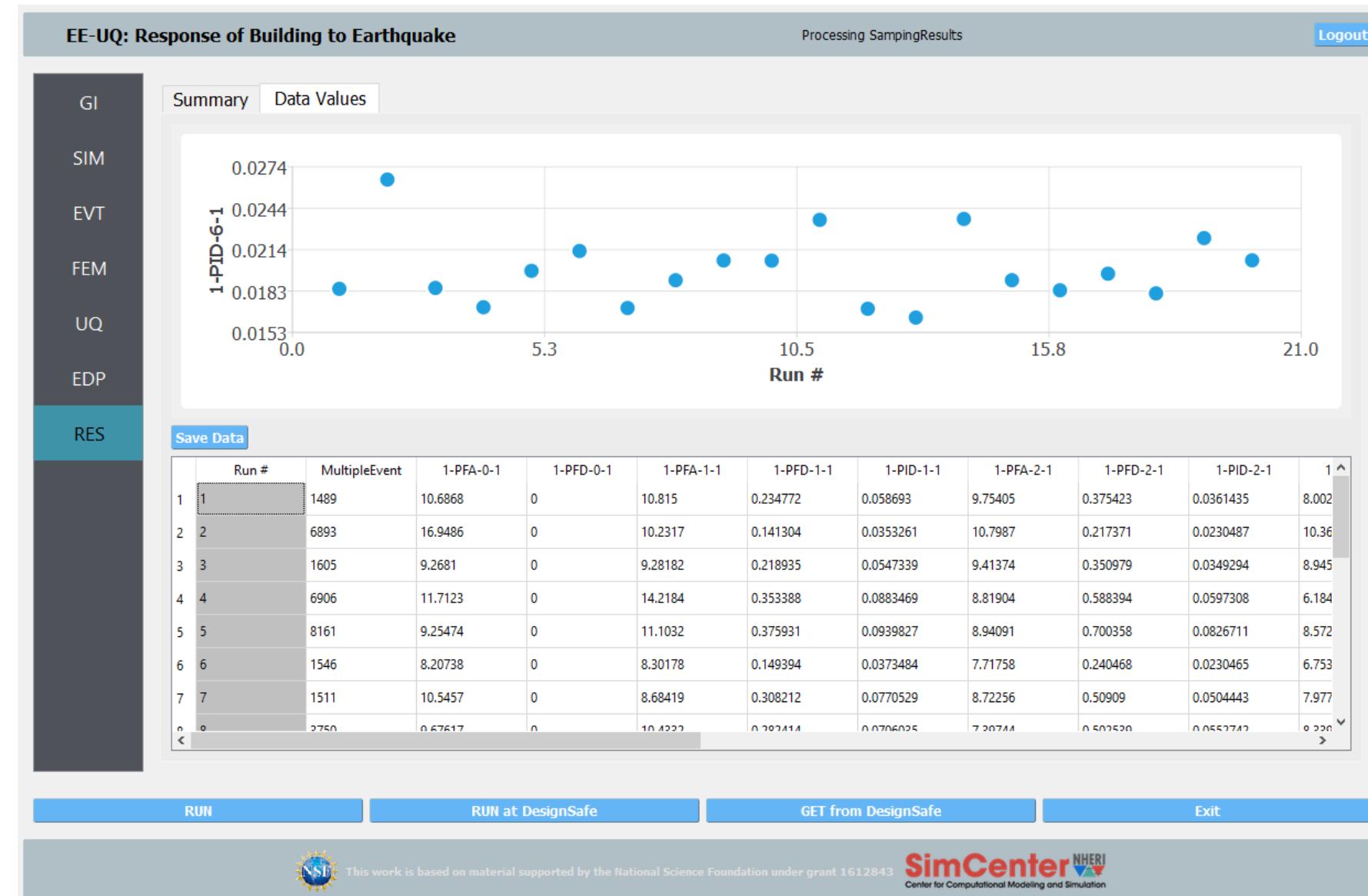
RUN RUN at DesignSafe **GET from DesignSafe** Exit

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

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

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

PBE - Performance Based Engineering Application

Running the UQ engine ...

Login

GI

SIM

EVT

FEM

UQ

DL

RES

Damage and Loss Assessment

FEMA P58

General Components Collapse Modes Dependencies

General Settings

Response Model

response description: EDP data: /dakotaTab.out Choose

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 0.01

Median 0.02

Log Standard Dev 0.3

Collapse Probability:

Approach: estimated

Prescribed value:

Basis: sampled EDP

Loss Model

Replacement Cost 10000000

Replacement Time 1000

Decision variables of interest:

Reconstruction Cost Reconstruction

Injuries Red Tag Prob:

Inhabitants:

Occupancy Type Commercial Office

Peak Population 50, 50, 50, 50, 50, 50

Custom distribution: Choose

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



Estimate damage and loss

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

GI
SIM
EVT
FEM
UQ
DL
RES

Damage and Loss Assessment FEMA P58

General Components Collapse Modes Dependencies

Define the Performance Model

Component Ensemble

Damage and Loss Data Folder: C:/UCSD/Fragility Data Choose

Available Components: B1031.001 Add Selected Add All **Load Performance Model from CSV**

Selected Components: B1033.111b Remove Selected Remove All **Save Performance Model to CSV**

Component Details

Name: Steel Buckling Restrained Brace (BRB), Single Diagonal brace, Weight of brace > 41 plf and < 99 plf.
Description None
EDP type: Story Drift Ratio
Default unit 1EA

Add Component Group Remove Component Group

location(s)	direction(s)	median quantity	unit	distribution	cov
all	1, 2	1, 1, 1	ea	N/A	

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

Estimate damage and loss

PBE

PBE - Performance Based Engineering Application

Running the UQ engine ...

Login

GI

SIM

EVT

FEM

UQ

DL

RES

Damage and Loss Assessment FEMA P58

General Components Collapse Modes Dependencies

List of Collapse Modes

add **remove**

name	probability	affected area	injuries
complete	0.2	1.0	0.6, 0.4
partial	0.8	0.1	0.4, 0.1

RUN RUN at DesignSafe GET from DesignSafe Exit

 This work is based on material supported by the National Science Foundation under grant 1612843 SimCenter NHERI 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	Mean	Standard Dev.	Minimum	10 th Percentile	Median	90 th Percentile
SIM	Decision Variable							
EVT	<i>event time: month</i>		6.4364	3.48758	1	2	6	11
FEM	<i>event time: weekday?</i>		0.7084	0.454545	0	0	1	1
UQ	<i>event time: hour</i>		11.6982	6.86802	0	2	12	21
DL	<i>inhabitants:</i>		88.8344	104.111	0	0	0	285
RES	<i>collapses: collapsed?</i>	0.0998	0.299763	0	0	0	0	0
	<i>collapses: mode</i>	0.785571	0.410837	0	0	1	1	1
	<i>red tagged?:</i>	0.995557	0.0665184	0	1	1	1	1
	<i>reconstruction: irreparable?</i>	0.528549	0.49924	0	0	1	1	1
	<i>reconstruction: cost impractical?</i>	0.11263	0.316214	0	0	0	0	1
	<i>reconstruction: cost</i>	7.62358e+06	3.28379e+06	986410	2.39672e+06	1e+07	1e+07	1e+07

RUN RUN at DesignSafe GET from DesignSafe Exit

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



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

A scatter plot showing the relationship between 'reconstruction/cost' (Y-axis, ranging from 749210.1 to 10237199.7) and 'Realization' (X-axis, ranging from -131.6 to 5130.6). The data points are scattered across the plot, with a higher density of points around the center.

	s/collapsed	collapses/mode	red_tagged?/	instruction/irrepair	reconstruction/cost_implied	construction/cost_implied	construction/time_implied	construction/time-seq	construction/time-pi	injuries/sev_1	injuries/sev_2
1		1.0				10000000.0		1000.0	1000.0	9.0	2.25
2			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
3			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
4		0.0				10000000.0		1000.0	1000.0	0.0	0.0
5			1.0	0.0	0.0	2059795.74238...	0.0	5719.28829537...	379.557638158...	0.0	0.0
6		1.0				10000000.0		1000.0	1000.0	6.0	1.5
7			1.0	0.0	0.0	2382485.88487...	0.0	6112.03157043...	530.207852319...	0.0	0.0
<		1.0	0.0	1.0	1.0	10000000.0	1.0	202275.107303	1000.0	0.0	0.0

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

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

	s/collapses	collapses/mode	red_tagged?/	instruction/irrepair	reduction/cost_impr	construction/co	reduction/time_impr	reduction/time-seq	reduction/time-pi	injuries/sev_1	injuries/sev_2
1		1.0				10000000.0		1000.0	1000.0	9.0	2.25
2			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
3			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
4		0.0				10000000.0		1000.0	1000.0	0.0	0.0
5			1.0	0.0	0.0	2059795.74238...	0.0	5719.28829537...	379.557638158...	0.0	0.0
6		1.0				10000000.0		1000.0	1000.0	6.0	1.5
7			1.0	0.0	0.0	2382485.88487...	0.0	6112.03157043...	530.207852319...	0.0	0.0
<		1.0	0.0	1.0	1.0	10000000.0	1.0	202275.107303	1000.0	0.0	0.0

RUN RUN at DesignSafe GET from DesignSafe Exit

This work is based on material supported by the National Science Foundation under grant 1612843

SimCenter NHERI
Center for Computational Modeling and Simulation

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

Cumulative Probability

reconstruction/cost

	s/collapse	collapses/mode	red_tagged?/	instruction/irrepair	reduction/cost_impr	construction/co	reduction/time_impr	reduction/time-seq	reduction/time-pa	injuries/sev_1	injuries/sev_2
1		1.0				10000000.0		1000.0	1000.0	9.0	2.25
2			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
3			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
4		0.0				10000000.0		1000.0	1000.0	0.0	0.0
5			1.0	0.0	0.0	2059795.74238...	0.0	5719.28829537...	379.557638158...	0.0	0.0
6		1.0				10000000.0		1000.0	1000.0	6.0	1.5
7			1.0	0.0	0.0	2382485.88487...	0.0	6112.03157043...	530.207852319...	0.0	0.0
^		1.0	0.0	1.0	1.0	10000000.0	1.0	202275.187202...	1000.0	0.0	0.0

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

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

	s/collapse	collapses/mode	red_tagged?/	instruction/irrepair	reconstruction/cost_impr	construction/cost	reconstruction/time_parallel	reconstruction/time_seq	reconstruction/time_parallel	injuries/sev_1	injuries/sev_2
1		1.0				10000000.0		1000.0	1000.0	9.0	2.25
2			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
3			1.0	1.0		10000000.0		1000.0	1000.0	0.0	0.0
4		0.0				10000000.0		1000.0	1000.0	0.0	0.0
5			1.0	0.0	0.0	2059795.74238...	0.0	5719.28829537...	379.557638158...	0.0	0.0
6		1.0				10000000.0		1000.0	1000.0	6.0	1.5
7			1.0	0.0	0.0	2382485.88487...	0.0	6112.03157043...	530.207852319...	0.0	0.0
8		1.0	0.0	1.0	1.0	10000000.0	1.0	202275.107202	1000.0	0.0	0.0

RUN RUN at DesignSafe GET from DesignSafe Exit

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

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**



National
Science
Foundation



UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Example Use of Research Tools

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

Adam Zsarnóczay, Postdoctoral Researcher

Stanford University, SimCenter

adamzs@stanford.edu



*Joint Researcher Workshop
UC San Diego, Lehigh & SimCenter*

*December 16-17, 2019
University of California, San Diego*



LEHIGH NHERI
Real-Time Multi-Directional Testing Facility

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

SIMCENTER
COMPUTATIONAL MODELING
AND SIMULATION CENTER